Sensur av hovedoppgaver

Høgskolen i Sørøst-Norge
Fakultet for teknologi og maritime fag

Prosjektnummer: **2017-19**
For studieåret: **2016/2017**
Emnekode: **SFHO3201**

Prosjektnavn
Avblødningsystem For Gassturbin
Gas Turbine Bleed System

Utført i samarbeid med: Dresser-Rand AS

Ekstern veileder: Øystein Selås

Sammendrag: Oppgaven vår har vært å utvikle alternative konsepter til et eksisterende avblødningsystem for gassturbinpakken RB211-GT30-DLE. Den eksisterende løsningen oppfattes av oppdragsgiver som vanskelig å montere/demontere, har komplekse deler, og tar mye plass i turbinpakken. Dette betyr i praksis at det tar lengere tid en ønsket å fjerne systemet ut under service av turbinen, i tillegg til at det blir krevende for servicepersonale å jobbe med.

Stikkord:
- Konseptevaluering
- Servicetid
- Fluidmekanikk

Tilgjengelig: DELVIS. Offentlig PDF inneholder ikke dokumentet «Testrapporter» i tillegg at noen parametere blir sensurert i alle dokumenter. CD med all informasjon, Usensurert PDF, og Perm skal ikke offentliggjøres. Prosjektet er tilgjengelig om et år.

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Dato: 9. Juni 2017

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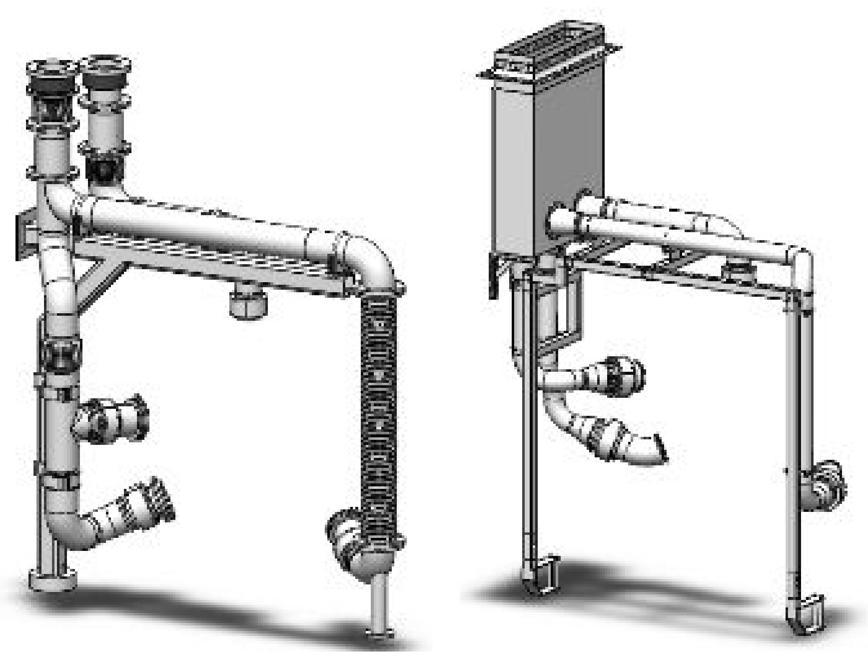
DRESSER-RAND

HSN University College of Southeast Norway

Gas Turbine Bleed System

A Bachelor Thesis



Gruppe 19

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23.05.2017

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This document describes the functions, technologies and components of concept 30.

11. Iteration Reports

This document describes the iterations done during the project.

12. Service Manual C30

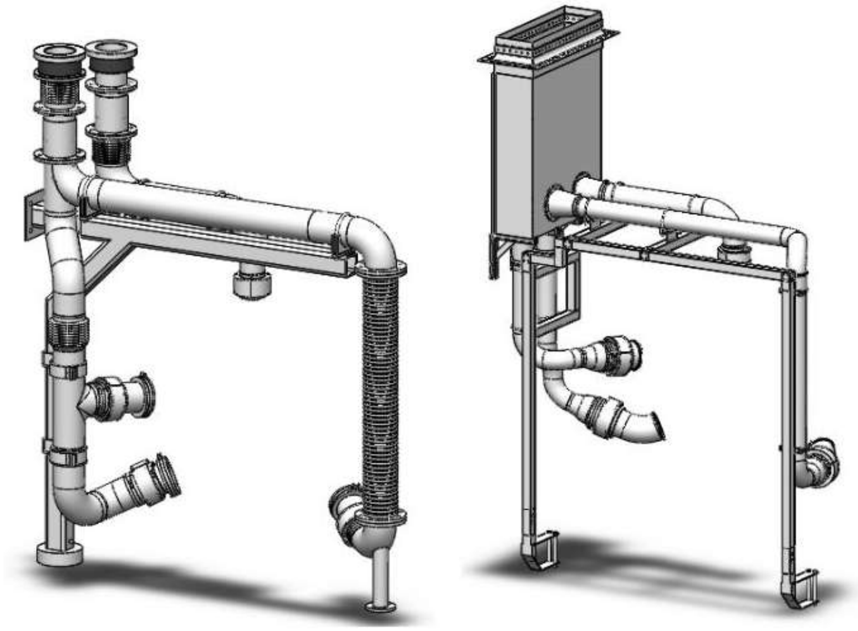
This document describes how to disassemble and assemble the bleed system during.

13. Attachments to Technology Documents

This document describes the technological choices and the components of the final concepts.

Project Summary Document

Gas Turbine Bleed System



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22.05.2017

Document History

Date	Version	Changes	Approved by
19.05.17	0.2	K30 inserted, filled in other parts of document	Daniel, Kristian
20.05.17	0.3	3.1, 3.2, 5.2, 5.3, 6, filled in for K30	Daniel, Kristian
22.05.17	0.4	Spell correcting and structuring	Daniel, Kristian
22.05.17	1.0	Approved for submission	Daniel

Table of Contents

1. Introduction

The function of this documents is to give the reader a quick summary of the project, as well as a review of what was planned in the project compared to the outcome. It is made as brief as possible. The reader will then be referred to relevant documents for further in depth reading.

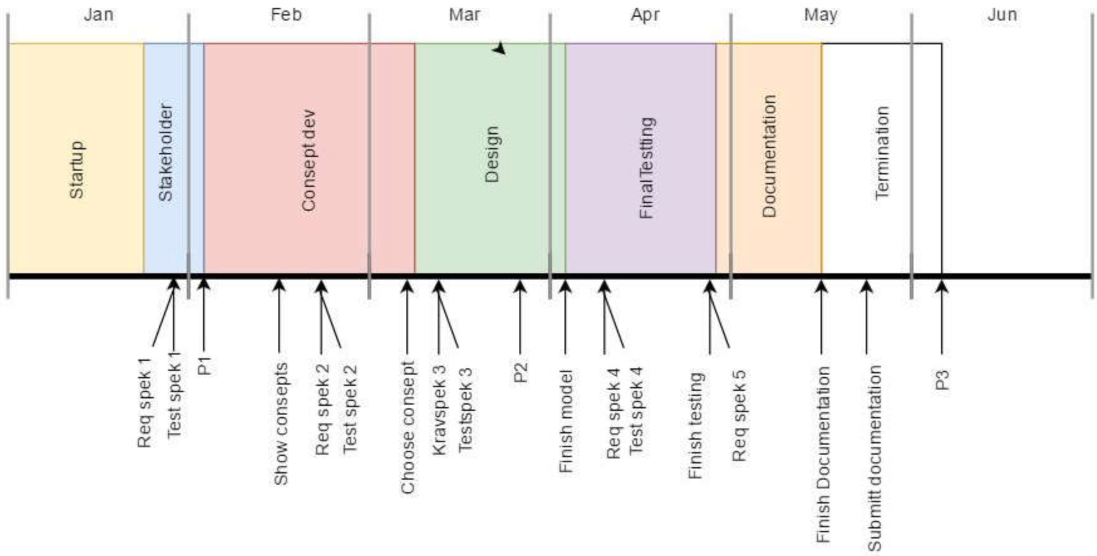
2. Review of the Project Plan

This section discusses how we managed to follow the project plan and the changes made.

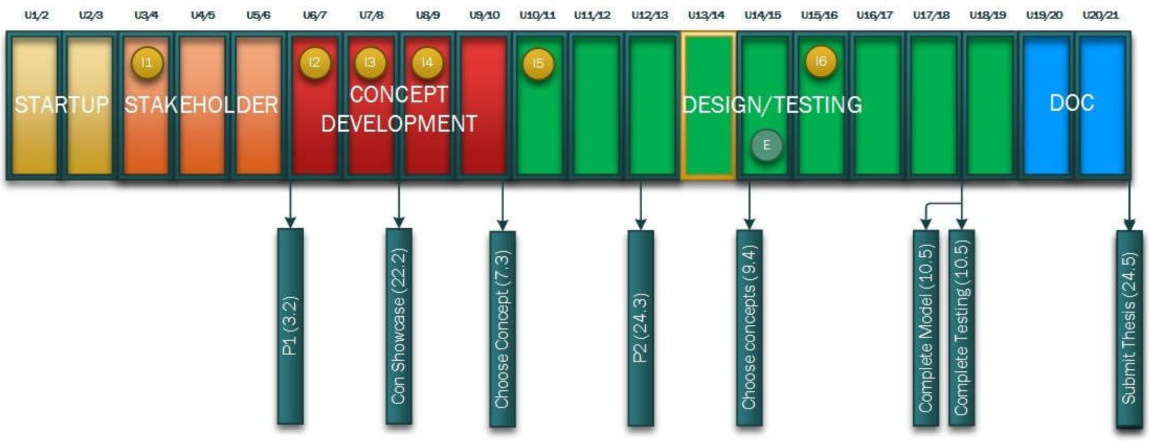
2.1 Project Timeline

The project plan is a contemporary document. For better control of the time and the resources available the main tasks need to be planned for long-term, this was also true for our case, but with the nature of our project it has been beneficial to plan the detailed activities more intermittently. This was to prevent us from having to use a lot of time on replanning, due to the amount of unknowns for the product. For this reason the plan has been developed somewhat with the project.

The structure of the first version of the timeline compared to the latest is somewhat the same. This especially refers to periods of time that were planned for each of the phases. although we have shortened and lengthened some periods with a week or two. Also the phases included are very similar, apart from the combining of the design and test phase.



Picture showing the first official version of the project timeline.



Picture showing the latest version of the project timeline.

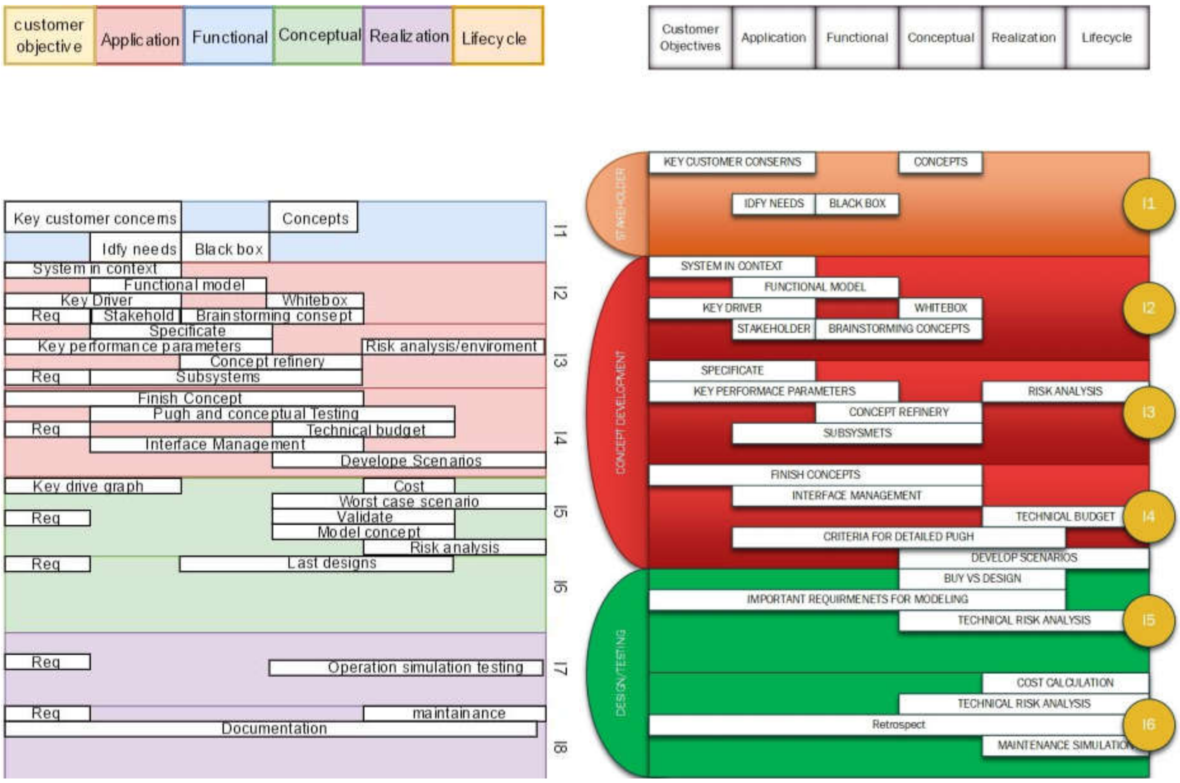
The dates of the milestones have had some significant changes. This is partly due to the fact that we wanted to work more with the development of concepts, designing and testing, and partly due to taking a different approach for the design and testing of the system. Therefore the milestone originally focused on choosing the concepts was split into two. One was to choose a narrow selection of concepts, and the other to choose the final two concepts to work with the rest of the project. The other reason for the deviation of the milestones was that we decided to work with design and testing simultaneously rather than alternately. Therefore the dates for the milestones “complete testing” and “complete mode”l where delayed and set to the same date. In spite of some modifications of date and definition in the end all the project milestones were met.
See project plan for further information on planning of the project.

2.2 Project Model

The project model used is CAFCR+. This is an iterative, user, and product focused model. ***The reason for choosing this model can be found in* 4.2 - [Choice of Project Model*]* *within the project plan document.*** We think we have used the model right and have got a lot of positives from it. To get a confirmation on this we have consulted with the maker of the CAFCR+ model, Mr. Gerrit Muller.

The model is based on iterations of view hopping. Performed all through the project for good understanding of the complete system in its context. ***See 4.2 [CAFCR+] in the project plan for more information on the CAFCR-model.*** Originally we planned for 8 such iteration rounds. but well into the project when we had gotten a good control over the system we decided we would only need 6. Other than that the iteration rounds have gone very smoothly as planned, with only minor tweaks along the way. This can be seen in the pictures of the original iteration plan compared to the second and final version.

A lot of the most essential understanding of our systems is gathered from the iteration activities during the iteration rounds of the CAFCR-model. In conjunction with company meetings this has been the main generator of most of the requirements in the project, giving us a basic knowledge about the system, its environment, an overview of the main stakeholders, giving us constantly new ideas and etc. ***See iteration reports for more details about information gathered from the iteration rounds.***



Left figure: showing the original iteration plan. Right figure: showing the latest Iteration plan.The iterations is numbered on the right side of each figure, I1, I2.

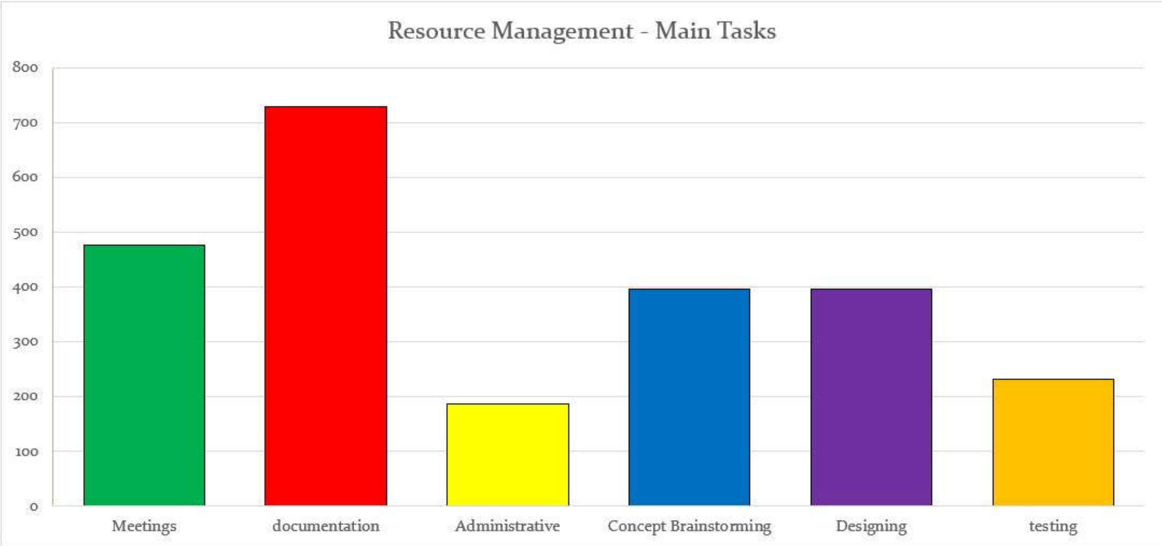
2.3 Resource Management

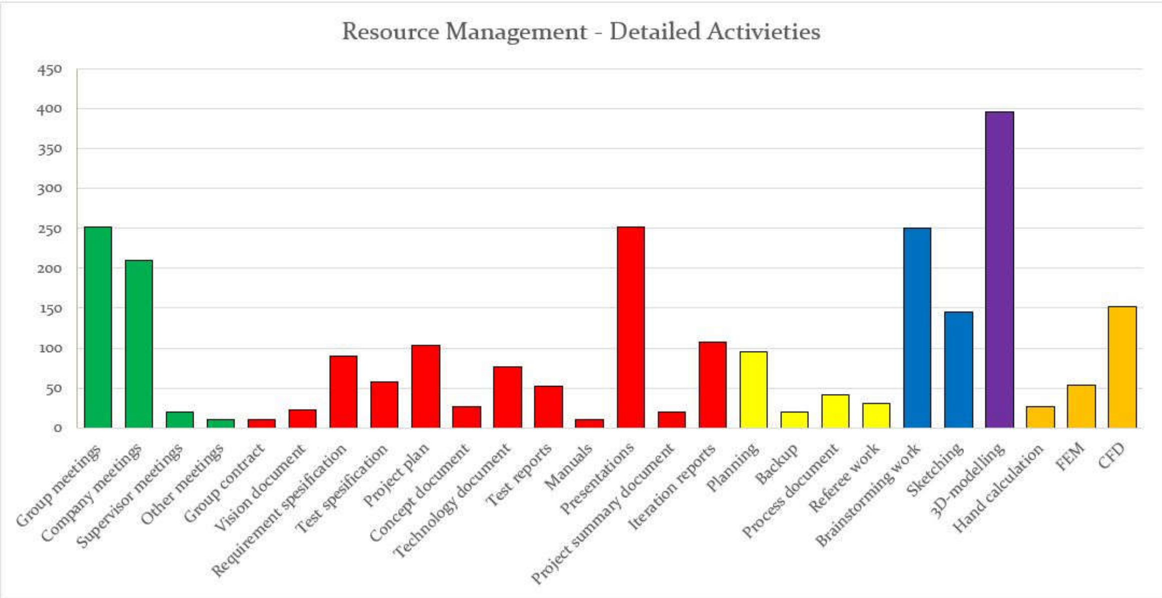
In the startup phase of the project we decided all the group members would invest around 600 hours in the project. resulting in a total of 2400 hours of work. We have managed to be very close to the estimate all throughout the project and by the end of the project we think we will have worked slightly above 2400 hours.

Uke	1	2	3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20
Sum	4	130.5	64.5	132.75	126.5	104	108	111	110	129.75	157.25	125.25	64.75	0.75	93.25	84.5	182.75	152.5	162	166.5
Total tid																				
2210.5																				

The table shows the hours worked each week and the total. Not including the last two weeks of work (18.-29. of May).

The time spent on each activity during the project has then been mapped. And the activity during the last phase of the project has been estimated. This is shown in the next two diagrams. The first chart shows the time distribution among the main top-level tasks of the project. and the second shows the detailed activities.





Figures showing the time distribution for the project. The vertical axis shows the hours spent.

What we have learned from the time distribution data is how much of the time has gone to document the things we have done in the project, which was somewhat a surprise to us. We can also see that we have worked many hours on brainstorming and sketching concepts, which has been very important to separate the wheat from chaff during the project. On the contrary as expected a lot of time was used to 3D-model, as this is a time consuming and comprehensive task. ***See timelog tables for more information on time distribution.***

The project phases have only been guiding for where the focus should be for that specific period of the project, but in reality we have been working with the main tasks of the project in parallel. The next diagram indicates how we have distributed the work across the project.

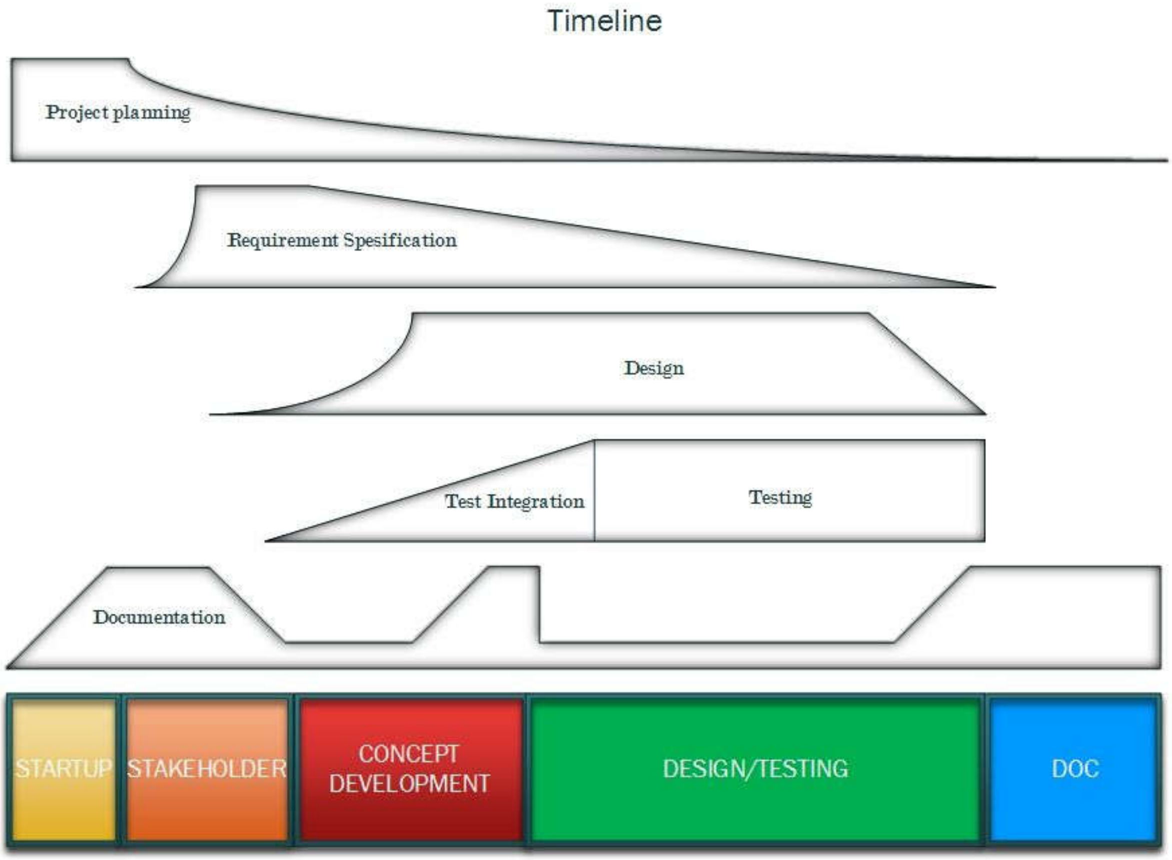


Figure showing the work distribution across the project.

2.4 Risks in the Project

During the startup of the project the general risks were mapped. We then decided which needed an active measure to be prevented.

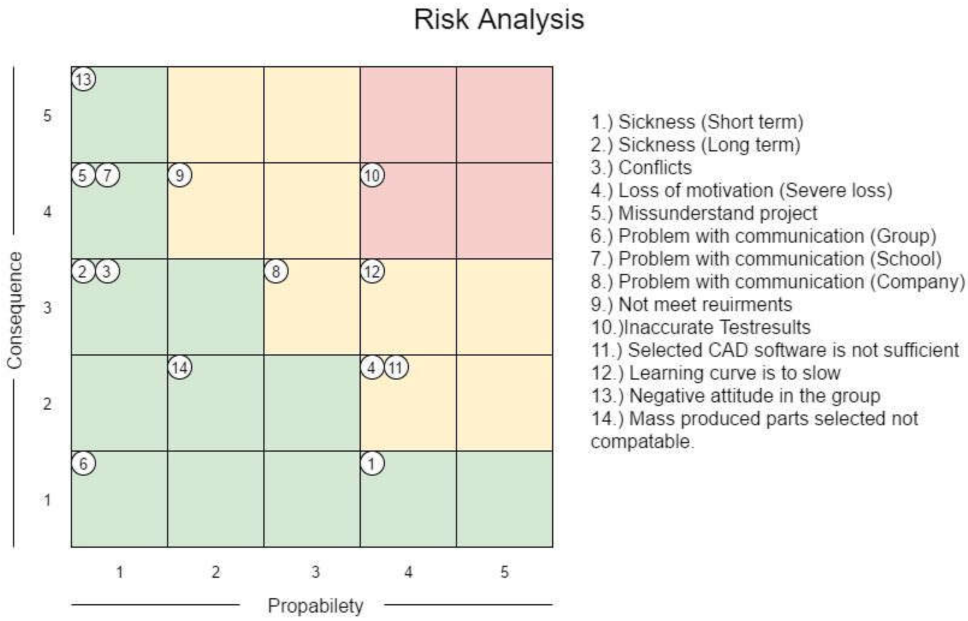


Figure showing the general risks in the project

The risks needed to be prevented included risk 4, and 10.

Risk 10 Inaccurate test results (high probability - high consequence)

We did decide to be extra critical to the assumptions for each test, and putting the assumptions to the test where possible, as well as just putting in a lot of work planning the tests, and plan what needed to be tested. We think that to an extent that we have been able to avoid inaccurate results from testing, although we did actually have a problem with a very important pressure drop test. Which could have resulted in an inaccurate result for a very important part of the thesis. Fortunately we discovered the mistake in time to prevent it from having a large impact on the project. ***See 2.5 [Technical challenges] in the technology document for more information on this incident.***

Risk 4 Less motivation (high probability - medium consequence)

To prevent this we tried to distribute the work of the project evenly and always try to motivate each other. But all through the project the spirit in the group has been high and the will to work has remained.

3. Product

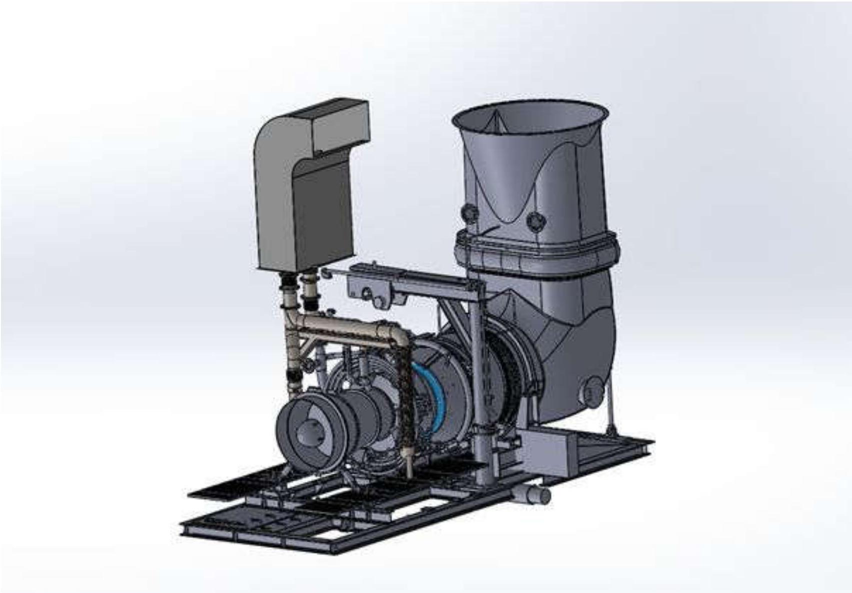
The product is a result of the requirements. The requirement specification is a comprehensive document. It is based on a system engineering method of product synthesis. This has allowed us to list a lot of requirements which normally are not thought of in a conceptual stage as this project is limited to. Therefore the products are strictly restrained by the requirement specification. The result are two quite functional systems.

The task of the project was to come up with two alternative solutions to replace an existing bleed line system made for the turbine package RB211-GT30-DLE. The current solution is difficult to disassemble, has components that are complex and that take up too much space inside the enclosure. This means that the time it takes to get it out will be long, it is demanding for technicians to disassemble and it is difficult to get to components under inspection. A turbine bleed system's task is to bleed of excess air from the compression stages before it hits the combustion chamber, during the unstable conditions of startup. In the case where the turbine is placed in an enclosure the excess air needs to be leaded from the turbine and out of the enclosure via some kind of a flow channel. ***See point 3 [Problem and product] in the vision document for more information on the problem.***

3.1 Final Product

The two resulting concepts chosen were Concept 16 and concept 30. In the rest of this document we will refer to the two concepts with abbreviations. As C16 and C30. **See the two technology documents for complete overview of the two systems.**

C16



Picture showing the bleed system (in slightly more grey) within its context.

Keywords

Concept 16 tries to solve the problem by placing the bleed line routing system on two rotating booms located beside the turbine. This way the whole pipe routing can be swung out of the way in a short amount of time during service of the gas turbine. ***It is highly recommended to read 2.2 and 3.1 [Solution & Concept functions] in the technology document (C16) for better understanding of the concept and the solution.***

Pros	cons
Allows for very fast service time.	Is relative complex to construct.
Allows for very good acces.	Is expensive to construct
Intuitive disassembly during service	Has many parts
Is very safe to handle.	
Requires little accuracy to build.	

Table showing main pros and cons of the concept.

Quality of the Solution

We think that Concept 16 has a good potential as an replacement for the current bleed system solution, but it still needs some work and analysis for the application. The idea behind concept 16 would allow for extremely easy and fast disconnection from the turbine, getting the system out of the way during a service of the turbine, and the other way around. We have managed quite well to develop the idea, and implement most of the desired functions from the initial idea of the concept. A service disassembly simulation was performed on concept 16 during the project. The result were based on number of screws, access, number of parts needed to be loosened, parts needed to be removed, and whether they would require a crane for removal or not. The same simulation was performed on the currently implemented bleed system. The results showed that the disassembly time would be around 6 times faster for the new system. The time was 4:45 min or, 6 min for concept 16, depending on the extend of removal, and 29:30min, or 31:45 for the old system. ***See the attachment to the technology document (C16) [Service description] for the sequence of the assembly and disassembly for C16.*** The fast service time is a valuable feature for the main application of the turbine package, offshore power applications. Every minute of the assembly time counts as every hour of stopping production on a offshore oil rig can cost millions of NOK.

A difficult task which we in the end managed to successfully implement was the accessibility around the bleed system. There was an ever lasting compromise between functionality and accessibility, and when working with such a large dimensions of pipes it is rather difficult to keep the service area open. This is one of the problems Dresser-Rand are having with the current system. This can be easily seen when looking at it. The bleed lines occupy far more volume than C16, making it difficult for service personnel to work on the turbine. ***See the technical choice attachment to the technology document (C16) [choice of boom] for more information on the amount of work put into providing the best possible access.***

One of the keys to make the service of the system as fast as possible was to make it as intuitive as possible. The goal was to make it so intuitive that you didn't evan need service manuals. This would eliminate the possibility of a mistake being done. which can have costly consequences.

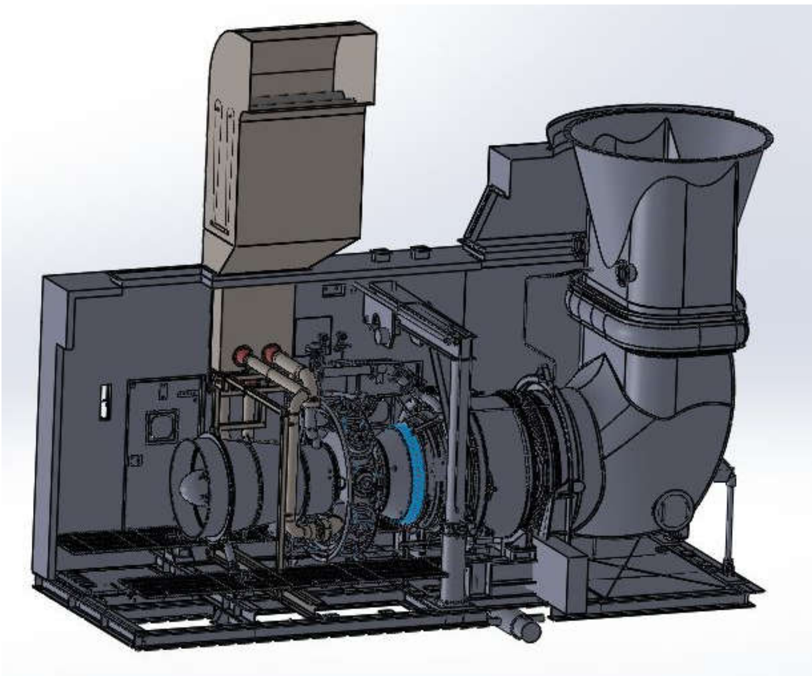
Safety was also a big concern when developing the concept, since this is one of the most important factors for the company. Therefore the solution is developed to almost eliminate all risks of accidents during service of the system. It does this largely by requiring almost no parts to be retrieved during service.

What we learned along the way in the project which was not included in the original idea of the concept was to configure the system in a manner that would not require extreme tight tolerances for each part. Not thinking about this would result in requiring a jig for the construction. That would first of all be an additional cost to the system and secondly it would make the installation of the system complex. The solution for this was to make the clearances between the system and the turbine relatively large with large sealing, and it would also be wise to drill the holes in which the pipeline of the system is to bypass the roof after the installation of the rest of the system. This way we think that it is possible to install the system without a jig.

We always knew that the system would be somewhat more complex and difficult to construct than for instance concept 30 or the current solution, and also more expensive. But that has to do with the function of the system. It requires eg. movable features to work. But we have done all we can to limit the price as much as possible. This included using as many standard parts as possible, using as few parts as possible, and using the cheapest possible part to produce where possible. ***See 3,7 [budget] in the technology document (C16) for more information on the budget.***

Whether the concept is feasible to construct and use is ultimately up to Dresser-Rand, but the research and development done in the project suggests it is fully feasible.
See the technical choice attachments to the technology document (C16) for more information on the development of C16.

C30



The picture shows the bleed system (light grey) in it's context.

Keywords

Concept 30 is designed to have less parts and shorter pipe lengths than the current system. This is done by leading all pipes directly into a duct, where flow from all pipes is dumped together. This results in a low pressure drop, called a dumping effect. This has allowed us to minimize the dimensions of the pipes. Together with the short pipe distances, this reduces the time to assemble and disassemble the system. ***It is highly recommended to read 2.2 and***

3.1 [Solution & Concept functions] in technology document (C30) for better understanding of the concept and the solution.

Pros	Cons
Allows for fast service time	More parts involved in assembly/disassembly, compared to C16
Allows for good acces	
Reliable design	
Few parts	
Low pressure drop	

Quality of the solution

Concept 30 has a good potential. It is a reliable solution with fewer parts than the current system. The idea of the concept was to achieve a dumping effect early in the system, allowing us to have short distances of pipes, with smaller dimensions than the current system. With the duct being able to hang on the wall during service, we now only have to remove 5 pipes and its supporting structure. After a simulation this is estimated to take 11 min, without removing the interface extensions, and 12:15 min if they are to be removed, which both are good values compared to the current system, taking 29:30 min, or 31:45 min, depending on if the interface extensions are removed or not. More on the disassembly and assembly of concept 30 can be found in "Service Manual C30".

A challenge with C30 was to achieve good accessibility around the turbine. This was mainly because of the big duct. Initially it was intended to have it at the same level as the lowest of the valves. This would cause it to block a big section of that side of the turbine, limiting the accessibility. Later on we decided to place the duct higher in the enclosure, just above the inspection doors. This allows a service person to walk underneath it. Some pipes will still be in the way, but these are easier to work around, and therefore still provide accessibility to the entire turbine.

The pipes from the turbine to the duct, offered some challenges too. First of we tried to use regular pipes, just thinner than the ones in the current system. The valves, however, are angled in an non-standard way, making it necessary to cut standard bends to achieve the right angles. Later we found a company called Niras, which had the possibility to bend the pipes in exact angles and in one single piece, with help of induction bending. After a while, we found out that the bending method required a very high wall thickness to make it possible to bend with a low bend radius. This made the pipes to heavy to handle manually, so we went back to the old method of cutting and welding the pipes together. After a lot of tests on the pressure drop, we found that the pipes could be scaled down, making it possible to have only 5 pipes in the entire bleed system, that are still possible to handle manually. This is a big advantage over the current system.

Concept 30 is not as complex as C16 or the current system. Comparing C30 and C16 this is relevant only when considering the first installation of the system. Considering assembly and disassembly during service C16 is actually the easiest of the two, taking, as mentioned above, only 4:45min or 6min, but C30 has it's advantages. It has a low pressure drop, giving more flexibility when considering materials close to the interface, where the pressure is highest, and offers a reliable and proven design. ***See attachment about Bleed Pipes (C30) for more information on the choice of pipes.***

To be able to pick one of the concepts over the other, we would have to do more research and development. But from what we know at this point it is pretty clear that C16 is the faster, but riskier option, because of its unproven design, while C30 is the slower, yet a safer option. ***See the technical choice attachments to the technology document (C30) for more information on the development of C30.***

3.2 Product Development

The two concepts presented in this document are a result of thorough and complex selection and product development. The concept development phase of the project was divided into selection rounds including brainstorming for concept ideas, and solutions, which were then evaluated, and finally we choose the concepts which showed the most promise for the next selection round. In the end we ended up with the two relevant concepts. ***See points 2 and 3 [Concept development process & Concept development] in the concept document for more information on why and how we selected these two concepts.***

Technical Risk

The strategy along the way for the development of the two systems has always been to focus on the things that are most important. Regularly we have stopped to think about which areas are most important to focus on and which technical risks need to be solved for the concepts to be feasible. What we have defined as a technical risk is: A risk that is sufficient to prevent the concept from working. On the other hand we have the technical difficulties which we have defined as: A technical difficulty that we know is possible to solve. The way we handled the technical risk is different for each case. But if there ever was a technical risk we made it a top priority and we knew we had to resolve it to be able to work with the specific concept. If it was not possible for us to investigate and resolve the technical risk we scrapped the concept.

Picture shows the process of risk management. (Riskmanagement, 2017)

Technical risk resolved

C16

The main technical risk associated with this concept in the beginning of this project were related to using flexible hoses instead of pipes. But along the way other risk also emerged. The list shows the main technical risk resolved during development of the concept.

- Using flexible hoses - Could load the turbine.
- Using flexible hoses - Pressure in hose could be to high.
- Using flexible hoses - Forces could rip hose apart.
- Using flexible hoses - Pressure drop could be too high as a result of using hoses.
- The configuration of the whole system - Pressure drop could be to high.
- Rockwool to seal interface - Could lose its properties due to temperature and compression.

C30

The main technical risks in C30 have been the duct and the pipes. But along the way we encountered several others. The list below shows an overview of the most important resolved technical risks.

- Duct - Volume of the duct could be too low to cause a sufficient dumping effect.
- Standard pipes - Too heavy to handle manually.
- Standard pipes - Too many parts, increasing the maintenance time.
- Induction bended pipes - Too long bend radius.
- Induction pipes - Too heavy to handle manually.
- Flexible connection duct - Pressure too high.

- Rockwool to seal interface - Could lose its properties due to temperature and compression.

Technical risk remaining for C16 and C30

The concept is not completely finished before all the requirements are satisfied, so there is still some work to be done to finish the concept completely. The remaining work would have to concern the remaining technical difficulties of the concept. These include the before mentioned unresolved requirements, but fortunately we can't find any remaining technical risks that cannot be resolved by a workaround. ***See 2.4 [Technical risk] in both of the technology documents, 5.2, & 6.2 [Iteration activities] in the Iteration reports for more information on technical risks in the project.***

4. Review of Requirements

4.1 Requirement Specification

For the submission of the thesis we have developed 2 different concepts. For this reason we have documented two requirement specifications. The two documents have the same user and system requirements, but the design requirements are different. In the end of the project we have established around 60 user requirements, 90 system requirements, and 25 - 50 design requirements for each of the two concepts.

4.2 Requirement Management

The structure of the requirements has the user requirements on top level, the system requirements as subordinate and the design requirements subordinate to each system requirement. ***See 5.2 [Requirements sorted by relevance] in both of the concept requirement specifications to see this structure.*** The test specification bases the test on the system requirements. If a test is satisfied the system requirement is satisfied and all subordinate design requirements are also satisfied. If all the systems requirements originating from a specific user requirement are satisfied the user requirement also is satisfied.

From the company there has been a request to focus on specific areas to analyse, and others have been approved for down prioritizing. Concerning satisfying requirement, the main interests of D-R where aspects concerning the flow, pressure buildup, thermal conditions as well as simplicity concerning assembly and disassembly during service. The aspects we were told to not focus on where structural strength of the supporting parts of the system, detailed sound calculations, and some aspects of cost calculations.

Based on the need of the company combined with the learning potential of the tests written we choose a set of tests to perform. The tests included where everything from simple visual tests to comprehensive CFD and thermal simulations. In the end we did not satisfy all of the written requirements from the thesis. But we satisfied most of the ones we focused on. ***See the test reports document for result on the comprehensive tests.*** The tables below show the requirements not satisfied for each of the two concepts. It shows which top level requirements are not satisfied, which system requirements tested are causing the dissatisfaction, and an explanation to why it did not satisfy the requirement. Note that the majority of the requirements not satisfied are not prioritized in the thesis.

C16

User req	Causing System req	Comment
U2 The bleed system shall not conflict with any other components in the environment.	**S9** External bleed system shall be clear of wiring and piping within the housing.	We do not have a 100% accurate model to test this.
U14 The bleed system shall meet all HSE requirements and regulations.	**S25** The individual employee's maximum exposure to noise during a 12 hours working day is 83 db **S26** The maximum allowable noise level in any situation is 130 dB. **S28** All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person.	Not prioritized, complicated, Is thought of.
U20 The bleed system maintenance cost shall be within budget.	**S31** The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours.	Not prioritized.
U21 The bleed system shall meet all cost impact targets.	**S32** Cost of transportation shall not cost more than current system.	Not important for D-R.
U31 The bleed system shall cool down during cooldown period of turbine.	**S42** The bleed system shall cool down to 70 degrees celsius within 240 minutes	Not prioritized.
U37 The bleed system shall last without failing between main service of the turbine.	**S46** The system shall sustain 26280 hours without maintenance.	To complicated, not prioritised.
U38 The bleed system shall be able to handle the excess air from the turbine.	**S48** The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s. **S49**	Not prioritized, time consuming. Not interesting for D-R to know structural strength.

	The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s. **S50** The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.	
U45 There shall be developed at least two alternative concepts to handle the bleed air.	**S57** The concept shall have manuals for service	Only request for C30.
U49 The bleed system shall last the lifetime of the turbine package.	**S67** The bleed system shall last for minimum 25 years	Too complicated, is thought of.
U51 The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation.	**S69** The fixtures shall be able to withstand ..N during transportation.	Not prioritized, is thought of.
U56 There shall be considered using solutions preventing service personnel to climb freestanding ladders.	No system requirement	Not enough time to analyse.
U63 All structural parts of the system shall handle the structural loading.	**S86** The structural parts shall be able to handle the loads associated with weight. **S87** All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.	Only some tests are performed to analyse this, not interesting to D-R.
U19 The cost of the system shall be within budget	**S30** The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost	The total cost of the building the system is above the budget.

C30

User req	Causing System req	Comment
U1 The bleed system can not allow large external forces, stress or moments to be imposed to the gas generator interface.	**S2** The gas generator interface shall move during expansion with at least 8 mm axial.	The thermal expansions is larger than the gap between the parts.
U2 The bleed system shall not conflict with any other components in the environment.	**S9** External bleed system shall be clear of wiring and piping within the housing.	We do not have a 100% accurate model to test this.
U14 The bleed system shall meet all HSE requirements and regulations.	**S25** The individual employee's maximum exposure to noise during a 12 hours working day is 83 db **S26** The maximum allowable noise level in any situation is 130 dB. **S28** All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person.	Not prioritized, complicated, Is thought of.
U20 The bleed system maintenance cost shall be within budget.	**S31** The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours.	Not prioritized
U21 The bleed system shall meet all cost impact targets.	**S32** Cost of transportation shall not cost more than current system.	Not important for D-R.
U31 The bleed system shall cool down during cooldown period of turbine.	**S42** The bleed system shall cool down to 70 degrees celsius within 240 minutes	Not prioritized.
U22 The bleed system shall have parts possible to produce	**S33** The bleed system shall have parts regulated in international standards.	The nozzle is custom made, later we found that this also could have been standardized.
U37 The bleed system shall last without failing between main service of the turbine.	**S46** The system shall sustain 26280 hours without maintenance.	To complicated, not prioritised.
U38 The bleed system shall be able to handle the excess air from the turbine.	**S48** The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s. **S49** The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s. **S50**	Not prioritized, time consuming. not interesting for D-R to know structural strength.

	The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.	
U49 The bleed system shall last the lifetime of the turbine package.	**S67** The bleed system shall last for minimum 25 years	Too complicated, is thought of.
U51 The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation.	**S69** The fixtures shall be able to withstand ..N during transportation.	Not prioritized, is thought of.
U62 The parts of the system shall be able to handle heat expansion.	**S84** Parts of the system that are fixed shall be able to withstand the stresses from the heat expansion. **S85** Parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material. **S88** The A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe.	Not prioritized. Interface thermal expansion causes collision. Not prioritized.
U63 All structural parts of the system shall handle the structural loading.	**S86** The structural parts shall be able to handle the loads associated with weight. **S87** All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.	Not prioritized.

See 4.4 [Test overview] for complete overview of satisfied requirements for both concepts.

5. Assignment

The scope of the assignment was large and we could have done even more if we would have more time. But we succeeded in developing the two concepts to where we planned from the beginning, so we are satisfied with the results we got.

5.1 What were we Good at?

- Focusing on the right things.
- Planning work to prevent unnecessary work.

- Finding help at the right places.
- Good communication in the group.
- Using the selected project model as intended.
- Including system engineering into the project development
- Listening to the customer.
- Using the data to choose the winning concepts, not involving feelings.
- Constantly working with requirements.
- Constantly working with documentation.
- We think we have managed to make the documentation more readable.

5.2 What was Difficult?

- Documenting all the work done in a way easy to read.
- Making a system fulfilling all requirements.
- Learning to use comprehensive simulation software.
- We misunderstood the method of calculating maximum pressure drop.

5.3 What did we Learn?

- Advanced fluid mechanical calculations by hand and CFD.
- A practical approach to engineering work.
- A whole lot about turbines and turbine packages.
- Each of the students learned a lot about their areas of responsibility.
- A practical approach to system engineering.

6. Conclusion

6.1 Aftermath

We want to discuss briefly the aftermath of the project. To enlighten about solutions appearing in the last stint of the project, giving us no time to research and consider. As well as give our thoughts on what we think the next step for development of our systems should be.

Very late in the project Dresser-Rand managed to find a solution that could work as a better interface than the one we came up with. This solution was a composite hose that could be pulled over the non touching connection of the turbine and the bleed system. We spend a lot of time in development of the systems trying to find this kind of a material that could withstand the heat, pressure, and forces from the application. But did not manage to find one. We struggled to get answers from suppliers, about the properties of the materials for the exact working conditions. ***See technical choice document for interface concept for more information on this matter.***

Dresser-Rand has been working so closely with us during this project that they most definitely know what would have to be the next considerations for further development of the systems. One specific area would be further research on the matter just mentioned. The right solution could be used both for connecting the turbine to the bleed system as well as true out the whole pipeline of the system to prevent the need for accurate alignment during installation. Otherwise there naturally would be a need to focused on the areas we have been asked not to analyse. These include structural properties, sound calculations, and detailed cost analysis.

6.2 Achievement of Goals

As for the achievement of our main goals in the project written in the startup of the project:

- Acquire new knowledge and improve the theoretical, technical and administrative skills.
- Be an asset to our company.
- Execute a process and make a product of good quality and achieve a corresponding grade.

We think we have achieved the first goal. As mentioned in 5.3 we have learned many new skills, as well as improved on many of the skills we have learned during our 3 years of our bachelor degree. As for the other two we can only hope that we have achieved those goals. Hopefully the documentation and 3D-model of the systems can act as an asset for the company at least to some extent. We would be truly honored knowing that a tiny feature implemented on any turbine package developed by Dresser-Rand was affected by the work we have done. We believe that we have done a good job in the thesis, and are happy with the results we got, but it will be up to the sensors to set the grade.

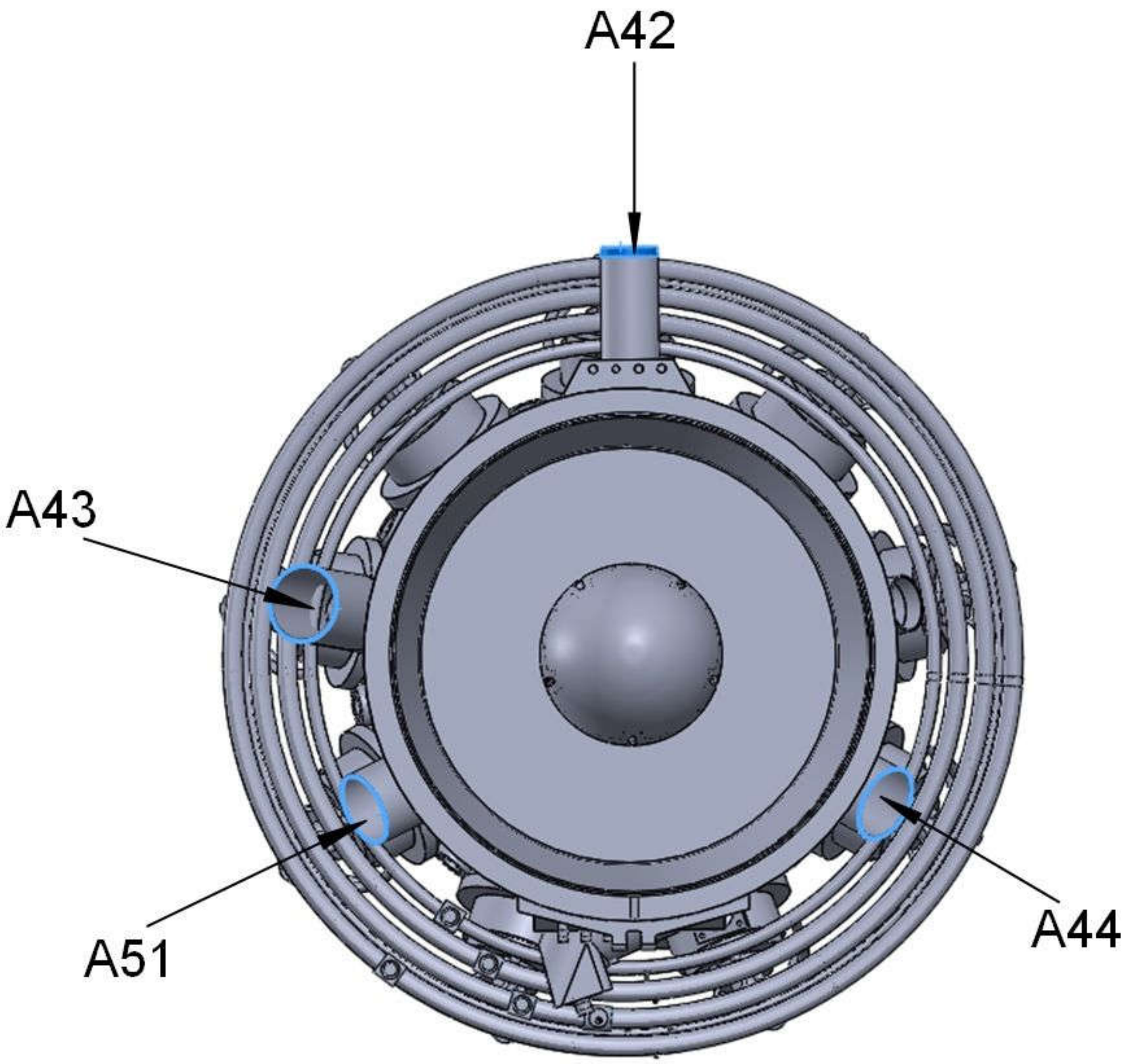
6.3 Special Thanks

In the end we would like to thank Dresser Rand for providing us with the thesis and the vast amount of hours spent guiding and helping us with the thesis. They have shown great spirit, and been very kind to us all through the whole project, providing us with all necessary network connections, for the project, both by email, as well as setting up meetings. Also they have shown us around in Dresser-Rand's test facilities several times.

We would also like to thank Niras, Isopartner, Frekkhaug Stål AS, Trelleborg and Intermec for spending a lot of time providing us with facts and consultation.

7. Valve Overview

For convenience we have included an overview of the different bleed valves, A42, A43, A44 and A51. These are referred to a number of times throughout the report.



Picture: Shows an overview of the position of the bleed valves (Turbine designed by Dresser-Rand)

8. References

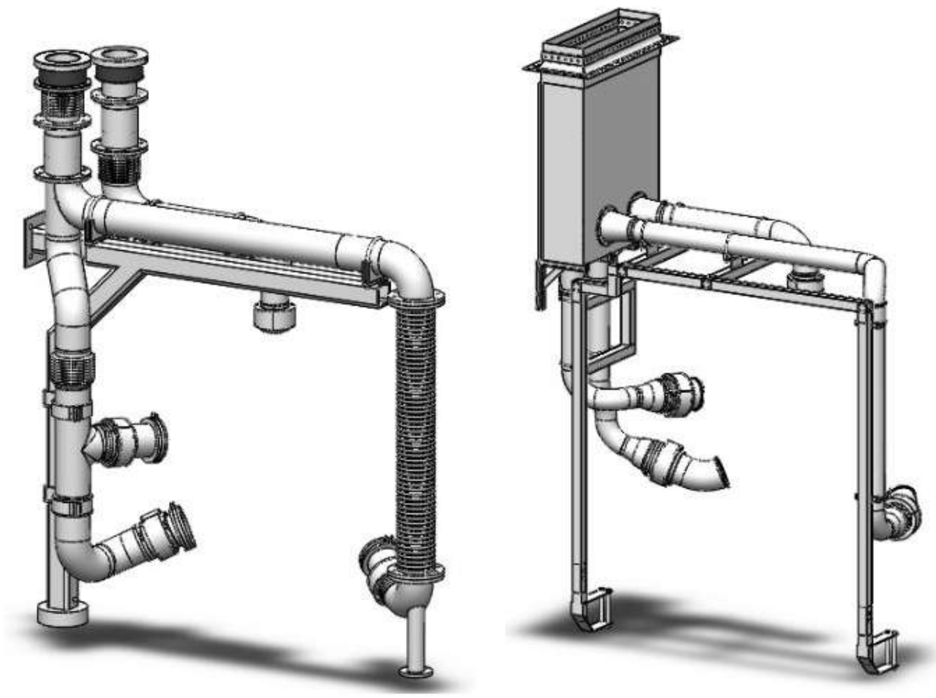
Riskmanagement (2011). *Risk management services* [Internet] Available at:
Riskmanagement.unt.edu
[Accessed: 22 may 2017].

DRESSER-RAND

University College of Southeast Norway

Vision Document

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
Svenn Bjørnstrøm
Kristian I. Asgeirsson

23.05.2017

Document History

Date	Version	Changes	Approved by
19.01.17	0.2	Introduction, other roles, background, existing solution, primary and secondary stakeholders.	Kristian Daniel
31.01.17	1.0	Approved for submission.	Øystein
22.05.17	1.1	Corrections, Structure	Øystein
23.05.17	2.0	Approved for submission	Kristian

Table of Contents

1. Introduction

The aim of this document is to make the reader familiar with the project's purpose and scope. It shows who are directly and indirectly involved in the project, the problem we face and what a good solution entails. It also shows what we hope to accomplish.

The task given to us by Dresser Rand AS department Kongsberg is to design a system that bleeds of excess air on a Rolls Royce RB211-GT30-DLE industrial gas turbines package, used as electrical generators and gas transportation boosters.

2. Organization

2.1 The Student Group

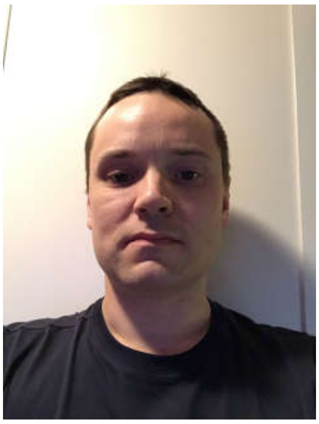
The group consists of four mechanical engineering students.

Daniel Herness

Main Area of Responsibility: Documentation

Kristian Inge Asgeirsson

Main Areas of Responsibility: Group Leader, Testing

	**Svenn Bjørnstrøm** Main Areas of Responsibility: Requirements, Systems Engineering
	**Øystein Botnen** Main Area of Responsibility: Design

2.2 Other Roles

2.2.1 Internal Supervisor

Shifteh Mihanyar: Employee at school. Will have an overview of the project from process document sent by the group. She also has the assignment to evaluate the work done by the group together with external supervisor and external censor.

2.2.2 External Supervisor

Øystein Selås: Our contracting entity. Cooperates with intern supervisor and external sensor for evaluating the project.

2.2.3 Intern Sensor

Karoline Moholt: Employee at USN. She has the final decision about grade. Cooperates with intern supervisor and external sensor

2.2.4 External Sensor

Øyvind Eidsmoen: Our contracting entity. Are needed to the presentations that the group will have. Will cooperate with intern sensor and external supervisor to evaluate the project.

2.3 Provider of Assignment

Dresser-Rand is one of the largest suppliers of rotating equipment solutions to oil, gas, chemical, petrochemical, process, power, military and other industries worldwide. Dresser-Rand department Kongsberg is a company based in Kongsberg specialized in gas turbines, and gas turbine/compressor solutions (Dresser-Rand, 2017).

Dresser-Rand originates from Kongsberg Weapons Factory which started with small-scale production of turbines in the 60's. In 1985 Dresser Industries buys Kongsberg Våpenfabrikk gas turbine division. First 50% but subsequently 100%. At the same time dresser industries merges with Ingersoll Rand and becomes Dresser-Rand. This structural change has given Dresser-Rand access to work on larger turbines that have had huge demand for power and compression equipment for the oil and gas industry worldwide.

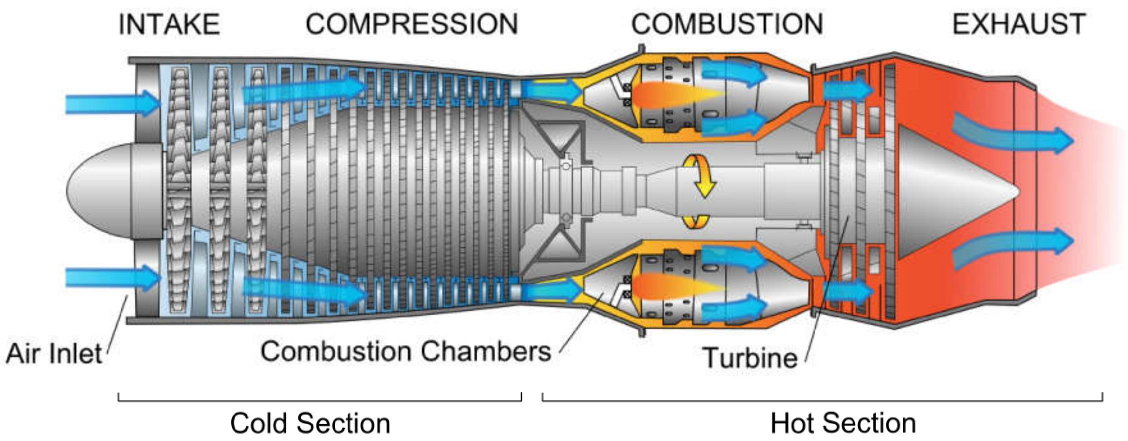
In 2015 Dresser-Rand was then bought by Siemens. Because Siemens owns Rolls-Royce division for industrial gas turbines, Dresser-Rand then expanded their access to a further series of highly advanced gas turbines.

3. Problem and Product

This chapter provides an overview of the problem in the bachelor thesis, pointing out what is important for an optimal solution, what is the existing solution and shows user requirements we must accommodate.

3.1 Background

In order for gas turbines of modern times to have dry low emissions they often operate with large surplus of air relative to fuel. This is to prevent the temperatures in the combustion chamber from exceeding limits for formation of NOx, a pollutant that can create major local environmental problems. Below it is shown a standard turbine with the various stages.



Picture: shows the various stages of a general gas turbine (Wikipedia, 2017).

The amount of fuel used is controlled by the load on the turbine or in other words the resistance from the system it will operate. At smaller loads, small quantities of fuel gets mixed with large amounts of air. This is the case during startup and partial loading. If the amount of air blown into the combustion chamber becomes too high relative to the amount of fuel, there is a great risk of a flame-out, and can result in extinguishment of the combustion flame.

The solution to the problem is a bleed system. A bleed system's task is to bleed of excess air from the compression stages before it hits the combustion chamber (see the picture above). In the case where the turbine is placed in an enclosure the excess air needs to be leaded from the turbine and out of the enclosure via some kind of a flow channel.

3.2 Existing Solution

An existing bleed system solution was designed by Dresser-Rand for the gas turbine package RB211-GT30-DLE. The problem is that the configuration of the system would require long maintenance times, it’s considered difficult to construct and assemble, and it occupies too much space in the structure housing of the gas turbine. This prevents access to other equipment and components.

3.3 User Requirements to the Solution

- Same or lower costs for production and maintenance
- Same or lower time for maintenance.
- Easier to construct and assemble.
- It must be possible to use existing equipment and structure housing.
- Must comply with all safety requirements.

4. Stakeholders

We have chosen to divide stakeholders into primary and secondary stakeholders. We define primary stakeholders as those who are directly involved in the development process, and secondary as those who have no direct effect, but can be affected by the outcome of our thesis.

4.1 Primary Stakeholders

4.1.1 Dresser-Rand

Our main stakeholder is Dresser-Rand department Kongsberg. They are the ones who have provided us with the problem statement, and want a solution to the problem. Their main interest in coherence with the project will be financial savings. Their responsibilities include assistance with technical and process-related consulting, evaluation of work, and paying any direct costs.

4.1.2 USN

The University College of Southeast Norway is another Primary Stakeholders. The work done in the project can be interesting for the school to use for educational purposes. The school will assist with evaluation in cooperation with the provider of the task.

4.1.3 Our Group

Another important stakeholder is ourselves in the project. We are the ones who have been requested to make a project for Dresser-Rand. Our interests are to get a good dividend from our work, and get the best possible assessment of the project. We provide at least two possible solutions to the problem of our cooperative business.

4.2 Secondary Stakeholders

4.2.1 The Customer of D-R

The customers of Dresser-Rand in association with this project is contractors, oil companies, pipeline operators and power generation companies. All customers of Dresser-Rand are in some way affected by our work indirectly. A successful solution to the bachelor thesis makes Dresser-Rand’s product less expensive to buy and/or less expansive in the long run.

4.2.2 Owners of Dresser-Rand

The owner of Dresser-Rand, Siemens, are also indirectly affected by our work. All financial gain and intellectual property received by Dresser-Rand would also inflict on Siemens.

4.2.3 System Operators

The direct user of the gas turbine system is also an important secondary stakeholder. A new solution could change a specific part of the work protocol for an operator of the gas turbine. Also the safety for themselves would be a concern.

4.2.4 Maintenance Crew

Maintenance workers can also indirectly be affected by our work. A better solution of the bleed system could make the maintenance time be shorter, and make it easier to do. Also, the safety for themselves would be a concern.

4.2.5 Shareholders

All shareholders in the Dresser-Rand or owners of dresser rand can be indirectly affected by our work. Their gains are strictly economical. All economic gain for Dresser-Rand would be beneficial for their shareholders.

4.2.6 Competitors of Dresser-Rand

The competitors of Dresser-Rand and their partners can also be indirectly affected by any success of Dresser-Rand. Their interest would be for our solution not to give any benefits to Dresser-Rand.

4.2.7 On-Site Workers

All workers located on site of the working gas turbine are indirectly affected. A new solution could change a specific part of the work protocol for any workers working nearby the gas-turbine. Also the safety for themselves would be a concern.

4.2.8 Suppliers

All suppliers of the parts in the bleed system are also affected. Their concern is to be able to produce the parts of the system.

4.2.9 Recycling company

The company who gets the responsibility of recycling the system is an indirect stakeholder. Their concern would be the recyclability of the system.

4.2.10 Government

We must consider the government as a stakeholder because of the laws and regulations we have to follow, mainly considering hazards and pollution.

5. Goals

It is important to have a set of goals, both for the group and the results of the project, so we have guidelines to follow throughout the project. At the end of the work we can measure our performance against these to assess whether the project has been a success.

5.1 Group Goals

During previous semesters, we have been through various subjects where we have built up skills in theoretical, technical and administrative issues. It has given us the foundation we need to implement a project of this size. On this basis, our group goals are the following:

- Acquire new knowledge and improve the theoretical, technical and administrative skills.
- Be an asset to our company.
- Execute a process and make a product of good quality and achieve a corresponding grade.

5.2 Result Goals

D-R expects that we develop at least two concepts that will be presented using 3D models with supporting documentation. Our goals for this result is therefore the following:

- The final concept meets all the "Top-Level" requirements.
- Complete detailed drawings of the concept in CAD.
- The results are analyzed using FEM and other documentation.

6. References

Dresser Rand (2017). *About us* [Internet]. Available from: http://norway.dresser-rand.com/aboutus.php [Accessed 31 January 2017].

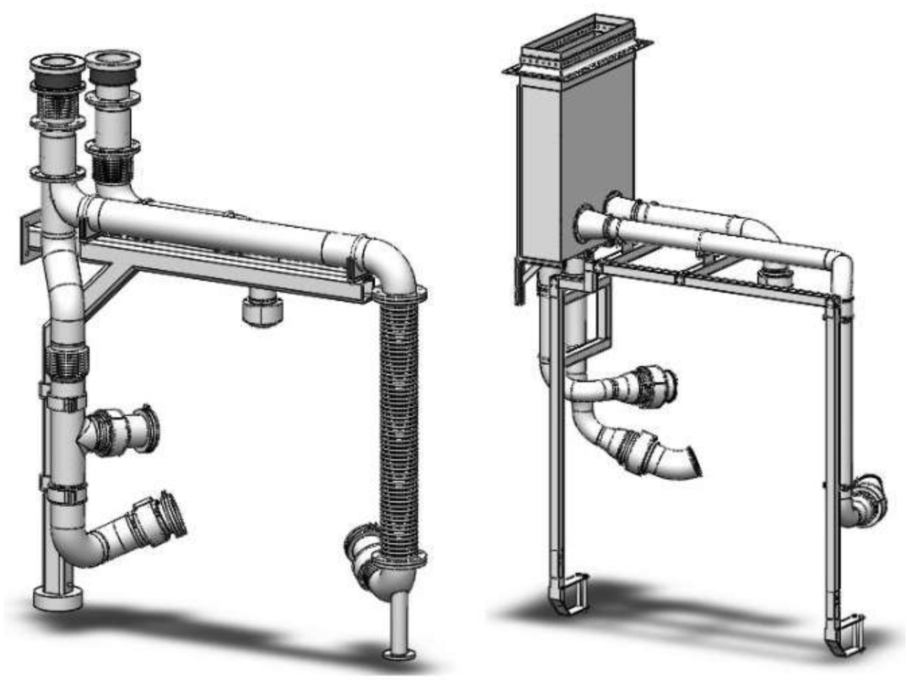
Wikipedia (2017). *Jet engine* [Internet]. Available from: https://en.wikipedia.org/wiki/Jet_engine [Accessed 12 January 2017].

DRESSER-RAND

HSN University College of Southeast Norway

Project Plan

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
Svenn Bjørnstrøm
Kristian I.
Asgeirsson

22.05.2017

Document History

Date	Version	Changes	Approved by
19.01.17	0.0	Created	Daniel
31.01.17	1.0	Approved for submission.	Øystein
21.03.17	2.0	Approved for submission	Kristian
17.05.17	2.1	Milestones, Timeline, Iteration Plan	Kristian
20.05.17	2.2	Difference between CAFCR+ & UP	Kristian, Øystein
22.05.17	2.3	Corrections, structure	Kristian
22.05.17	3.0	Approved for submission	Kristian

Table of Contents

1. Introduction

Dresser-Rand AS (D-R) department Kongsberg is our collaborators in this bachelor project. They have given us a bachelor thesis about designing a bleed system for a gas turbine. This document gives a brief overview of the project and shows how the main areas of responsibility are divided among the group members and the project model we are using. It will also give an overview of the planned progress throughout the entire period of the project.

2. The Project

2.1 Limitations

Limitations in this project will be the time limitations in this semester before hand in at 19th of May, it will also have design limitations that must follow Norsok R-002 Lifting equipment and S-002 Working environment and limitations from user, D-R. Limitations from the user will be continually processed during group iterations and updated during the project.

When designing for lifecycle we also need to be aware of which material we choose to use, and consider all the stakeholders' views. Our concept should last for 25 years, as for the turbine. So after 25 years all of the components we are using must be dealt with and sorted in the best manner. The Norsok S-003 Environmental care will be a limitation for the selection of materials.

2.2 Preconditions

The student group have some basic needs for fulfilling the bleed lines system task. The first and most important goal is to get the understanding of the project. All the requirements must be collected from Dresser-Rand, and for this we need weekly meetings and correspondence by phone or e-mail. Dresser-Rand also need to give access to a simplified model transformed into a format we can use in Solid Works(3D). For the presentation, there will be needed a intern supervisor from the school, intern supervisor from the company, and an external sensor, also provided by the company. The student group needs a place to work with the project, and internet for the use of a cooperation platform like google disk, Facebook etc.

3. Main Areas of Responsibility

Six different areas of responsibility have been divided among the members of the group. The person responsible of a specific area of responsibility (the responsible) will ensure the progress on that particular field every week and needs to have a good overview of the given area. In case of large deviations from the project plan, the responsible of the given area will inform the others about the status, and the group will decide the next step. The role is purely administrative, and there is no authority to decide actions in the area alone. The responsible can, however, suggest delegation of different activities within his area.

The Main Areas of Responsibility is divided in this manner:

- Kristian: *"Group Leader"* and responsible for "*Testing"*.
- Daniel: Responsible for "*Documentation"*.
- Svenn: Responsible for *"Requirements"* and *"Systems Engineering"*.
- Øystein: Responsible for *"Design"*.

3.1 Group Leader

The responsibilities of this area are to ensure:

- That the project is on the right track.
- Flow in the project by organizing, planning and have a general overview.
- The right focus during the entire project.
    - That the grade impact of the different parts of the project is reflected in the amount of work invested in each of them.

3.2 Testing

The responsibilities of this area are to ensure:

- That the testing is done based on the requirements.
- That the testing is done as realistic and reliable as possible.
- That the results and the test process is evaluated to exclude errors.
- That the results and the test process is noted in a manner that is understandable and possible to document in the report.

3.3 Documentation

The responsibilities of this area are to ensure:

- That all documentation is done in the right manner.
- That all the relevant information of the documents is included.
- That all documents are structured according to the correct layout.
- That all testing is well documented.
  - With focus on requirements.
- That all the text is written in an informative and understandable way.
  - As short as possible, but still complete.
- That all work is backed-up on at least two external devices.
  - This is done several times during a week and after every day with a lot of time invested in documentation.

3.4. Requirements

The responsibilities of this area are to ensure:

- A good overview of the requirements.
  - Knows the status of all existing requirements.
  - Knows what kind of requirements we are lacking.
- Generating of new requirements when new relevant information is acquired.
- That all choices on the product is related to the requirements.
- The traceability of the requirements.

3.5. Systems Engineering

The responsibilities of this area are to ensure:

- The right use of the project model throughout the project cycle.
  - The right use of iteration phases.
    - Right content in these phases.

3.6. Design

The responsibilities of this area is to ensure:

- Realistic concepts of the product.
- Good usable models of the product.
- A design that reflects all the requirements.
- Material use

4. Project Model

4.1 Introduction

All the developers want to make the right product before the competitors, and this is the key success factor. A project model guides the participants to a good result the customer(s) are satisfied with. If used the correct way the problems in a project will be eliminated already in a early phase, and some of the models can lead back to earlier stages to fix problems, and still this won't affect the rest of the project. The start is finding requirements, and then the developing to be followed by the final product. Throughout the project trade-offs and compromises are needed to reconcile requirements with what is feasible (Stevens, 1998). If the requirements are misunderstood, badly written, or possible to interpret the project might fail. The factors influencing the failure the most is incomplete requirements and the lack of involvement from the customer. To design a system, this is not only the final product. All factors in the user world must be taken into account. Making a fantastic product doing the wrong tasks wouldn't do the trick. With full operational capability, there will be delivered operational procedures, support, processes material training and disposal. With the project model suited for the right project, all requirements are traceable, it gives a good understanding of the project by text, diagrams or pictures. It will be possible to solve the problems effectively, at the same time as the complexity in the system is managed in a good way. Using the model is a creative process, defining requirements and the end product.

4.2 Choice of Project Model

At the beginning of the project there existed some ideas about the solution, a solution that wasn't good enough for the owner of the project. We began with structuring the understanding of both the problems and the solutions. To find them we need some basic methods, analysis, and communication. For having a structure during these operations and the whole process from the beginning all the way to the end product it is a great help in following a project model.

We started the selection by looking at and discussing several models; Waterfall Model, the V-model, Unified Process, Scrum, CAFCR, spiral model, Ad hoc, and some more. Our project is a development project. The scope and the solutions of the project for us is rather unknown, and with some known and unknown requirements. The space we operate in is limited and multiple variants of the solution is wanted from our project owner. Also, we as a group are inexperienced with a task of this scale. Many of the models were soon to be excluded since they didn't suit our project. The elimination process pointed out two models in the end that we wanted to work with. One was Unified Process, and the other CAFCR+. Unified process and CAFCR+ have much of the same good qualities that suited our project. They both are iterative, they both let you get fast right into the project, giving you a good overview early in the project, and they both provide you with the opportunity of making changes in the project. In the end we choose CAFCR+. The reasons for choosing CAFCR+

was that in addition to the common benefits of unified process it is adaptive to the different engineering disciplines, it comes with some excellent supporting tools in the form of diagrams and models, and we also have experience from before using CAFCR to build a fairly complex system. and an important advantage with the CARCR-model is its product focused rather than being purely project focused like most other project models.

Some requirements are well known from international standards, some are given by Dresser-Rand and some we have to construct ourselves. The CAFCR model iterates on several perspectives and should give a solid understanding of all the requirements. The system also needs to be reevaluated often to find the best solution from all the different designs and we need a good understanding of the context to understand the problem and solution. The CAFCR+ model is as said before also adaptive to different disciplines within engineering, so even if we have a purely mechanical approach the model fits well to this project.

The projects in newer time are more complex, stretches over borders, and is produced part by part in different locations in the world. Therefore, there is a need for the use of a work structure that can include a lot of different disciplines within engineering. There must be some people with the skills of a t-shaped employee, that have a deep understanding in specific skills, but also have the desire and ability to work across disciplines. The horizontal part in the T represents the breadth in the knowledge, and the stem symbolizes the deep knowledge of subjects. These people oversee the models and keep a complete overview of the project.

4.3 CAFCR+

The CAFCR model gives five views of the problem, the WHAT view in the form of customer objective explaining what the customer wants, the HOW view, where it gives application and how the customer gets what he wants. The functional view is the WHAT of the development, and the conceptual and realization is the HOW of the product. The + in the CAFCR+ addresses the lifecycle of the product. The phases through its lifetime must be considered. With this we mean: operations, maintenance, upgrades, manufacturing and installation. In the life cycle there can be many stakeholders involved and many considerations must be taken. The most important, and that will be worked with until the end, is the requirements. All of the functions in the complete system shall be connected and traceable to the requirements. And to capture a view hopping method is used, looking at the problem from the different view of primary and secondary stakeholders (Muller, 2011)

The views are used concurrently, and should not be looked at in a top-down view like the waterfall model. The Waterfall model consist of a requirements phase, followed by the design, implementation, verification and maintenance. By using the waterfall model the developers work from the top, and lack the opportunity to go back to earlier stages without changing the other following steps. The CAFCR+ is much about understanding the customer(s), by its concerns and needs. The CAFCR+ also embraces the decomposition in every stage, where customer objective is decomposed into different “customers”, and will consider all the stakeholders through the project having a direct or indirect connection to the project. The stages are much the same in all the models, with the stages taken into consideration in the waterfall model. The big difference is the work breakdown structure, and the possibility to consider more than one stage at a time. The working process in the CAFCR+ model uses iterations, where stages are divided into time bulks, ranging from 15 minutes and up depending where we are in the project. The iterations are creative “throw thoughts to the table” processes, and is short to give many ideas in a short period. The iterations have an established agenda, and when the ideas are slowing down or time is up, the subject is changed to another stage. This is repeated through the whole project, and the links to requirements is always in the back of the mind. When doing the iterations, it is not the intention to be done with the theme of each step, but more to have an effective iteration process and rather move on in the iteration process.

5. Follow-Up

5.1. Process Document

The process document gives the supervisor at USN a thorough insight in how the progress of the project is, and if there needs to be made some adjustments. The weekly “keep-track-of” document stretches back and forth one week at a time. In the last week, it gives a complete brief overview over stages the project was in, and progress compared to the project plan. If the progress is not as intended, It also derives why the plan isn’t complied. Every group member needs to document hours used, what kind of critical activities they have worked with, and the total number of hours used in general. The next week shows the planned critical activities, time to be used on the activities, and the total time group members plan to spend. The document is sent to USN supervisor at least 24 hours prior to the next meeting.

5.2. Meetings

5.2.1. Internal meetings with supervisor

Meetings with USN supervisor is scheduled once a week. The student group books a room in advance for the meeting, and the supervisor prepares by reading the process document received the day before. The meetings are scheduled to be held Fridays at 09:30, and will last for approximately 30 minutes. The supervisor will guide the student group, and will give suggestions if the group needs guidance. After the meetings, the student group write a report, and submit to the supervisor within 24 hours of the meeting.

5.2.2. External Meetings with D-R

Regular meetings with the project owner is of great value to the group. The project model CAFCR+ emphasizes requirements, and the best way to get them is working with the problem and have meetings to track new ones. Meetings are scheduled once a week, for at least one hour at their facilities. Usually the group sends an agenda and questions in advance, and the project owner schedules meetings in google calendar. In general, these meetings don't have a specific layout, except introduction of meeting with one safety subject of the day. The topics in the meetings varies, and the student group have a good possibility to ask questions. The meetings are attended and represented by the company's external sensor, external supervisor and a 3D model mechanical engineer. After the meetings, the student group write a report, and submit to the company representatives within 24 hours of the meeting.

5.2.3. Group Meetings

The group meetings are where we discuss relevant issues relating to the whole group. It will be the where we can discuss the progress of the project and together see where we are compared to the schedule. We have set a fixed time ones a week on Wednesdays for the group meetings. The agenda for this meeting will be a review of the week. and the plan for the next. We will in this meeting divide work from the high-level work breakdown schedule to the group members for the week. When needed, outside the regular meetings we will have the opportunity for brief meetings where we can update each other and find solutions to current problems. This is important and timesaving and lets us advance the process with better flow. It also clarifies for everyone in the group and helps everyone to participate in the process.

6. Milestones

- 03.02.17: Presentation 1.
- 22.02.17: Showcase of concepts for D-R.
- 07.03.17: Choose a narrow selection of concepts.
- 24.03.17: Presentation 2.
- 09.04.17: Choose final concepts.
- 01.05.17: Complete model.
- 01.05.17: Complete testing.
- 19.05.17: Submission of report.
- 29.05.17: Presentation 3.

6.1 First presentation

In general, all the presentations will display the progress in the project to the external sensor, internal sensor and the internal supervisor. All the presentations contributes to the total evaluation in june 2017. The sensors and the supervisor will also evaluate the progress in the project, both regarding the use of systems engineering as a tool, and the result of the development. When presentations are held, it is open for all who wants to listen.

The main goal of the group until the first presentation is the planning of the project, with the necessary background information, scopes and goals. Less prioritized is the concept itself. The student group will be evaluated on the planning, the work method, presentation skills, requirements collection, testing and document configuration. The presentation will be approximately 20 minutes, with sensors and supervisor meets half an hour before and after to prepare and do their evaluation.

6.2 Showcase of concepts for D-R

We will choose the concepts we think have the most promise and share them with D-R. And in a presentation, the concepts will be introduced. The goal here is to get useful feedback from D-R about which of the concepts are worth looking more into and not. This is important to help us sort out the best concepts and do further research on them. The plan is to have a relatively large selection of concepts on this occasion.

A preview showing will also be held before to get feedback. We do this to get an idea about which concepts we should work more with and which absolutely don't work. We will thus Prevent meeting with totally useless concepts on the actual showcase. This way we prevent the event of having to start all over again after the showcase.

6.3 Choose a narrow selection of Concepts.

From the time, we show the first proposal of concepts we are going to examine and test the feasibility of the concepts. It is likely that several of the concepts will work as solutions to the problem, but this is where we will find out whom are the best to go ahead with, considering all the requirements set and new ones. In a presentation with Dresser-Rand we will then introduce a narrow specter of concepts we think will work best and why, and decide together about which concepts we should choose to work on with.

6.4 Second Presentation

The progress and where we are in the project will be presented together with how the student group stands in comparison to the project plan. If there are large deviations to the plan, there shall be reasoned why, and how the deviations are solved. But more importantly we will present the work done on the system. There shall be a definitive technical focus in this presentation. The time planned and the meeting policy of the supervisor and the sensors are the same as for presentation one.

6.5 Choose final Concepts

From the last round of concept selection, we are left with a few concepts we have been working on in detail. At this selection round, we will decide which two concepts we think are the best to be implemented as products for the problem. It is these two concepts that will be worked on towards the end of the project.

6.6 Complete Model

After two specific concepts are determined to proceed with, we work a lot with detailed design. This happens in the design/testing phase of the project. During this time, we will go from the simple concept to a fully functioning design of the system. The design will then be ready for the final test period.

6.7 Complete Testing

Testing will occur all throughout the project, and especially in the design/testing phase, where the testing and designing is done in parallel. When testing is completed we should end up with a fully functional system.

6.8 Submission of Report

The last phase of our project is the documentation of the project. All the phases of the project need to be documented, to convey the outcome. Everything that isn't will not be considered done so it is important that everything is included. It is important for us to keep documenting all true the project, but the goal is to have all the documentation from the project done for this milestone.

6.9 Third Presentation

This presentation is selling the product to the customer. ⅓ will contain the business and marketing part of the project, ⅓ the technical part and the last ⅓ will be a question round to the group. Every of the thirds will take approximately 20 minutes, and this is the last presentation that gives the student group individually their grade.

7. Resources

7.1 Activities

For each phase of the project we will plan the steps and activities based on milestones and iteration rounds. For every new week we will then break down the planned activities to detailed activities with activity names and numbers with estimates of time spent that we hand out to group members on weekly meetings. This breakdown of activities will form a system which we will use to register into the time logging document. We will then to some degree be able to keep track of how the estimated time of project activities compares to the actual time it takes.

7.2 Time Logging

Timesheets are shared in google disk, and each group member has a responsibility to keep track of time spent. The sheets last one week at a time, from the group's own constructed week, related to the weekly meetings with USN supervisor. The week begins at Thursday, includes weekends, and ends on Wednesday. Members fill out their own week, with activities and time spent within the week. The programed timesheet calculates the total time of every day, every week and total group time in the project.

7.3 Cost Details

The budget is set for the project, and is limited by a specified amount. The specified amount is decided by the project owner at an early stage. That limits the student group within the budget as specified. The students shall not receive any payment for the work done for the company, either it involves money or gifts. If there are expenses related to the project the project owner will pay for this.

8. Schedule

This is an overview over the planned process in this thesis. It gives us control and overview over the whole process and at the same time possibility to do changes and updates.

8.1 Timeline

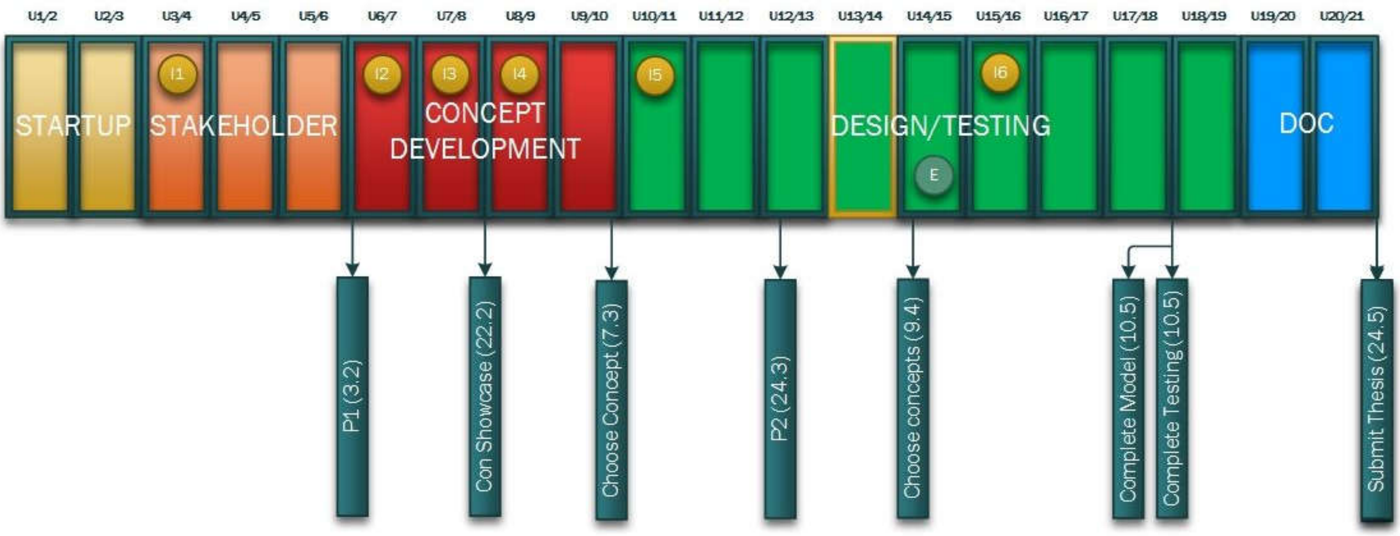


Diagram: Showing Timeline of the project.

The diagram shows the timeline for the project based on the phases involved. The phases indicate which areas we are focusing on at each period. The project consists of 5 different phases. These include startup, stakeholder, concept development, design/testing, and documentation. An overview of the weeks can be seen on top of the diagram. They include half a part of two different weeks because of the specially modified week schedule we use. The milestones along the timeline are shown below with arrows pointing to the estimated time they will occur. The iteration rounds from the cafcr model are shown within the week they are to be conducted indicated with yellow circles. And also, the one week dedicated to exam work is indicated by the yellow framed week.

8.2 Iteration Plan

8.2.1 Iteration overview

Iteration rounds and activities were planned already in the startup phase of the project. In planning, it was important to include activities sufficient enough spread across the views of the CAFCR model to get the most breadth in the project all the time. It is planned to include 6 iteration rounds, divided into 3 of the phases in the project. Some activities fit well to where they are performed in the project, but it is also important that the activities provide information on other stages of the project, so some of the activities have nothing to do with stages they occur in. Most of the activities are established CAFCR activities, which are fully described how performed, but the CAFCR model also provides room to create your own iteration activities, so some of the activities are made by the group.

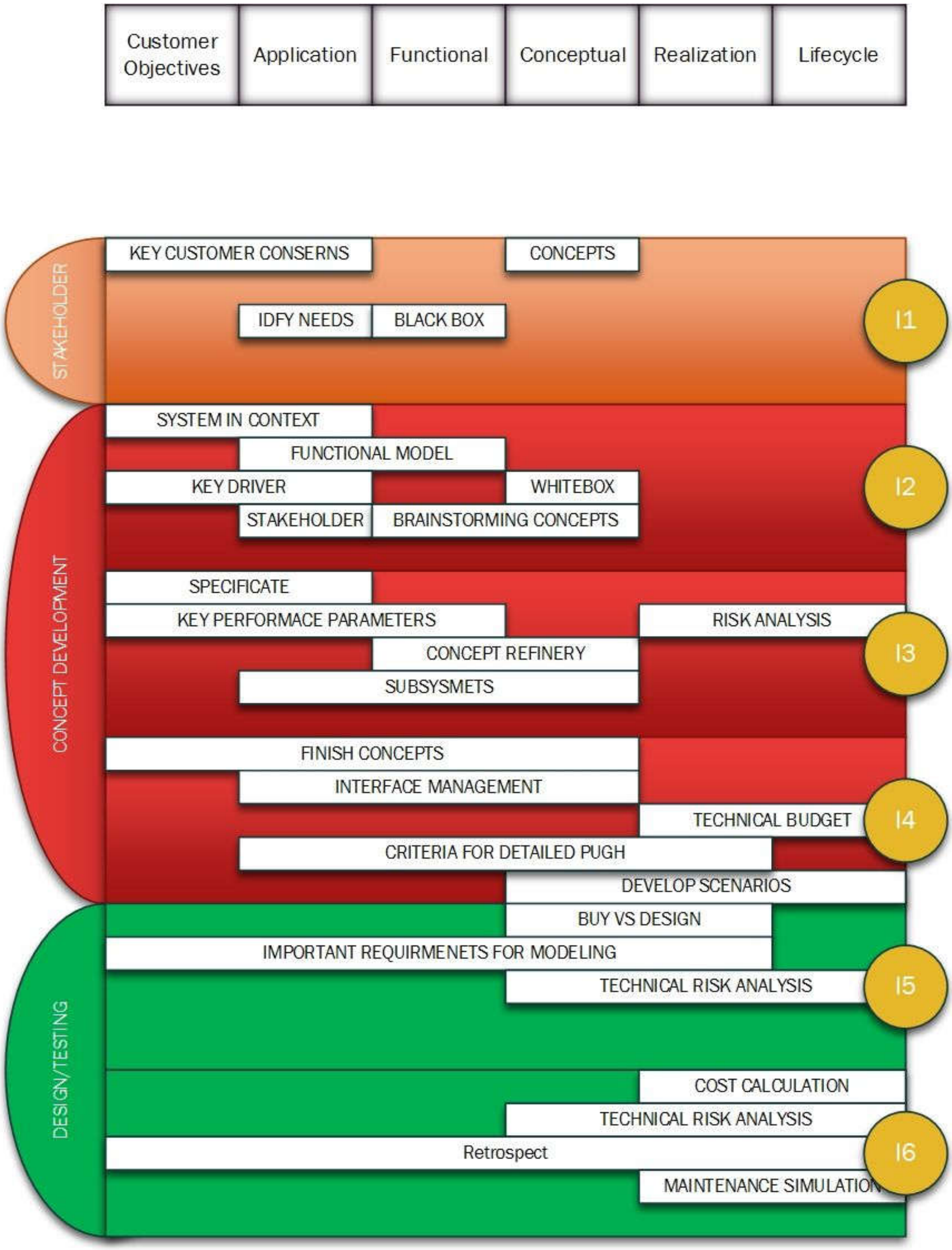


Diagram: Showing the iterasjon plan.

The diagram above shows the iteration plan, how the CAFCR model comes into the project, and the structure of the iteration rounds. Here we see how during the project we iterate between the focus areas of the CAFCR model. The Iteration number is indicated beside the iteration boxes with the same yellow circles from the timeline in diagram of the timeline, and the iteration activities are inside the boxes within each iteration. We can also see which of the project phases the iteration round occur at indicated with the same color scheme as from the timeline in diagram 1 and with the name of the phases on the left side of the model.

By following the CAFCR-model and working with activities associated with all the different phases of the project we in fact work with all the phases of the project in parallel. In this way we constantly have focus on the entire life of the system and get an understanding of as much as possible of any Issues that may arise in all the later phases, and thus minimize technical risks in an early stage.

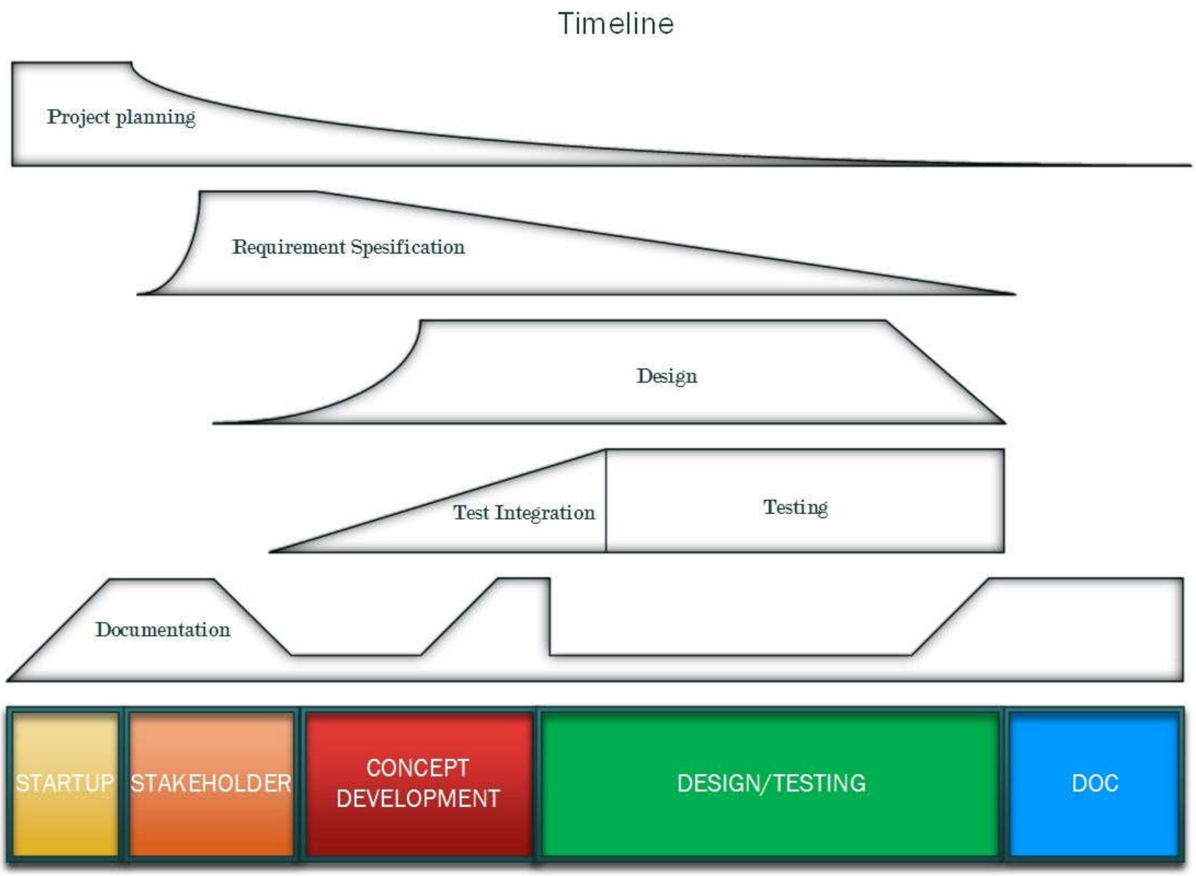


Diagram: shown how the group will work in the project.

In the diagram above we show the effect of the iteration work with the CAFCR-model. As can be seen the phases in the project plan are only defined by the biggest focus in the time interval. The views of the CAFCR-model will take us through the different stages of the system in all the phases of the project with the appropriate weight at each time, allowing us to as said before to work with the phases in parallel. The diagram shows how project planning will be emphasized in the startup phase, and then it will be gradually worked less on over time in the project. We will work with the requirement specification all through the project, but be a major part of the workload in the stakeholder and concept development phase, but gradually after that be less emphasized. There is little work done with the designing of the project at first in the project, but gradually from the stakeholder phase we start the work with the concepts and then amp up the designing work. and the preparation work for the tests starts early. with lot of focus in the end of the concept development phase, before we do a lot of work with testing. Documentation will be performed all through the project with a big emphasis on this in the start, before the second presentation, and in the end.

8.2.2 Iteration Activities

In this section, we show the detailed plan for each of the iterations. Information about the results in each Iteration is given in a separate iteration report document.

8.2.2.1 Iteration round 1

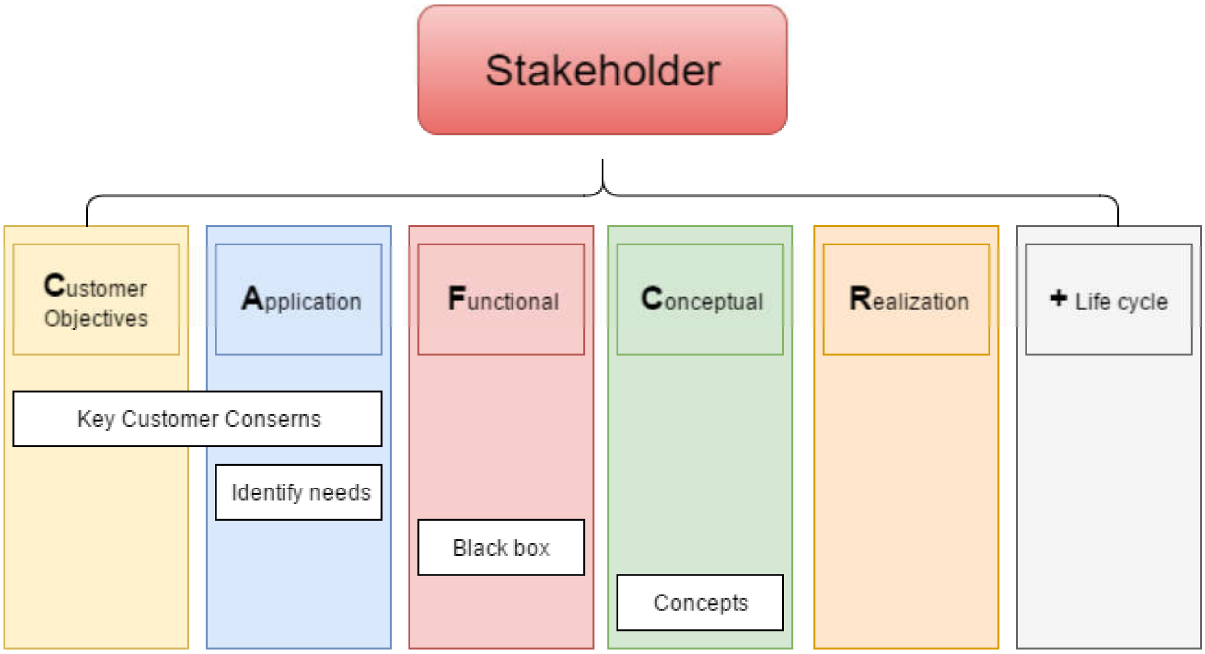


Diagram: shows an overview of iteration 1, and which views the activities are correlated to.

Introduction

The group decided four main fields to investigate in the first iteration. Key customer concern, needs, black box and design. We will use a timer for the different rounds, and to stop the clock before time is up if the ideas slow down. The CAFCR+ model has iterations as a key stone, and they are to be stopped when ideas stop flowing.

Date: 20.01.2017

Phase: Stakeholder

Iteration views:
- Customer objectives
- Application
- Functional
- Conceptual

Activities:
- Key customer concerns
- Identify needs
- Black box
- Design

Time scheduled: 20 min timeboxing

8.2.2.2 Iteration round 2

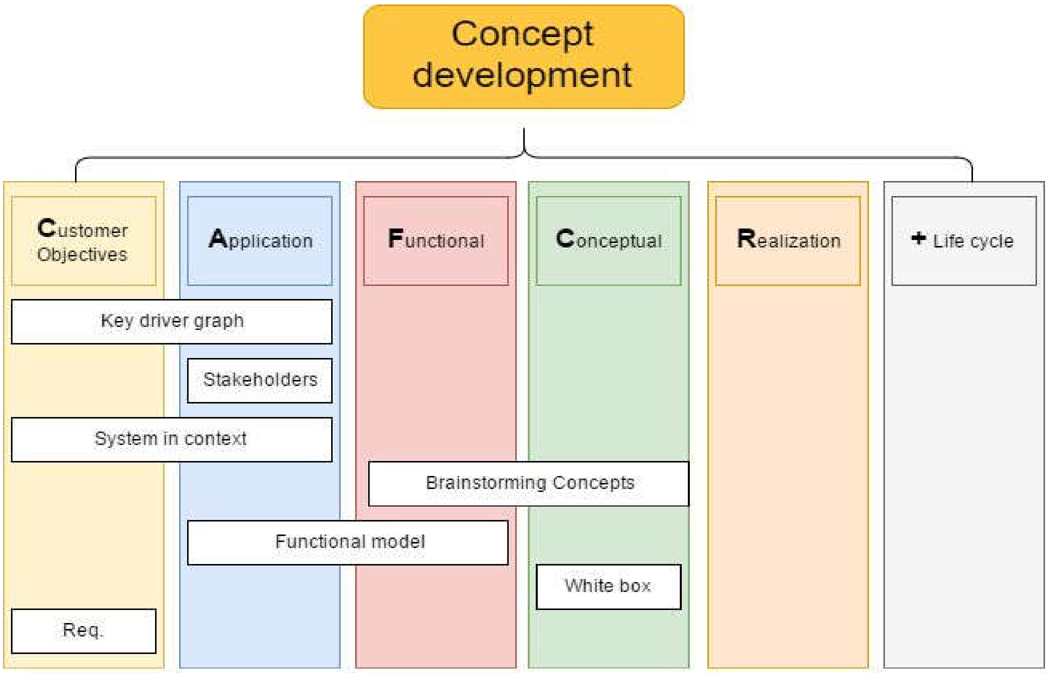


Diagram: shows an overview of iteration 2, and which views the activities are correlated to.

Introduction

This iteration is in the introduction to the concept phase. The goal is therefore to make several concepts to work on further into the phase. Simultaneously we have to validate existing requirements and generate new ones so that the concepts we develop always is what the customer wants and needs. As soon as a requirement is made that is in conflict with a concept, the concept must be eliminated. The activities done during this iteration reflects this iteration goal.

Date: 07.02.17

Phase: Conceptual development

Iteration views:
- Customer objectives
- Application
- Functional
- Conceptual

Activities:

- Key drivers
- Stakeholders
- System in context
- Brainstorming concepts
- Functional model
- Whitebox
- Requirements

Time scheduled: 20 min timeboxing (some may need 2 timeboxes).

8.2.2.3 Iteration round 3

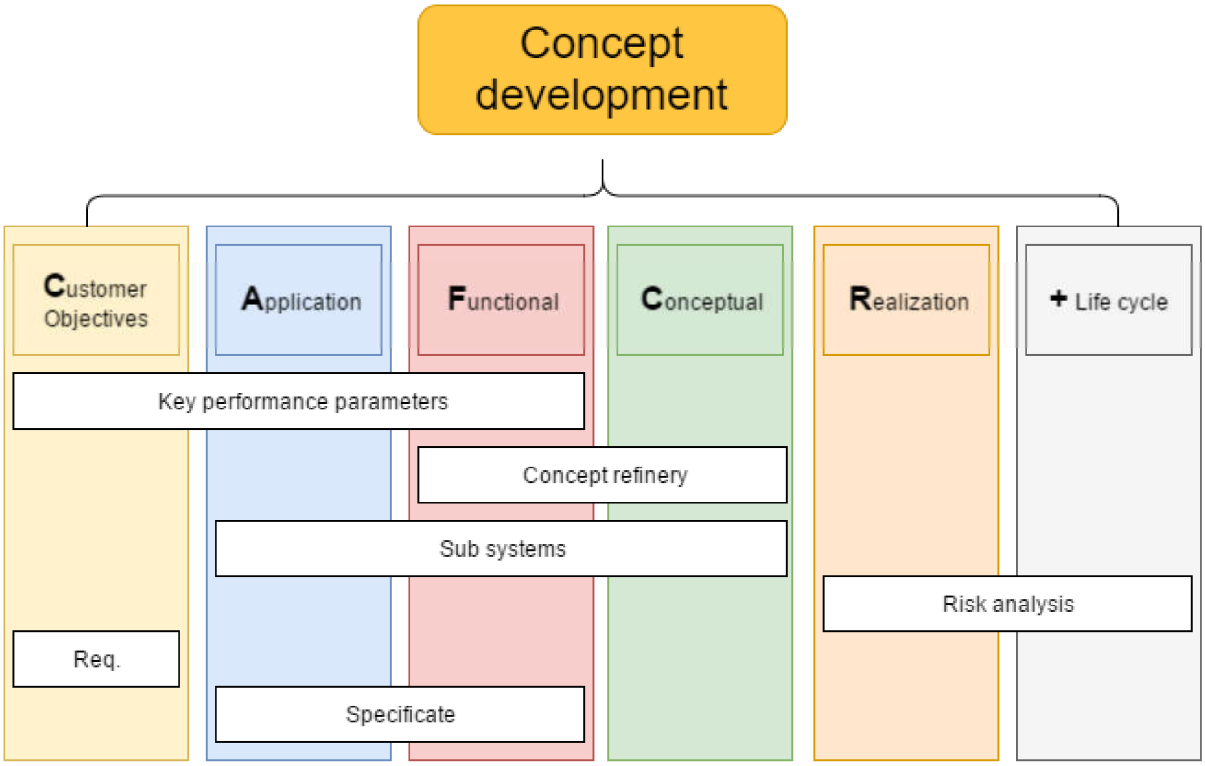


Diagram: shows an overview of iteration 3, and which views the activities are correlated to.

Introduction

Working with concepts will continue in this iteration and som concept refinery will be needed. More focus on the smaller parts, sub systems, is also important when we start focusing with a more detailed view on remaining concepts. We will also use a risk analysis to see which events will be serious for our project. New requirement will always emerge and must be written down in the requirement document. And the last activity is about specification for coupling methods we can use for the piping.

Date: 17.02.2017

Phase: Concept development

Iteration views:

- Customer objective
- Application
- Functional
- Conceptual
- Realization
- Lifecycle

Activities:

- Key performance parameters
- Concept refinery
- Sub system
- Risk analysis
- Requirement
- Specificate

Time scheduled: 20 min timeboxing

8.2.2.4 Iteration round 4

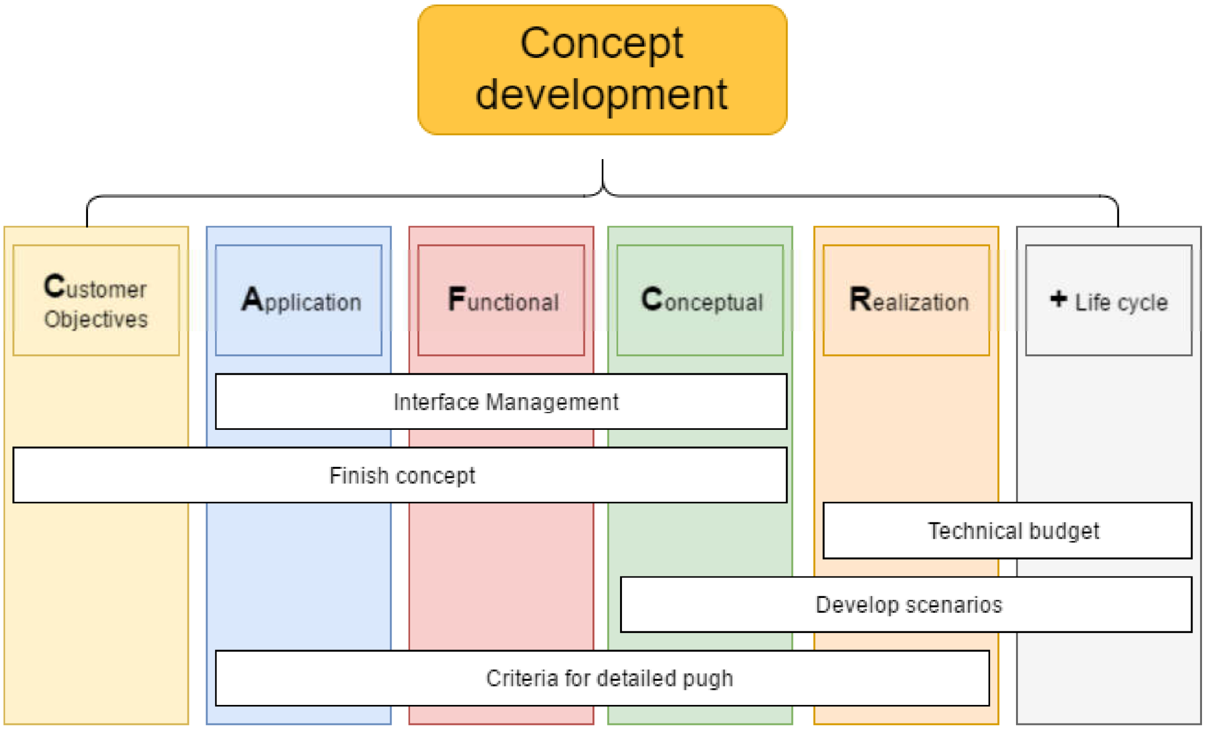


Diagram: shows an overview of iteration 4, and which views the activities are correlated to.

Introduction

Iteration 4 will be focused on gathering useful information to have a good basis for concept selection. The order of this week's iteration activities is somewhat more important than the former, since this week's activities retrieve information from each other. We will first conduct a review where all concepts are given more detailed interfaces between the bleed system and adjacent systems, secondly, we will think about details in the remaining parts of the various concepts, which will form the basis for performing technical budget for each of the concepts. scenarios of each of the concepts will then be of help to discover the more abstract problems. Finally we have a good basis to create criteria for the detailed Pugh matrix.

Date: 24.02.2017

Phase: Concept dev

Iteration views:

- Customer objectives
- Application
- Functional
- Conceptual
- Realization
- Life cycle

Activities:

- Interface management
- Finish concepts
- Technical budget
- Develop scenarios
- Detailed pugg criteria

Time scheduled: 30 min Time Boxes

8.2.2.5 Iteration round 5

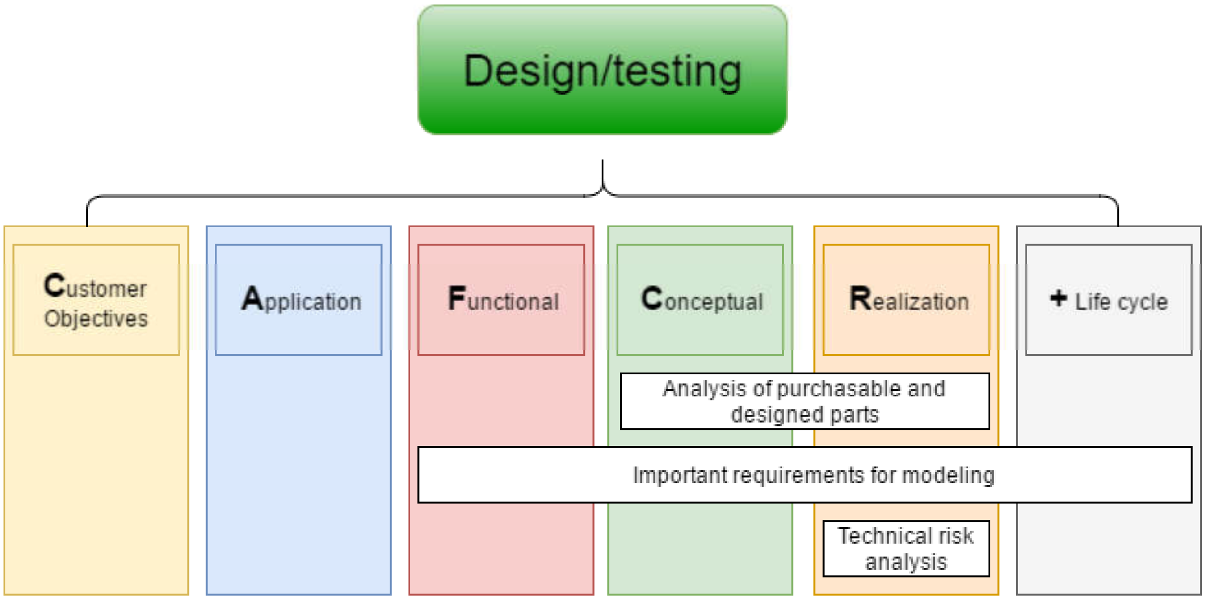


Diagram: shows an overview of iteration 5, and which views the activities are correlated to.

Introduction

This iteration is meant to give a foundation for us to use when we start designing the models of the concepts in SolidWorks. It will sort out which parts will be purchasable and therefore can be simplified in the model, saving time. Using knowledge from the past iteration rounds we will prioritize the modelling of each concept, so that we don't model the changeable parts of the system. All in all the iteration will be a tool to save time, gain knowledge about the concepts that will improve their quality and to avoid making mistakes and doing unnecessary work during modeling of the concepts.

Date: 09.03.2017

Phase: Design/Testing

Iteration views:

- Functional
- Conceptual
- Realization
- Life cycle

Activities:

- Analysis of Purchasable and Designed Parts
- Important Requirements for Modeling
- Technical Risk Analysis

Time scheduled: 30 min Time Boxes

8.2.2.6 Iteration round 6

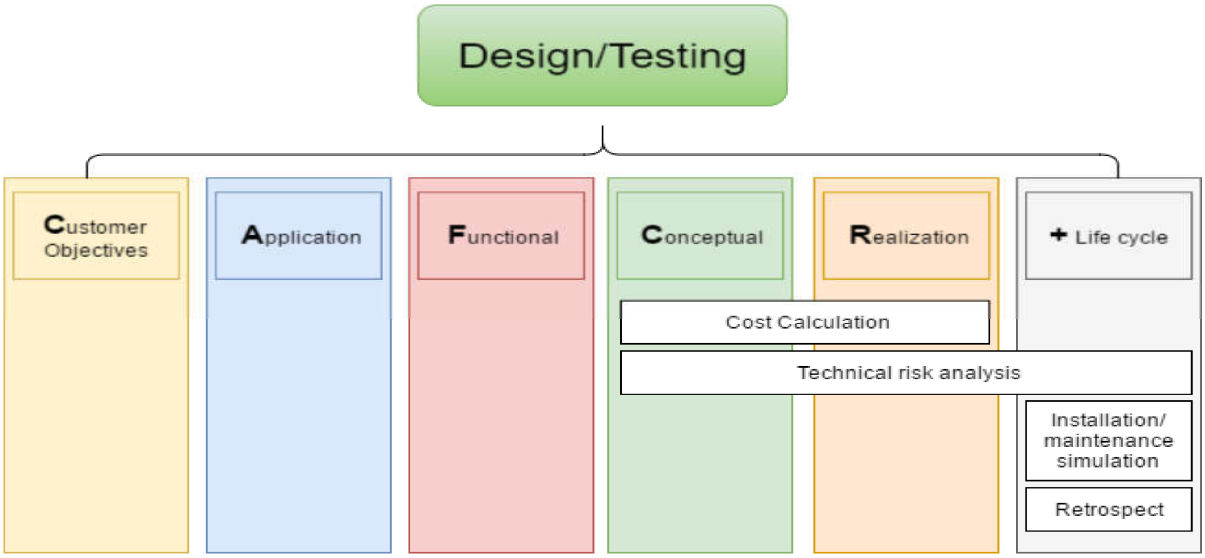


Diagram shows the overview of iteration 6, and which views the activities are correlated to.

Introduction
At the moment we are working for the last week with designing and testing, and preparing to change the focus towards documenting all of the work in the project. The most of the technical specifications are falling into place, and we are close to implement the right components and configurations to get the wanted functionality of the two remaining design concepts. As usual we think it is of great importance to always be on top of technical risks at all times during the project, thus we also conduct a technical risk study in this iteration. In conjunction with the assembling of the final design it is natural for us to focus on the the best possible way of installation and assembly/disassembly during service. It is only when we have established how we want to stack the system together that we can be sure that the configuration of the parts is right. although we have a rough idea about the price of the two systems as this has been an important factor when choosing the best possible parts. We can now get an more accurate answer on the price. lastly we prepare the next phase of the project by looking back on some of the most important technical decisions and changes associated with the designing of the two systems.

Phase:
Design/Testing

Iteration views:

- Application
- Functional
- Conceptual
- Realization
- Life cycle

Date: 4.5.2017

Time scheduled:
30 min Time Boxes

Activities:
- Cost calculation
- Technical risk analysis
- Maintenance simulation
- Retrospect

9. Risk

There will be risks related to the project. The risk areas considered is human risks, which is the most important together with environmental risks. Secondary the financial, technical and lifetime risks is considered. In the beginning there will be taken a general risk analysis of the whole project.

9.1 Risk Analysis

From the requirements there is need for risk analysis for the project. The risk analysis will rate the severity degree and the likelihood of an activity delaying, causing problems, or cause a direct hazard to environment/people in the project. The risk analysis is a key piece in the project model, and in a early stage it can tell about the risks and the subsistence of the project. The risks can stop the whole project if somebody of the stakeholders doesn't want to accept the risks, and the risk is impossible to reduce or eliminate.

The risk analysis is based on a typical setup. The resulting risk of a shortcoming in the project consist of the value of probability of the occurrence multiplied with the consequence. Risks that are highly probable of occurring but don’t have great impact, and risks that have reasonable impact but low probability of occurring won't be a big concern, but the risk with higher probability and bigger impact will be spotted and according to the risk level the right measures will be made.

9.2 Results

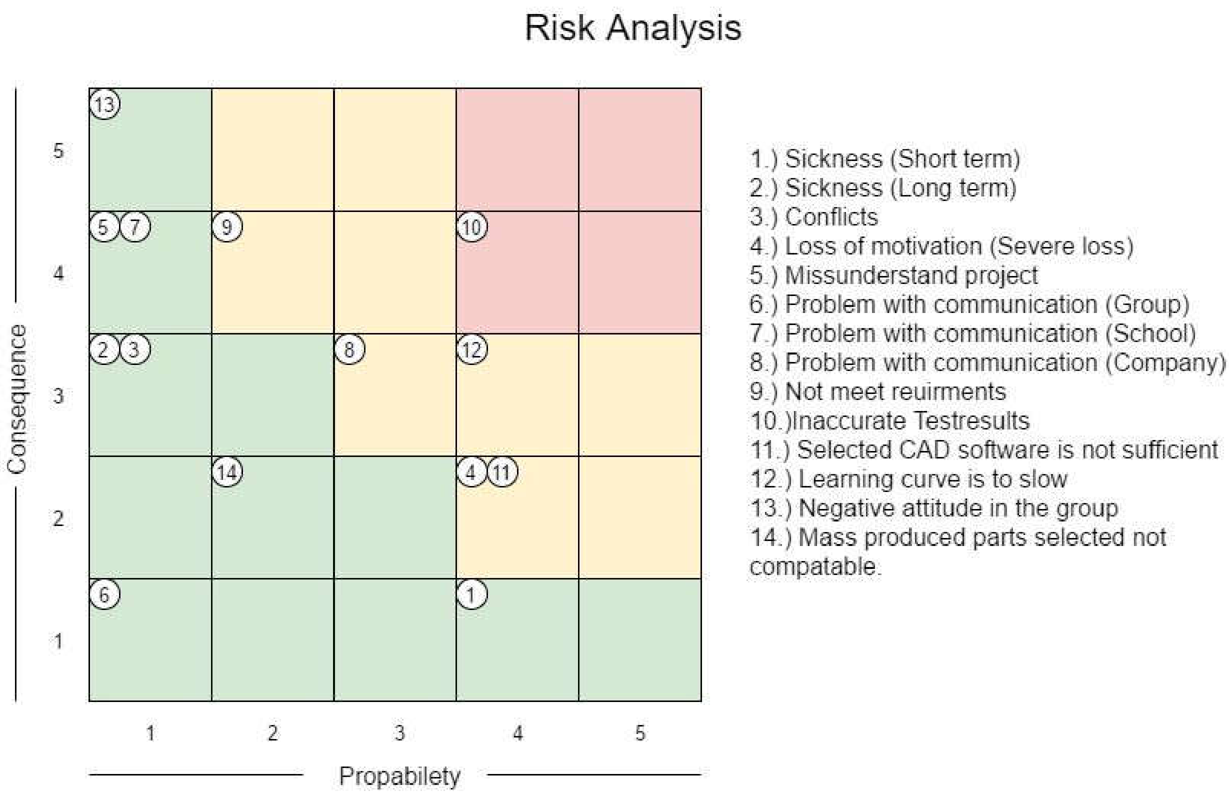


Diagram: the numbered risks is located in its associated color.

We learned that several risks need to be considered and dealt with, but also fortunately we discovered that many of the risks we came up with would have little or no impact on the project.

9.3 Risk handling

We have decided that risks arranged to the green tiles of the model (shown in diagram 4) are accepted, and no actions will be made regarding these. The risks arranged to the yellow tiles are considered to be the ones that need to be discussed among the group members to decide whether to make an active measure to prevent the occurrence of the risk factor. The risk arranged to the red tiles represent the ones that we will definitely make actions to prevent the occurrence of the risk factor.

We will have to decide on how to deal with the risks that have a great impact. There are different solutions to this. We can try to avoid the risk happening, we can share the risk (insurance), or just accept it.

The following decisions were made to handle the risks:

Risk 10 Inaccurate test results (High probability - high consequence)

It was decided that we would have to have a great focus on the reports of the tests. Sufficient enough time would have to be set aside to discuss the reliability of the results, and possible error sources. Also the integration of the tests will need to be done thoroughly, meaning that we would put in a lot of work planning the tests, and plan what needed to be tested.

Risk 9 Not meet requirements (Low probability - high consequence)

No active measure would be taken to avoid this risk sins we felt that we had sufficient enough meetings with D-R to be updated on the requirements. We also plan to quality ensure the requirements list with the company regularly throughout the project.

Risk 8 communication problems with the company (low probability - high consequence)

No active measure would be taken to avoid this risk for the same reasons as for risk 9.

Risk 12 Learning curve to slow (medium probability - medium consequence)

No active measure would have to be taken to avoid this risk because we think that for this project we need to focus on implementing the things we have learned on the study until now, rather than using too much time on learning new techniques.

Risk 4 Less motivation (high probability - medium consequence)

We will try to distribute the work of the project evenly and always try to motivate each other. But otherwise the spirit in the group is high and the will to work has remained throughout the project.

Risk 11 Selected CAD software not sufficient (High probability - low consequences)

No active measure would have to be taken for the same reasons as for risk 12.

10. References

Stevens, R., P. Brook, K. Jackson and A. Stuart (1998) *Systems engineering: Coping with complexity.* (p. 20 - 76). 4edge Ltd. British Library Cataloguing. p.4.

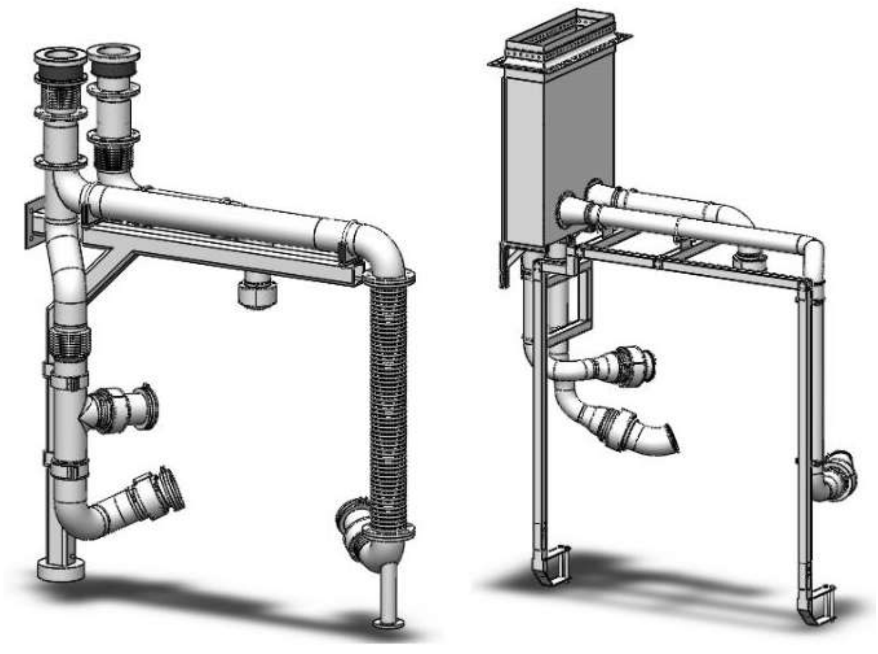
Muller, G. Short introduction to basic CAFCR model. Buskerud University College. 2011

DRESSER-RAND

HSN University College of Southeast Norway

Requirement Specification C16

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
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Kristian I. Asgeirsson

22.05.2017

Document History

Date	Version	Changes	Approved by
19.01.17	0.0	Created	Svenn
31.01.17	1.0	Approved for submission.	Daniel
21.03.17	2.0	Approved for submission.	Kristian
03.05.17	2.1	New req, Fix req, Delete req	Svenn
08.05.17	2.2	New req	Svenn
09.05.17	2.3	New system req, New design req	Svenn, Kristian
12.05.17	2.4	Req sorted into req matrix	Kristian
15.05.17	2.5	Own documented created, New design req	Daniel, Øystein
19.05.17	2.6	Approve req, Delete req	Svenn
19.05.17	2.7	Structure	Svenn
22.05.17	2.8	Correction, Structure	Svenn
22.05	3.0	Approved for submission	Kristian

Table of Contents

1. Introduction

This document gives an overview over the stakeholders, both primary and secondary, and it gives all the requirements from the involved stakeholders. The requirements is documented by who is making them, when they are made, and how they are possible to track. The requirements are crucial for the project. They give the limitations and specifications needed to engineer a good system (Stevens et al., 1998). If requirements are changed, or skipped, the whole project might be a failure. The study of stakeholder concerns, and forming them into requirements, together with requirements set by Dresser-Rand AS (D-R) gives the student group knowledge to what the customer want. We want the project to be a success, that can only be accomplished by designing exactly what the customer want, within the government regulations. Some trade-offs will be made with requirements, to make all parties convinced about the final solution.

2. Stakeholders and their Concerns

The priority of main stakeholders in the project is first safety, then technical requirements, the third priority is time to disassemble/assemble during service, and last priority is cost.

2.1 Primary Stakeholders

- Siemens/Dresser-Rand
    - Administrative Workers
        - *Contract*
    - Engineers
        - *Students*
        - *Malfunction*
    - Owners
        - *Budget*
        - *Reputation*
        - *Quality*
        - *Losses*
    - HSE Responsible
        - *Injuries*
- Our Group
    - *Integration*
    - *Good dividend for our work*
    - *Reputation*
    - *Produce network*
    - *Quality of result*
    - *Professionality*
    - *Deadlines*
- *USN*
    - *Usability of thesis*
    - *Reputation*

2.2 Secondary Stakeholders

- Recycle
- System operator
    - Hazard
    - Change of protocol
- Maintenance Crew
    - *Access*
    - *Hazards*
- Suppliers
    - *Producible*
- Shareholders
    - *Financial*
- Customers
    - *Quality*
    - *Mainteance*
    - *Price*
    - *Safety*
    - *Cost*
    - *Confidentiality*
- Government
    - *Pollution*
    - *Hazard*
- Competitors
    - *Competitiveness of own system*
- On-site Workers
    - *Hazard*
    - *Change of protocol*

3. Introduction to the Requirements

3.1 General Description

The requirements is made for a gas turbine package delivered by Dresser-Rand, and explicitly for the bleed line system. The bleed line system is a part of a package containing a housing, turbine and power turbine. The turbine package is movable and is installed in factories, oil platforms and other utilities demanding continuous flow of electricity, or for transport of liquids. One solution for the bleed system exists, and contains pipes leading from each bleed valve and gather in one pipe. The turbine itself is a Rolls Royce RB211 rebuilded jet engine from aeroplanes, converted into an industrial version. The jet engine is developed in the mid 70's.

3.2 General Capabilities

All the air compressed in the turbine isn't always used. Consider the turbine is dry low emission the fire in the combustion chamber is sensitive for sudden change in airflow. This can result in lack of combustion and the turbine will stop. The bleed line system handles the excessive air produced during startup and part load operation, and shall be ducted out through the exhaust or other methods out to the environment. The main reason for leading the excess air out of the housing is the high temperature and energy in the air.

3.3 General Constraints

The bleed line system shall not conflict with any other of the components of the package, and the housing is permanent. This does not restrict the bleed lines within the housing, but other measures have to be accounted for when having the system out in the open. If the housing should be breached and the bleed lines goes out in the open, the ventilation area shall have a sound muffler. The entrance doors to the housing shall be no more than four, excluded the main door to lift the turbine out of the housing. To reach every part of the turbine, four doors is needed to give the service personnel access to the turbine. A main maintenance door is also installed, and this door is not to be redesigned. The heat from the air released in the housing without bleed lines is too high and contents high energy. Most of the components within the housing will not withstand the heat from the air in the bleed lines if released in the housing. The noise generated by the package shall have a noise reduction. Workers operating close to the turbine shall not be exposed for excessive noise. In addition there is constraints regarding different users of the product, and they will be more elaborated in the requirements set.

3.4 User Characteristics

To start the engine, which is done remotely or on-.site, demand approximately 200 hp (150kW). This is performed by gas and electro hydraulic systems which are incorporated into the base. The system provides real time monitoring and control of turbine critical functions including: sequencing, speeds, guide vane positioning, firing temperature limiting and data event logging. The gas turbine controls offer either local or remote modes of operation. Viewing of the operating parameters is available locally or remotely. (Siemens, 2014)

4. Main Requirement

The bleed system shall prevent hot excess air from compressor from entering the enclosure.

5. Requirements

The requirements are both listed in a rising manner, and also included in a traceability map.

The first list holds the user requirements, the next the system requirements and the last the design requirements

5.1 Requirements overview

5.1.1 User Requirements

U1. The bleed system can not allow large external forces, stress or moments to be imposed to the gas generator interface.

U2. External constructions attached to the housing shall not conflict with any other components in the environment.

U3. The bleed system shall meet all the gas turbine interface requirements.

U4. The bleed system shall not blow hot air directly to any components external to the bleed system.

U5. The bleed system can access the exhaust.

U6. The bleed system shall not be connected to the turbine, other than the bleed valves.

U7. Valve 42 centered at the top of the turbine shall have separate piping.

U8. If the bleed air is led into the housing ventilation duct, there needs to be checked if all the bleed valves is opened simultaneously.

U9. Pipe within pipe shall have no leakages.

U10. The turbine and its components shall be accessible through the four existing man sized doors.

U11. The maintenance doors shall not be moved.

U12. No bleed lines shall be mounted below the inlet center of the turbine within the enclosure.

~~**U13.** The new bleed line system shall ensure the availability.~~

U14. The bleed system shall meet all HSE requirements and regulations.

U15. The system shall be delivered with risk assessment for possible injuries on working crew during installing/removing of bleed system.

~~**U16.** Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).~~

U17. Installation of low noise equipment shall be the primary noise control measure (Norsok Standard S-002, Aug 2004).

U18. For piping systems, selection of low noise valves and other components with low noise shall be given priority (Norsok Standard S-002, Aug 2004).

U19. The cost of the system shall be within budget

U20. The bleed system maintenance cost shall be within budget.

U21. The bleed system shall meet all cost impact targets.

U22. The bleed system shall have parts possible to produce.

U23. The bleed system shall follow guidelines from D-R

U24. The bleed system shall be suitable for turbine package with crane attached to both sides.

~~**U25.** The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.~~

~~**U26.** The bleed lines can share the same sound muffler.~~

U27. The bleed system shall allow the use of the gas turbine maintenance crane.

U28. The bleed system total removing and installing time shall be below 4,2% of the total service time of the turbine.

U29. The bleed system shall be fitted with fixtures possible to remove and install with standard tools.

U30. Removal of the bleed system shall be possible without removing any other components unless components needs to be removed in the maintenance service.

U31. The bleed system shall cool down during cooldown period of turbine.

U32. The bleed system shall have manuals with instructions

U33. The bleed system shall not contribute to lower efficiency in turbine while turbine is working on maximum load.

U34. The bleed system shall not contribute to lower efficiency during start-up.

U35. The bleed system shall not contribute to efficiency losses during partial loading of the turbine.

U36. There shall be delivered risk assessment for component failure.

U37. The bleed system shall last without failing between main service of the turbine.

U38. The bleed system shall be able to handle the excess air from the turbine.

~~**U39**. All the pipes from bleed valves shall not be connected together.~~

~~**U40.** The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.~~

U41. The bleed line system shall withstand fully developed turbulence within the piping during the whole operation time.

U42. The bleed line system shall withstand the strong flow created in the enclosure by the ventilation system ([redacted] kg/s).

U43. All bolts and nuts shall have bursting discs to prevent them to loosen under operation.

U44. There shall be proper materials to handle different environments.

U45. There shall be developed at least two alternative concepts to handle the bleed air.

U46. The model shall be available by may 24th 2017.

U47. When developed this priority shall be considered.

U48. The system shall have environmental care.

U49. The bleed system shall last the lifetime of the turbine package.

U50. The bleed system shall not conflict with any of the existing transportation procedures.

U51. The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation

U52. Gaskets in the bleed system shall withstand the heat and pressure from the air.

U53. There shall be heat resistant material between duct and enclosure.

U54. Parts of the bleed system outside of enclosure shall be personal protected.

U55. The movable parts of the bleed system attached in the enclosure shall have fixtures for transportation.

U56. There shall be considered using solutions preventing service personnel to climb freestanding ladder.

U57. The external parts of bleed system on top of roof shall be possible to dismantle.

U58. The enclosure walls shall withstand the forces from bleed system attached to them.

U59. The bleed system shall have such a configuration that contributes to good access for service personnel.

U60. There shall be no conflicting parts between the bleed system and the rest of the turbine package

U61. The bleed system shall be able to handle the high temperatures from the flow.

U62. The parts of the system shall be able to handle heat expansion.

U63. All structural parts of the system shall handle the structural loading.

U64. The fabrication shall be as easy as possible. Kunne fabrikeres uten at det skal gjøres en tilpasning

5.1.2 System requirements

S1. The gas generator interface shall move freely during expansion with at least 4 mm radial.

S2. The gas generator interface shall move freely during expansion with at least 8 mm axial.

S3. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in radial direction with more than 15 kg.

S4. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in axial direction with more than 15 kg.

S5. External bleed system blocking the maintenance door in the housing shall be removable during cooldown.

S6. ~~External bleed system outside blocking the maintenance door shall be possible to disassemble before cooldown of the turbine.~~

S7. External bleed system shall be clear of other components on top of housing.

S8. External bleed system shall not make the roof height of existing turbine package higher.

S9. External bleed system shall not build out more sideways then the width of the maintenance doors, 1870mm.

S10. The bleed system shall be clear of wiring and piping within the housing.

S11. The bleed system must use the existing access point to the exhaust if leaded to the exhaust.

S12. ~~The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.~~

S13. If the bleed line A42 is led to the exhaust it needs to be connected to the outlet with the check valve.

S14. If the bleed valve A42 opens simultaneously with valve A51, A43 and A44 the bleed air can be led to the housing ventilation duct, but the back pressure needs to be calculated.

S15. Valve A42 leaded out of the enclosure within the pipe of valve A43, A44 and A51 shall not have any leakage between them.

S16. Dresser-Rand shall approve it when the bleed system requires the four inspection doors to be moved.

S17. Parts of the bleed system manual lifted by the crew service shall not exceed 25 kg (Norsok Standard R-002, Sep 2012).

S18. The maximum temperature released from the housing through the ventilation shall not exceed 70 degrees celsius.

S19. The parts of the bleed system from valve 43, 44 and 51 shall withstand [redacted] degrees celsius during the whole operation time.

S20. The parts of the bleed system from valve 42 shall withstand [redacted] degree celsius during the whole operation time.

S21. The backpressure in the bleed system valve 43, 44 and 51 together shall be maximum 70 kPa.

S22. The back pressure from valve 42 shall be maximum 24 kPa.

S23. It shall not be possible to reach parts of the bleed system with temperatures exceeding 70 degrees celsius (Norsok Standard S-002, Aug 2004).

S24. It shall not be possible to reach parts of the bleed system with temperatures below -10 degrees (Norsok Standard S-002, Aug 2004).

S25. The individual employee's maximum exposure to noise during a 12 hours working day is 83 db (Norsok Standard S-002, Aug 2004).

S26. The maximum allowable noise level in any situation is 130 dB.

S27. All edges of the system shall be be rounded.

S28. All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person.

S29. All parts of the system lighter than 25 kg shall be reachable for a person from the operation area.

S30. The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost

S31. The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours

S32. Cost of transportation shall not cost more than for the current system.

S33. The bleed system shall have parts regulated in international standards.

S34. ~~Valve 42 shall have its own bleed line.~~

S35. The bleed system can be designed for left side crane, but shall then also be designed for right hand side

S36. The bleed system can be designed for right hand side crane, but shall then also be designed for left side.

S37. The crane shall move freely of parts of the bleed system left after disassembly in the enclosure.

S38. The bleed system shall take not more than 30 min to remove.

S39. The bleed system shall take not more than 30 min to install.

S40. The Fastening method shall always be the fastest possible.

S41. The bleed system shall use the metric system.

S42. The bleed system shall cool down to 70 degrees celsius within 240 minutes.

S43. The bleed system shall have instructions in standards of material received from Dresser-Rand for assembly during maintenance.

S44. The bleed system shall have instructions in standards of material received from Dresser-Rand for disassembly during maintenance.

S45. ~~The system shall have risk assessment for at least two critical components in the bleed system.~~

S46. The system shall sustain 26280 hours without maintenance.

S47. The bleed system outlet shall in total be able to handle bleed air in amounts of [redacted] kg/s.

S48. The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s.

S49. The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s.

S50. The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.

S51. ~~The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.~~

S52. There shall be considered using the stainless steel SS-316 in the bleed system.

S53. There shall be considered using the stainless steel SS-316L if there is weldings in the material.

S54. The material used shall withstand vibrations from the turbine.

S55. The solutions shall be presented in the form of a 3D model.

S56. The 3D model shall have supporting documentation.

S57. The concept shall have manuals for service.

S58. The concept shall have understandable manuals for installation and use.

S59. The 1st priority is safety

S60. The 2nd priority is technical requirements

S61. The 3rd priority is time

S62. The 4th priority is cost

S63. ~~The time it takes to assemble the system is prioritized above the cost of the system.~~

~~**S64.** The time it takes to disassemble the system is prioritized above the cost of the system.~~

S65. All the materials are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).

S66. All the substances are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).

S67. The bleed system shall last for minimum 25 years.

S68. The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.

S69. The fixtures shall be able to withstand 0,98G during transportation.

S70. Gaskets in the bleed system from valve 43, 44 and 51 shall withstand [redacted] degree celsius.

S71. Gaskets in the bleed system from valve, 43, 44 and 51 shall withstand pressure of 70 kPa.

S72. Gaskets in the bleed system from valve 42 shall withstand [redacted] degree celsius.

S73. Gaskets in the bleed system from valve 42 shall withstand 24 kPa.

S74. The parts the pipeline from bleed system touches from valve 43, 44 and 51 shall withstand transferring heat at [redacted] degree celsius.

S75. The parts the pipeline system touches from valve 42 shall withstand transferring heat at [redacted] degree celsius.

S76. The material used between pipes and enclosure shall withstand [redacted] degree celsius.

S77. Piping and ducts reachable external shall be protected with physical blocking, like fence, isolation etc, to prevent anyone to touch.

~~**S78.** The walls shall withstand the maximum load of …..N.~~

~~**S79.** It shall be possible to move the turbine in vertical direction during removal without touching the bleed system.~~

~~**S80.** The strip wound hose shall be able to swing around the turbine.~~

S81. There shall be room enough for a service person to access every part of the turbine needed for service.

S82. There shall not be any collision between parts of the bleed system and the turbine during removal of the turbine.

S83. all components in touch with the flow of the (A43, A44, A51) part of the bleed system shall be able to handle [redacted] degrees celsius.

S84. Parts of the system that are fixed shall be able to withstand the stresses from the heat expansion.

S85. parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material.

S86. All structural parts of the system shall be able to handle the loads associated with weight.

S87. All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.

S88. The A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe.

5.1.3 Design Requirements

~~**D1** Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)~~

~~**D2** Disassembly of external bleed system takes no more than …. minutes.~~

D3 The distance between boom and wall shall be 225mm.

D4 The gap between during boom and turbine during service shall minimum be 225mm.

D5 With vertical lift of 30 mm, the turbine shall go free of the boom to valve 42.

D6 The stripwound hose shall be able to handle displacement from heat expansion in the bleed system of 9mm in x-direction.

D7 The strip wound hose shall handle displacement from heat expansion of 8 mm in the y-direction.

D8 The stripwound hose shall prevent thermal induced forces impacting the bleed system.

D9 The bearing on the boom 1 shall withstand the forces due to gravity.

D10 The mounting structure to the boom 1 shall have a clearance to the underlying components with 10mm.

D11 The foot to the boom 1 shall be mounted and fit to the mounting structure with bolts.

D12 the foot of elbow A44 shall fit the mounting structure with bolts.

D13 The boom shall handle the forces created by the weight of the system.

D14 It shall be possible to lock the boom in a position perpendicular to the center axis of the turbine.

D15 It shall be possible to lock the boom in a position parallel to the center axis of the turbine.

D16 it shall be possible to lock boom1 and boom 2 to the wall during transport.

D17 The locking mechanism to boom 1 shall handle forces during transport 0,98 G.

D18 The boom 2 shall be mounted to boom 1 during transport.

D19 The flange between the hose and fl1 shal be able to rotate into position.

D20 the extension pipe shall be mountable with a v-band.

D21 The extension pipe and v-band connections to valve 43,44 and 51 shall not exceed 15kg.

D22 It shall be possible to position the valves into the interface with a clearance distance between pipe and interface of minimum 4 mm.

D23 When the extension pipe to the valve is attached to the valve, the boom shall be able to rotate.

D24 the clearance between the extension pipe of valve A42 and the bleed system without the interface shall be ..mm.

D25 the clearance between the extension pipe of valve A43 and the bleed system without the interface shall be ..mm.

D26 the clearance between the extension pipe of valve A44 and the bleed system without the interface shall be ..mm.

D27 the bend after valve A44 shall take up all the loading from the flow from the valve.

D28 the clearance between the extension pipe of valve A51 and the bleed system without the interface shall be ..mm.

D29 The pipe system on top of the horizontal part of beam B1 shall be restrained from movement i vertical direction.

D30 The pipe system on top of the horizontal part of beam B1 shall be free to move 9mm in horizontal direction.

D31 The clearance between pipe clamp C1 and pipe RB23 shall be more than 0,8mm.

D32 The tee joint RB16 shall be fixed from movement in all directions

D33 All the flanges shall have the same configuration for attachment.

D34 The lower brackets C2 shall support the weight of all the parts from part RB16 and down in that specific branch.

D35 The lower brackets C2 shall be able to withstand the residual force from the heat expansion that is not taken up by the expansion joint E1. the parts from part RB16 and down in that specific branch.

~~**D36** The connection interfaces to valve 43, 44 and 51 shall a maximum displacement in the y direction of 1 mm.~~

~~**D37** The connecting interfaces to valve 43, 44, and 51 shall have a maximum displacement in the x-direction of 10mm.~~

D38 The expansion joint E1 shall handle 5mm movement in the y-direction

D39 The expansion joint E2 shall handle movement in the y-direction of 2mm.

D40 The boom b1 shall have a configuration such that allows the piping system for valves A43, and A51 to flow from the outside of the beam to the center point before going trew the roof.

D41 All structural loading from the bleed system part (A43, A44, and A51) shall be collected by the beam b1 and the footbased elbow RB21.

D42 All structural loading from the bleed system part A42 shall be collected by the beam second beam.

D43 The gasket through the roof shall handle expansion in the pipes of 1mm.

D44 The boom 1 shall be possible to swing during service by one person.

D45 The boom 2 shall be possible to swing by one person during service.

D46 The minimum height of boom b1 is at least the total height of RB16, FL2, S1, and E2.

D47 the minimum height of boom b2 is at least the total height of RB32, E3, and S1.

D48 The surface finish shall be 150 micrometer inside the pipes.

D49 The booms shall move on their each axis.

D50 The lower brackets C2 shall be placed in the middle of valve 43 and 51.

D51 The upper brackets C2 shall have a clearance to the pipe of 0,8mm in the radial direction.

D52 The upper brackets shall have shims between them and boom.

D53 The strip wound hose shall be able to swing around the turbine.

D54 The pressure drop in the metal hose must not contribute to larger backpressure than 70 KPa.

D55 The pressure drop in the interface part must not contribute to larger backpressure than 24 Kpa in the A42 branch of the system and 70 Kpa in the A43, A44, A51 branch of the system.

In the tables below there is a detailed traceability map of the requirements. First the requirements are divided into areas. On top comes the user requirements, the system requirements follows, and the comes the design requirements. All requirements needs to be numbered in a way to makes it possible to trace tests back to the requirements with the use of the requirement ID. The system of the traceability map is as follows:

- A1 stands for area number one, which is “Restrictions”.
- U2 stands for user requirement number two in the given area.
- S5 stands for system requirement number one in the given user requirement.
- D2 stands for design requirement number two in the given system requirement.

This leads us to the design requirement: *“Disassembly of external bleed system takes no more than …. minutes”.* Further the requirements is given priorities from A to C according to how important they are for the system. Where priority:

- A is requirements that is an absolute necessity.
- B is requirements that is important, but not necessary.
- C is requirements that is not important, but desirable.

5.2 Requirements sorted by relevance

A1. Restriction

U1. User Requirement **Origin: D-R** **Priority: A** The bleed system can not allow large external forces, stress or moments to be imposed to the gas generator interface.
System Requirements **S1.** The gas generator interface shall move during expansion with at least 4 mm radial.
D22. It shall be possible to position the valves into the interface with a clearance distance between pipe and interface of minimum 4 mm. **D50.** The lower brackets C2 shall be placed in the middle of valve 43 and 51.
S2. The gas generator interface shall move during expansion with at least 8 mm axial.
D24. the clearance between the extension pipe of valve A42 and the bleed system without the interface shall be 10 mm. **D25.** the clearance between the extension pipe of valve A43 and the bleed system without the interface shall be 10 mm. **D26.** the clearance between the extension pipe of valve A44 and the bleed system without the interface shall be 10 mm. **D28.** the clearance between the extension pipe of valve A51 and the bleed system without the interface shall be 10 mm.
S3. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in radial direction with more than 15 kg.
D21. The extension pipe and v-band connections to valve 43,44 and 51 shall not exceed 15kg.
S4. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in axial direction with more than 15 kg.
D27. The bend after valve A44 shall take up all the loading from the flow from the valve.

U2. User Requirement	**Origin: D-R**	**Priority: A**
External constructions attached to the housing shall not conflict with any other components in the environment.		

System Requirements

- **S5.** External bleed system blocking the maintenance door in the housing shall be removable during cooldown.
  - ~~**D1.** Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)~~
  - ~~**D2.** Disassembly of external bleed system takes no more than …. minutes.~~
  - ~~**D3.** External bleed system outside blocking the maintenance door shall be possible to disassemble before cooldown of the turbine.~~
- **S6.** External bleed system shall be clear of other components on top of housing.
- **S7.** External bleed system shall not make the roof height of existing turbine package higher.
- **S8.** External bleed system shall not build out more sideways then the width of the maintenance doors, 1870mm.
- **S9.** The bleed system shall be clear of wiring and piping within the housing.

U3. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall meet all the gas turbine interface requirements.		

U4. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not blow hot air directly to any components external to the bleed system.		

U5. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system can access the exhaust.		
System Requirements **S11.** The bleed system must use the existing access point to the exhaust if leaded to the exhaust.		

U6. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not be connected to the turbine, other than the bleed valves.		
System requirement ~~**S12.** The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.~~		

U7. User Requirement	**Origin: D-R**	**Priority: A**
Valve 42 centered at the top of the turbine shall have separate piping.		
System requirement **S13.** If the bleed line A42 is led to the exhaust it needs to be connected to the outlet with the check valve.		

U8. User Requirement	**Origin: D-R**	**Priority: A**
If the bleed air is led into the housing ventilation duct, there needs to be checked if all the bleed valves is opened simultaneously.		
System Requirement **S14.** If the bleed valve A42 opens simultaneously with valve A51, A43 and A44 the bleed air can be led to the housing ventilation duct, but the back pressure needs to be calculated.		

U9. User Requirement	**Origin: D-R**	**Priority: A**
Pipe within pipe shall have no leakages.		
S15. Valve A42 leaded out of the enclosure within the pipe of valve A43, A44 and A51 shall not have any leakage between them.		

U60. User Requirement	**Origin: D-R**	**Priority: A**
There shall be no conflicting parts between the bleed system and the rest of the turbine package		
S82. There shall not be any collision between parts of the bleed system and the turbine during removal of the turbine.		
D5. With vertical lift of 30 mm, the turbine shall go free of the boom to valve 42. **D53.** The strip wound hose shall be able to swing around the turbine.		

U62. User Requirement	**Origin: D-R** **Priority: A**
The parts of the system shall be able to handle heat expansion.	
S84. Parts of the system that are fixed shall be able to withstand the stress from the heat expansion.	
D35. The lower brackets C2 shall support the weight of all the parts from part RB16 and down in that specific branch.	
S85. parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material.	
D6. The stripwound hose shall be able to handle displacement from heat expansion in the bleed system of 9mm in x-direction.	
D7. The strip wound hose shall handle displacement from heat expansion of 8 mm in the y-direction.	
D8. The stripwound hose shall prevent thermal induced forces impacting the bleed system.	
D30. The pipe system on top of the horizontal part of beam B1 shall be free to move 9mm in horizontal direction.	
D32. The tee joint RB16 shall be fixed from movement in all directions	
D38. The expansion joint E1 shall handle 5mm movement in the y-direction	
D39. The expansion joint E2 shall handle movement in the y-direction of 2mm.	
D43. The gasket through the roof shall handle expansion in the pipes of 1mm.	
D51. The upper brackets C2 shall have a clearance to the pipe of 0,8mm in the radial direction.	
D52. The upper brackets shall have shims between them and boom.	
D31. The clearance between pipe clamp C1 and pipe RB23 shall be more than 0,8mm.	

S88. the A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe.

U63. User Requirement **Origin: D-R** **Priority: A**

All structural parts of the system shall handle the structural loading.

S86. All structural parts of the system shall be able to handle the loads associated with weight.

D9. The bearing on the boom 1 shall withstand the forces due to gravity.

D13. The boom shall handle the forces created by the weight of the system.

D34. The lower brackets C2 shall support the weight of all the parts from part RB16 and down in that specific branch.

D41. All structural loading from the bleed system part (A43, A44, and A51) shall be collected by the beam b1 and the footbased elbow RB21.

D42. All structural loading from the bleed system part A42 shall be collected by the second beam.

S87. All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.

D14. It shall be possible to lock the boom in a position perpendicular to the center axis of the turbine.

D29. The pipe system on top of the horizontal part of beam B1 shall be restrained from movement i vertical direction.

D41. All structural loading from the bleed system part (A43, A44, and A51) shall be collected by the beam b1 and the footbased elbow RB21.

D42. All structural loading from the bleed system part A42 shall be collected by the second beam.

A2. Access

U10. User Requirement	**Origin: D-R**	**Priority: A**
The turbine and its components shall be accessible through the four existing man sized doors.		

U11. User Requirement	**Origin: D-R**	**Priority: A**
The maintenance doors shall not be moved.		
System Requirement **S16.** D-R shall approve it when the bleed system requires the four inspection doors to be moved.		

U12. User Requirement	**Origin: D-R**	**Priority: C**
No bleed lines shall be mounted below the inlet center of the turbine within the enclosure.		

~~**U13. User Requirement**~~	~~**Origin: D-R**~~	~~**Priority: A**~~
~~The new bleed line system shall ensure the availability.~~		

U59. User Requirement	**Origin: D-R Priority: A**
The bleed system shall have such a configuration that contributes to good access for service personnel.	
System Requirement	
S81. There shall be room enough for a standard service person to access every part of the turbine needed for service.	
Design Requirements	
D3. The distance between boom b1 and wall shall be 225mm.	
D4. The gap between during boom and turbine during service shall minimum be 225mm.	

A3. Safety

U14. User Requirement	**Origin: Government**	**Priority: A**
The bleed system shall meet all HSE requirements and regulations.		
System Requirements **S17.** Parts of the bleed system manual lifted by the crew during service shall not exceed 25 kg (Norsok Standard R-002, Sep 2012). **S18.** The maximum temperature released from the housing through the ventilation shall not exceed 70 degrees celsius. **S19.** The parts of the bleed system from valve 43, 44 and 51 shall withstand [redacted] degrees celsius during the whole operation time. **S20.** The parts of the bleed system from valve 42 shall withstand [redacted] degree celsius during the whole operation time. **S21.** The backpressure in the bleed system valve 43, 44 and 51 together shall be maximum 70 kPa.		
D48. The surface finish shall be 150 micrometer inside the pipes. **D54.** The pressure drop in the metal hose must not contribute to larger backpressure than 70 KPa.		
S22. The back pressure from valve 42 shall be maximum 24 kPa.		
D48. The surface finish shall be 150 micrometer inside the pipes.		
S23. It shall not be possible to reach parts of the bleed system with temperatures exceeding 70 degrees celsius (Norsok Standard S-002, Aug 2004). **S24.** It shall not be possible to reach parts of the bleed system with temperatures below -10 degrees (Norsok Standard S-002, Aug 2004). **S25.** The individual employee's maximum exposure to noise during a 12 hours working day is 83 db (Norsok Standard S-002, Aug 2004). **S26.** The maximum allowable noise level in any situation is 130 dB. **S27.** All edges of the system shall be be rounded. **S28.** All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person. a. All parts lighter than 25 kg, and with geometry difficult to lift shall have handles, grip points etc.		

S29. All parts of the system lighter than 25 kg shall be reachable for a person from the operation area.

U15. User Requirement **Origin: D-R** **Priority: B**

The system shall be delivered with risk assessment for possible injuries on working crew during installing/removing of bleed system.

~~**U16. User Requirement** **Origin: D-R** **Priority: A**~~

~~Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).~~

U17. User Requirement **Origin: D-R** **Priority: A**

Installation of low noise equipment shall be the primary noise control measure (Norsok Standard S-002, Aug 2004).

U18. User Requirement **Origin: D-R** **Priority: A**

For piping systems, selection of low noise valves and other components with low noise shall be given priority (Norsok Standard S-002, Aug 2004).

U53. User Requirement **Origin: D-R** **Priority: A**

There shall be heat resistant material between duct and enclosure.

S74. The parts the pipeline from bleed system touches from valve 43, 44 and 51 shall withstand transferring heat at [redacted] degree celsius.

S75. The parts the pipeline system touches from valve 42 shall withstand transferring heat at [redacted] degree celsius.

S76. The material used between pipes and enclosure shall withstand [redacted] degree celsius.

U54. User Requirement	Origin: D-R	Priority: A
Parts of the bleed system outside of enclosure shall be personal protected.		
S77. Piping and ducts reachable external shall be protected with physical blocking, like fence, isolation etc, to prevent anyone to touch.		

U58. User Requirement	Origin: D-R	Priority: A
U65. The enclosure walls shall withstand the forces from bleed system attached to them.		
S78. The walls shall withstand the maximum load of 0,98G.		

A4. Economy

U19. User Requirement	Origin: D-R	Priority: A
The cost of the system shall be within budget		
System Requirement **S30.** The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost		

U20. User Requirement	Origin: D-R	Priority: A
The bleed system maintenance cost shall be within budget.		
System Requirement **S31.** The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours		

U21. User Requirement	**Origin: D-R**	**Priority: B**
The bleed system shall meet all cost impact targets.		
System Requirement **S32.** Cost of transportation shall not cost more than for the current system.		

A5. Producing

U22. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall have parts possible to produce.		
System Requirement **S33.** The bleed system shall have parts regulated in international standards.		
D40. The boom b1 shall have a configuration such that allows the piping system for valves A43 and A51 to flow from the outside of the beam to the center point before going through the roof. **D46.** The minimum height of boom b1 is at least the total height of RB16, FL2, S1, and E2. **D47**. the minimum height of boom b2 is at least the total height of RB32, E3, and S1. **D49.** The booms shall move on their each axis.		

U23. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall follow guidelines from D-R		
System Requirement ~~**S34.** Valve 42 shall have its own bleed line.~~		

U24. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall be suitable for turbine package with crane attached to both sides.		
S35. The bleed system can be designed for left side crane, but shall then also be designed for right hand side.		
S36. The bleed system can be designed for right hand side crane, but shall then also be designed for left side.		

U25. User Requirement	**Origin: D-R**	**Priority: A**
~~The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.~~		

~~**U26. User Requirement**~~	~~**Origin: D-R**~~	~~**Priority: B**~~
~~The bleed lines can share the same sound muffler.~~		

A6. Maintenance

U27. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall allow the use of the gas turbine maintenance crane.		
System Requirement **S37.** The crane shall move freely of parts of the bleed system left after disassembly in the enclosure.		

U28. User Requirement **Origin: D-R** **Priority: A**

The bleed system total removing and installing time shall be below 4,2% of the total service time of the turbine.

System Requirements

S38. The bleed system shall take not more than 30 min to remove.

D12. the foot of elbow A44 shall fit the mounting structure with bolts.

D19. The flange between the hose and fl1 shal be able to rotate into position.

D20. the extension pipe shall be mountable with a v-band.

D23. When the extension pipe to the valve is attached to the valve, the boom shall be able to rotate.

D33. All the flanges shall have the same configuration for attachment.

D44. The boom 1 shall be possible to swing during service by one person.

D45. The boom 2 shall be possible to swing by one person during service.

S39. The bleed system shall take not more than 30 min to install.

D12. the foot of elbow A44 shall fit the mounting structure with bolts.

D19. The flange between the hose and fl1 shal be able to rotate into position.

D20. the extension pipe shall be mountable with a v-band.

D23. When the extension pipe to the valve is attached to the valve, the boom shall be able to rotate.

D33. All the flanges shall have the same configuration for attachment.

D44. The boom 1 shall be possible to swing during service by one person.

D45. The boom 2 shall be possible to swing by one person during service.

~~**S40.** The Fastening method shall always be the fastest possible.~~

U29. User Requirement **Origin: D-R** **Priority: A**
The bleed system shall be fitted with fixtures possible to remove and install with standard tools.
System Requirement **S41.** The bleed system shall use the metric system
D11. The foot to the boom 1 shall be mounted and fit to the mounting structure with bolts.

U30. User Requirement **Origin: D-R** **Priority: A**
Removal of the bleed system shall be possible without removing any other components unless components needs to be removed in the maintenance service.

U31. User Requirement **Origin: D-R** **Priority: A**
The bleed system shall cool down during cooldown period of turbine.
System Requirement **S42.** The bleed system shall cool down to 70 degrees celsius within 240 minutes.

U32. User Requirement **Origin: D-R** **Priority: A**
The bleed system shall have manuals with instructions
System Requirement **S43.** The bleed system shall have instructions in standards of material received from Dresser-Rand for disassembly during maintenance. **S44.** The bleed system shall have instructions in standards of material received from for assembly during maintenance.

U56. User Requirement **Origin: D-R** **Priority: A**

There shall be considered using solutions preventing service personnel to climb freestanding ladders.

A7. Operation

U33. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall not contribute to lower efficiency in turbine while turbine is working on maximum load.

U34. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall not contribute to lower efficiency during start-up.

U35. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall not contribute to efficiency losses during partial loading of the turbine.

U36. User Requirement **Origin: D-R** **Priority: B**

There shall be delivered risk assessment for component failure.

System Requirement

~~**S45.** The system shall have risk assessment for at least two critical components in the bleed system.~~

U37. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall last without failing between main service of the turbine.

System Requirement

S46. The system shall sustain 26280 hours without maintenance.

U38. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall be able to handle the excess air from the turbine.

System Requirement

S47. The bleed system outlet shall in total be able to handle bleed air in amounts of [redacted] kg/s.

S48. The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s.

S49. The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s.

S50. The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.

~~**U39. User Requirement**~~ ~~**Origin: D-R**~~ ~~**Priority: A**~~

~~All the pipes from bleed valves shall not be connected together.~~

~~**S51.** The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.~~

U40. User Requirement **Origin: D-R** **Priority: A**

~~The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.~~

U41. User Requirement	**Origin: D-R**	**Priority: A**
The bleed line system shall withstand fully developed turbulence within the piping during the whole operation time.		

U42. User Requirement	**Origin: D-R**	**Priority: A**
The bleed line system shall withstand the strong flow created in the enclosure by the ventilation system ([redacted] kg/s).		

U43. User Requirement	**Origin: D-R**	**Priority: A**
All bolts and nuts shall have bursting discs to prevent them to loosen under operation.		

.

U52. User Requirement	**Origin: D-R**	**Priority: A**
Gaskets in the bleed system shall withstand the heat and pressure from the air.		
System Requirement **S70.** Gaskets in the bleed system from valve 43, 44 and 51 shall withstand [redacted] degree celsius. **S71.** Gaskets in the bleed system from valve, 43, 44 and 51 shall withstand pressure of 70 kPa. **S72.** Gaskets in the bleed system from valve 42 shall withstand [redacted] degree celsius. **S73.** Gaskets in the bleed system from valve 42 shall withstand 24 kPa.		

U61. User Requirement **Origin: D-R** **Priority: A**
The bleed system shall be able to withstand the high temperatures from the flow.
System Requirement
S83. all components in touch with the flow of the (A43, A44, A51) part of the bleed system shall be able to handle [redacted] degrees celsius.

A8. Materials

U44. User Requirement **Origin: D-R** **Priority: C**
There shall be proper materials to handle different environments.
System Requirement
S52. There shall be considered using the stainless steel SS-316 in the bleed system.
S53. There shall be considered using the stainless steel SS-316 L if there is weldings in the material.
~~**S54.** The material used shall withstand vibrations from the turbine.~~

A9. Administrative

U45. User Requirement **Origin: D-R** **Priority: A**
There shall be developed at least two alternative concepts to handle the bleed air.
System Requirement
S55. The solutions shall be presented in the form of a 3D model.
S56. The 3D model shall have supporting documentation.
S57. The concept shall have manuals for service.
S58. The concept shall have understandable manuals for installation and use.
~~**S59.** The time it takes to assemble the system is prioritized above the cost of the system.~~
~~**S60.** The time it takes to disassemble the system is prioritized above the cost of the system.~~

U46. User Requirement	**Origin: USN**	**Priority: A**
The model shall be available by may 24th 2017.		

U47. User Requirement	**Origin: D-R**	**Priority: A**
When developed this priority shall be considered.		
S61. The 1st priority is safety **S62.** The 2nd priority is technical requirements **S63.** The 3rd priority is time **S64.** The 4th priority is cost		

A10. Recycle

U48. User Requirement	**Origin: Government**	**Priority: A**
The system shall have environmental care.		
System Requirement **S65.** All the materials are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003). **S66.** All the substances are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).		

A11. Life Time

U49. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall last the lifetime of the turbine package.		
System Requirement **S67.** The bleed system shall last for minimum 25 years.		

A12. Transport

U50. User Requirement **Origin: D-R** **Priority: A**
The bleed system shall not conflict with any of the existing transportation procedures.
System Requirement **S68.** The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.

U51. User Requirement **Origin: D-R** **Priority: A**
The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation.
System Requirement **S69.** The fixtures shall be able to withstand 0,98G during transportation.
D15. It shall be possible to lock the boom in a position parallel to the center axis of the turbine.
D16. it shall be possible to lock boom1 and boom 2 to the wall during transport.
D17. The locking mechanism to boom 1 shall handle forces during transport of 0,98G.
D18 The boom 2 shall be mounted to boom 1 during transport.

U57. User Requirement **Origin: D-R** **Priority: A**
The external parts of bleed system on top of roof shall be possible to dismantle.

A13. Deleted requirements

D1. Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)
Approved by: Dresser-Rand **Why deleted:** It is not relevant since the system is inside the package.

D2. Disassembly of external bleed system takes no more than …. minutes.
Approved by: Dresser-Rand **Why deleted:** It is not relevant since the system is inside the package.

U13 The new bleed line system shall ensure the availability.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.59

U16. Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).
Approved by: Dresser-Rand **Why deleted:** The noise is already localized in the specification from dresser rand, and there is no vibration analysis in the thesis.

U25. The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.12

U26. The bleed lines can share the same sound muffler.
Approved by: Dresser-Rand **Why deleted:** It is not a requirement

U39. All the pipes from bleed valves shall not be connected together.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.7

U40. The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.
Approved by: Dresser-Rand **Why deleted:** It is not valid. Based on a misunderstanding.

S12. The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.
Approved by: Dresser-Rand **Why deleted:** Rewritten requirement to U.6

S34. Valve 42 shall have its own bleed line.
Approved by: Dresser-Rand ok **Why deleted:** Written two times, valid is U7

S45. The system shall have risk assessment for at least two critical components in the bleed system.
Approved by: Dresser-Rand ok **Why deleted:** Rewritten to U36.

S51. The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.
Approved by: Dresser-Rand **Why deleted:** Written to U7.

S63. The time it takes to assemble the system is prioritized above the cost of the system.
Approved by: Dresser-Rand **Why deleted:** It is written into the evaluating criterias under stakeholders and concerns.

S64. The time it takes to disassemble the system is prioritized above the cost of the system.
Approved by: Dresser-Rand **Why deleted:** It is written into the evaluating criterias under stakeholders and concerns.

S79. It shall be possible to move the turbine in vertical direction during removal without touching the bleed system.
Approved by: Dresser-Rand **Why deleted:** Written to S82.

S80. The strip wound hose shall be able to swing around the turbine.
Approved by: Dresser-Rand (ok) **Why deleted:** Moved to D53.

6. References

Norsok Standard R-002. Edition 2 Sep 2012. *Lifting Equipment.* Standard Norge.

Norsok Standard S-002, Rev.4 Aug 2004, *Working environment*. Rev. 4. Standard Norge.

Norsok Standard S-003, Rev.3 Des 2003, *Environmental care.* Standard Norge

Siemens (2014) Industrial RB211 Gas Turbines [Internet]. Avaiable from: https://www.energy.siemens.com/hq/pool/hq/power-generation/gas-turbines/RB211/industrial-rb211.pdf. [Accessed 25 January 2017]

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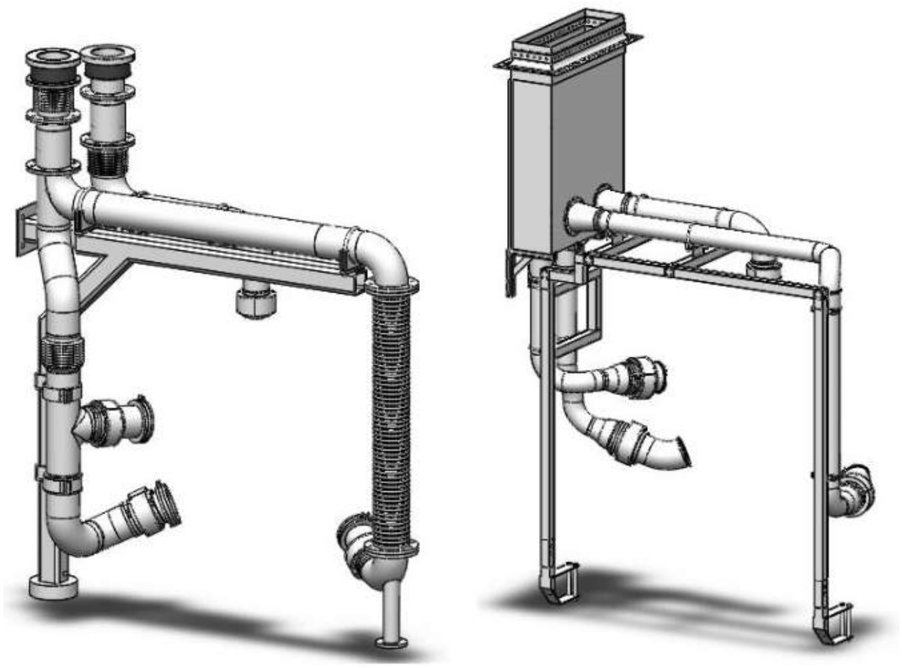
DRESSER-RAND

HSN University College of Southeast Norway

Requirement Specification C30

Gas Turbine Bleed System



Gruppe 19

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22.05.2017

Document History

Date	Version	Changes	Approved by
19.01.17	0.0	Created	Svenn
31.01.17	1.0	Approved for submission.	Daniel
21.03.17	2.0	Approved for submission.	Kristian
03.05.17	2.1	New req, Fix req, Delete req	Svenn
08.05.17	2.2	New req	Svenn
09.05.17	2.3	New system req, New design req	Svenn, Kristian
12.05.17	2.4	Req sorted into req matrix	Kristian
15.05.17	2.5	Own documented created, New design req	Daniel, Øystein
19.05.17	2.6	Req approved, Req deleted	Svenn
22.05.17	2.7	Corrections, structure	Svenn
22.05.17	3.0	Approved for submission	Kristian

Table of Contents

1. Introduction

This document gives an overview over the stakeholders, both primary and secondary, and it gives all the requirements from the involved stakeholders. The requirements is documented by who is making them, when they are made, and how they are possible to track. The requirements are crucial for the project. They give the limitations and specifications needed to engineer a good system (Stevens et al., 1998). If requirements are changed, or skipped, the whole project might be a failure. The study of stakeholder concerns, and forming them into requirements, together with requirements set by Dresser-Rand AS (D-R) gives the student group knowledge to what the customer want. We want the project to be a success, that can only be accomplished by designing exactly what the customer want, within the government regulations. Some trade-offs will be made with requirements, to make all parties convinced about the final solution.

2. Stakeholders and their Concerns

The priority of main stakeholders in the project is first safety, then technical requirements, the third priority is time to disassemble/assemble during service, and last priority is cost.

2.1 Primary Stakeholders

- Siemens/Dresser-Rand
    - Administrative Workers
        - *Contract*
    - Engineers
        - *Students*
        - *Malfunction*
    - Owners
        - *Budget*
        - *Reputation*
        - *Quality*
        - *Losses*
    - HSE Responsible
        - *Injuries*
- Our Group
    - *Integration*
    - *Good dividend for our work*
    - *Reputation*
    - *Produce network*
    - *Quality of result*
    - *Professionality*
    - *Deadlines*
- *USN*
    - *Usability of thesis*
    - *Reputation*

2.2 Secondary Stakeholders

- Recycle
- System operator
    - Hazard
    - Change of protocol
- Maintenance Crew
    - *Access*
    - *Hazards*
- Suppliers
    - *Producible*
- Shareholders
    - *Financial*
- Customers
    - *Quality*
    - *Mainteance*
    - *Price*
    - *Safety*
    - *Cost*
    - *Confidentiality*
- Government
    - *Pollution*
    - *Hazard*
- Competitors
    - *Competitiveness of own system*
- On-site Workers
    - *Hazard*
    - *Change of protocol*

3. Introduction to the Requirements

3.1 General Description

The requirements is made for a gas turbine package delivered by Dresser-Rand, and explicitly for the bleed line system. The bleed line system is a part of a package containing a housing, turbine and power turbine. The turbine package is movable and is installed in factories, oil platforms and other utilities demanding continuous flow of electricity, or for transport of liquids. One solution for the bleed system exists, and contains pipes leading from each bleed valve and gather in one pipe. The turbine itself is a Rolls Royce RB211 rebuilded jet engine from aeroplanes, converted into an industrial version. The jet engine is developed in the mid 70’s.

3.2 General Capabilities

All the air compressed in the turbine isn't always used. Consider the turbine is dry low emission the fire in the combustion chamber is sensitive for sudden change in airflow. This can result in lack of combustion and the turbine will stop. The bleed line system handles the excessive air produced during startup and part load operation, and shall be ducted out through the exhaust or other methods out to the environment. The main reason for leading the excess air out of the housing is the high temperature and energy in the air.

3.3 General Constraints

The bleed line system shall not conflict with any other of the components of the package, and the housing is permanent. This does not restrict the bleed lines within the housing, but other measures have to be accounted for when having the system out in the open. If the housing should be breached and the bleed lines goes out in the open, the ventilation area shall have a sound muffler. The entrance doors to the housing shall be no more than four, excluded the main door to lift the turbine out of the housing. To reach every part of the turbine, four doors is needed to give the service personnel access to the turbine. A main maintenance door is also installed, and this door is not to be redesigned. The heat from the air released in the housing without bleed lines is too high and contents high energy. Most of the components within the housing will not withstand the heat from the air in the bleed lines if released in the housing. The noise generated by the package shall have a noise reduction. Workers operating close to the turbine shall not be exposed for excessive noise. In addition there is constraints regarding different users of the product, and they will be more elaborated in the requirements set.

3.4 User Characteristics

To start the engine, which is done remotely or on-.site, demand approximately 200 hp (150kW). This is performed by gas and electro hydraulic systems which are incorporated into the base. The system provides real time monitoring and control of turbine critical functions including: sequencing, speeds, guide vane positioning, firing temperature limiting and data event logging. The gas turbine controls offer either local or remote modes of operation. Viewing of the operating parameters is available locally or remotely. (Siemens, 2014)

4. Main Requirement

The bleed system shall prevent hot excess air from compressor from entering the housing.

5. Requirements

- The requirements are both listed in a rising manner, and also included in a traceability map.
- The first list holds the user requirements, the next the system requirements and the last the design requirements

5.1 Requirements overview

5.1.1 User Requirements

U1. The bleed system can not allow large external forces, stress or moments to be imposed to the gas generator interface.

U2. External constructions attached to the housing shall not conflict with any other components in the environment.

U3. The bleed system shall meet all the gas turbine interface requirements.

U4. The bleed system shall not blow hot air directly to any components external to the bleed system.

U5. The bleed system can access the exhaust.

U6. The bleed system shall not be connected to the turbine, other than the bleed valves.

U7. Valve 42 centered at the top of the turbine shall have separate piping.

U8. If the bleed air is led into the housing ventilation duct, there needs to be checked if all the bleed valves is opened simultaneously.

U9. Pipe within pipe shall have no leakages.

U10. The turbine and its components shall be accessible through the four existing man sized doors.

U11. The maintenance doors shall not be moved.

U12. No bleed lines shall be mounted below the inlet center of the turbine within the enclosure.

~~**U13.** The new bleed line system shall ensure the availability.~~

U14. The bleed system shall meet all HSE requirements and regulations.

U15. The system shall be delivered with risk assessment for possible injuries on working crew during installing/removing of bleed system.

~~**U16.** Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).~~

U17. Installation of low noise equipment shall be the primary noise control measure (Norsok Standard S-002, Aug 2004).

U18. For piping systems, selection of low noise valves and other components with low noise shall be given priority (Norsok Standard S-002, Aug 2004).

U19. The cost of the system shall be within budget

U20. The bleed system maintenance cost shall be within budget.

U21. The bleed system shall meet all cost impact targets.

U22. The bleed system shall have parts possible to produce.

U23. The bleed system shall follow guidelines from D-R

U24. The bleed system shall be suitable for turbine package with crane attached to both sides.

~~**U25.** The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.~~

~~**U26.** The bleed lines can share the same sound muffler.~~

U27. The bleed system shall allow the use of the gas turbine maintenance crane.

U28. The bleed system total removing and installing time shall be below 4,2% of the total service time of the turbine.

U29. The bleed system shall be fitted with fixtures possible to remove and install with standard tools.

U30. Removal of the bleed system shall be possible without removing any other components unless components needs to be removed in the maintenance service.

U31. The bleed system shall cool down during cooldown period of turbine.

U32. The bleed system shall have manuals with instructions

U33. The bleed system shall not contribute to lower efficiency in turbine while turbine is working on maximum load.

U34. The bleed system shall not contribute to lower efficiency during start-up.

U35. The bleed system shall not contribute to efficiency losses during partial loading of the turbine.

U36. There shall be delivered risk assessment for component failure.

U37. The bleed system shall last without failing between main service of the turbine.

U38. The bleed system shall be able to handle the excess air from the turbine.

~~**U39**. All the pipes from bleed valves shall not be connected together.~~

~~**U40.** The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.~~

U41. The bleed line system shall withstand fully developed turbulence within the piping during the whole operation time.

U42. The bleed line system shall withstand the strong flow created in the enclosure by the ventilation system ([redacted] kg/s).

U43. All bolts and nuts shall have bursting discs to prevent them to loosen under operation.

U44. There shall be proper materials to handle different environments.

U45. There shall be developed at least two alternative concepts to handle the bleed air.

U46. The model shall be available by may 24th 2017.

U47. When developed this priority shall be considered.

U48. The system shall have environmental care.

U49. The bleed system shall last the lifetime of the turbine package.

U50. The bleed system shall not conflict with any of the existing transportation procedures.

U51. The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation

U52. Gaskets in the bleed system shall withstand the heat and pressure from the air.

U53. There shall be heat resistant material between duct and enclosure.

U54. Parts of the bleed system outside of enclosure shall be personal protected.

U55. The movable parts of the bleed system attached in the enclosure shall have fixtures for transportation.

U56. There shall be considered using solutions preventing service personnel to climb freestanding ladder.

U57. The external parts of bleed system on top of roof shall be possible to dismantle.

U58. The enclosure walls shall withstand the forces from bleed system attached to them.

U59. The bleed system shall have such a configuration that contributes to good access for service personnel.

U60. There shall be no conflicting parts between the bleed system and the rest of the turbine package

U61. The bleed system shall be able to handle the high temperatures from the flow.

U62. The parts of the system shall be able to handle heat expansion.

U63. All structural parts of the system shall handle the structural loading.

U64. The fabrication shall be as easy as possible.

5.1.2 System requirements

S1. The gas generator interface shall move freely during expansion with at least 4 mm radial.

S2. The gas generator interface shall move freely during expansion with at least 8 mm axial.

S3. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in radial direction with more than 15 kg.

S4. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in axial direction with more than 15 kg.

S5. External bleed system blocking the maintenance door in the housing shall be removable during cooldown.

S6. ~~External bleed system outside blocking the maintenance door shall be possible to disassemble before cooldown of the turbine.~~

S7. External bleed system shall be clear of other components on top of housing.

S8. External bleed system shall not make the roof height of existing turbine package higher.

S9. External bleed system shall not build out more sideways then the width of the maintenance doors, 1870mm.

S10. The bleed system shall be clear of wiring and piping within the housing.

S11. The bleed system must use the existing access point to the exhaust if leaded to the exhaust.

S12. ~~The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.~~

S13. If the bleed line A42 is led to the exhaust it needs to be connected to the outlet with the check valve.

S14. If the bleed valve A42 opens simultaneously with valve A51, A43 and A44 the bleed air can be led to the housing ventilation duct, but the back pressure needs to be calculated.

S15. Valve A42 leaded out of the enclosure within the pipe of valve A43, A44 and A51 shall not have any leakage between them.

S16. Dresser-Rand shall approve it when the bleed system requires the four inspection doors to be moved.

S17. Parts of the bleed system manual lifted by the crew service shall not exceed 25 kg (Norsok Standard R-002, Sep 2012).

S18. The maximum temperature released from the housing through the ventilation shall not exceed 70 degrees celsius.

S19. The parts of the bleed system from valve 43, 44 and 51 shall withstand [redacted] degrees celsius during the whole operation time.

S20. The parts of the bleed system from valve 42 shall withstand [redacted] degree celsius during the whole operation time.

S21. The backpressure in the bleed system valve 43, 44 and 51 together shall be maximum 70 kPa.

S22. The back pressure from valve 42 shall be maximum 24 kPa.

S23. It shall not be possible to reach parts of the bleed system with temperatures exceeding 70 degrees celsius (Norsok Standard S-002, Aug 2004).

S24. It shall not be possible to reach parts of the bleed system with temperatures below -10 degrees (Norsok Standard S-002, Aug 2004).

S25. The individual employee's maximum exposure to noise during a 12 hours working day is 83 db (Norsok Standard S-002, Aug 2004).

S26. The maximum allowable noise level in any situation is 130 dB.

S27. All edges of the system shall be be rounded.

S28. All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person.

S29. All parts of the system lighter than 25 kg shall be reachable for a person from the operation area.

S30. The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost

S31. The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours

S32. Cost of transportation shall not cost more than for the current system.

S33. The bleed system shall have parts regulated in international standards.

S34. ~~Valve 42 shall have its own bleed line.~~

S35. The bleed system can be designed for left side crane, but shall then also be designed for right hand side

S36. The bleed system can be designed for right hand side crane, but shall then also be designed for left side.

S37. The crane shall move freely of parts of the bleed system left after disassembly in the enclosure.

S38. The bleed system shall take not more than 30 min to remove.

S39. The bleed system shall take not more than 30 min to install.

S40. The Fastening method shall always be the fastest possible.

S41. The bleed system shall use the metric system.

S42. The bleed system shall cool down to 70 degrees celsius within 240 minutes.

S43. The bleed system shall have instructions in standards of material received from Dresser-Rand for disassembly during maintenance.

S44. The bleed system shall have instructions in standards of material received from Dresser-Rand for assembly during maintenance.

S45. ~~The system shall have risk assessment for at least two critical components in the bleed system.~~

S46. The system shall sustain 26280 hours without maintenance.

S47. The bleed system outlet shall in total be able to handle bleed air in amounts of [redacted] kg/s.

S48. The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s.

S49. The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s.

S50. The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.

S51. ~~The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.~~

S52. There shall be considered using the stainless steel SS-316 in the bleed system.

S53. There shall be considered using the stainless steel SS-316L if there is weldings in the material.

S54. The material used shall withstand vibrations from the turbine.

S55. The solutions shall be presented in the form of a 3D model.

S56. The 3D model shall have supporting documentation.

S57. The concept shall have manuals for service.

S58. The concept shall have understandable manuals for installation and use.

S59. The 1st priority is safety

S60. The 2nd priority is technical requirements

S61. The 3rd priority is time

S62. The 4th priority is cost

S63. ~~The time it takes to assemble the system is prioritized above the cost of the system.~~

~~**S64.**~~ ~~The time it takes to disassemble the system is prioritized above the cost of the system.~~

S65. All the materials are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).

S66. All the substances are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).

S67. The bleed system shall last for minimum 25 years.

S68. The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.

S69. The fixtures shall be able to withstand 0,98G during transportation.

S70. Gaskets in the bleed system from valve 43, 44 and 51 shall withstand [redacted] degree celsius.

S71. Gaskets in the bleed system from valve, 43, 44 and 51 shall withstand pressure of 70 kPa.

S72. Gaskets in the bleed system from valve 42 shall withstand [redacted] degree celsius.

S73. Gaskets in the bleed system from valve 42 shall withstand 24 kPa.

S74. The parts the pipeline from bleed system touches from valve 43, 44 and 51 shall withstand transferring heat at [redacted] degree celsius.

S75. The parts the pipeline system touches from valve 42 shall withstand transferring heat at [redacted] degree celsius.

S76. The material used between pipes and enclosure shall withstand [redacted] degree celsius.

S77. Piping and ducts reachable external shall be protected with physical blocking, like fence, isolation etc, to prevent anyone to touch.

~~**S78.** The walls shall withstand the maximum load of …..N.~~

~~**S79.** It shall be possible to move the turbine in vertical direction during removal without touching the bleed system.~~

~~**S80.** The strip wound hose shall be able to swing around the turbine.~~

S81. There shall be room enough for a service person to access every part of the turbine needed for service.

S82. There shall not be any collision between parts of the bleed system and the turbine during removal of the turbine.

S83. all components in touch with the flow of the (A43, A44, A51) part of the bleed system shall be able to handle [redacted] degrees celsius.

S84. Parts of the system that are fixed shall be able to withstand the stresses from the heat expansion.

S85. parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material.

S86. All structural parts of the system shall be able to handle the loads associated with weight.

S87. All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.

S88. The A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe.

5.1.3 Design requirements

D1. It shall be possible to position the valves into the interface with a clearance distance between pipe and interface of minimum 4 mm.

D2. The fixing points for the bleed lines are the fastening U bolts closest to the interface.

D3. The clearance between the extension pipe of valve A43, A44 and A51 and the bleed system without the interface shall be more than 11,1mm.

D4. The extension pipe and v-band connections to valve A43, A44 and A51 shall not exceed 15kg.

D5. The extension pipe and v-band connections to valve A43, A44 and A51 shall not exceed 15kg.

~~**D6.** Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)~~

~~**D7.** Disassembly of external bleed system takes no more than …. minutes.~~

~~**D8.** External bleed system outside blocking the maintenance door shall be possible to disassemble before cooldown of the turbine.~~

D9. With the current position of the duct, it can not be moved more than 200mm further from the wall.

D10. The gap surrounding the pipes entering the duct should be greater than 0,3mm.

D11. The gap in the roof transition must be more than 2.71mm in depth (Z) direction and 1.93mm in width (X) direction.

D12. The brackets supporting the duct have to permit an expansion of more than 0.6mm in depth (Z) direction of the duct.

D13. The frame shall be able to withstand the loads inflicted by the weight of all the components connected to it.

D14. The brackets supporting the duct shall be able to withstand the loads inflicted by the weight of the duct.

D15. It shall be possible to lock the pipes in position that withstands the load from the flow.

D16. The flexible membrane connection shall not be in direct contact with the flow.

D17. The duct shall be positioned high enough for a standard service person to fit underneath it.

D18. It shall be possible to let the duct hang on the wall during maintenance.

D19. V band connections shall be used.

D20. The pipe straights and bends shall be welded together.

D21. It shall be possible to strap the duct to fix it completely during transportation.

D22. The straps shall be able to withstand the forces from the duct inflicted by transportation.

D23. The brackets holding the duct shall be able to withstand the forces inflicted by transportation.

In the tables below there is a detailed traceability map of the requirements. First the requirements are divided into areas. On top comes the user requirements, the system requirements follows, and the comes the design requirements. All requirements needs to be numbered in a way to makes it possible to trace tests back to the requirements with the use of the requirement ID. The system of the traceability map is as follows:

- A1 stands for area number one, which is “Restrictions”.
- U2 stands for user requirement number two in the given area.
- S5 stands for system requirement number one in the given user requirement.
- D2 stands for design requirement number two in the given system requirement.

This leads us to the design requirement: *“Disassembly of external bleed system takes no more than …. minutes”.* Further the requirements is given priorities from A to C according to how important they are for the system. Where priority:

- A is requirements that is an absolute necessity.
- B is requirements that is important, but not necessary.
- C is requirements that is not important, but desirable.

5.2 Requirements sorted by relevance

A1. Restriction

U1. User Requirement **Origin: D-R** **Priority: A** The bleed system can not allow large external forces, stress or moments to be imposed to the gas generator interface.
System Requirements **S1.** The gas generator interface shall move during expansion with at least 4 mm radial.
D1. It shall be possible to position the valves into the interface with a clearance distance between pipe and interface of minimum 4 mm. **D2.** The fixing points for the bleed lines are the fastening U bolts closest to the interface.
S2. The gas generator interface shall move during expansion with at least 8 mm axial.
D3. the clearance between the extension pipe of valve A43, A44 and A51 and the bleed system without the interface shall be more than 11,1mm.
S3. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in radial direction with more than 15 kg.
D4. The extension pipe and v-band connections to valve A43, A44 and A51 shall not exceed 15kg.
S4. The bleed system shall not load the bleed valves A51, A43, A44 and A42 in axial direction with more than 15 kg.
D5. The extension pipe and v-band connections to valve A43, A44 and A51 shall not exceed 15kg.

U2. User Requirement **Origin: D-R** **Priority: A**

External constructions attached to the housing shall not conflict with any other components in the environment.

System Requirements

S5. External bleed system blocking the maintenance door in the housing shall be removable during cooldown.

~~**D1.** Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)~~

~~**D2.** Disassembly of external bleed system takes no more than …. minutes.~~

S6. ~~External bleed system outside blocking the maintenance door shall be possible to disassemble before cooldown of the turbine.~~

S7. External bleed system shall be clear of other components on top of housing.

S8. External bleed system shall not make the roof height of existing turbine package higher.

S9. External bleed system shall not build out more sideways then the width of the maintenance doors, 1870mm.

S10. The bleed system shall be clear of wiring and piping within the housing.

U3. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall meet all the gas turbine interface requirements.

U4. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall not blow hot air directly to any components external to the bleed system.

U5. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system can access the exhaust.		
System Requirements **S11.** The bleed system must use the existing access point to the exhaust if leaded to the exhaust.		

U6. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not be connected to the turbine, other than the bleed valves.		
System requirement ~~**S12.** The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.~~		

U7. User Requirement	**Origin: D-R**	**Priority: A**
Valve 42 centered at the top of the turbine shall have separate piping.		
System requirement **S13.** If the bleed line A42 is led to the exhaust it needs to be connected to the outlet with the check valve.		

U8. User Requirement	**Origin: D-R**	**Priority: A**
If the bleed air is led into the housing ventilation duct, there needs to be checked if all the bleed valves is opened simultaneously.		
System Requirement **S14.** If the bleed valve A42 opens simultaneously with valve A51, A43 and A44 the bleed air can be led to the housing ventilation duct, but the back pressure needs to be calculated.		

U9. User Requirement **Origin: D-R** **Priority: A** Pipe within pipe shall have no leakages.	

S15. Valve A42 leaded out of the enclosure within the pipe of valve A43, A44 and A51 shall not have any leakage between them.

U60. User Requirement **Origin: D-R** **Priority: A**

There shall be no conflicting parts between the bleed system and the rest of the turbine package

S82. There shall not be any collision between parts of the bleed system and the turbine during removal of the turbine.

D9. With the current position of the duct, it can not be moved more than 200mm further from the wall.

U62. User Requirement **Origin: D-R** **Priority: A** The parts of the system shall be able to handle heat expansion.	
S84. Parts of the system that are fixed shall be able to withstand the stress from the heat expansion.	
S85. parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material.	
D3. the clearance between the extension pipe of valve A43, A44 and A51 and the bleed system without the interface shall be more than 11,1mm.	
D10. The gap surrounding the pipes entering the duct should be greater than 0,3mm.	
D11. The gap in the roof transition must be more than 2.71mm in depth (Z) direction and 1.93mm in width (X) direction.	
D12. The brackets supporting the duct have to permit an expansion of more than 0.6mm in depth (Z) direction of the duct.	
S88. the A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe.	

U63. User Requirement **Origin: D-R** **Priority: A** All structural parts of the system shall handle the structural loading.
S86. All structural parts of the system shall be able to handle the loads associated with weight.
D13. The frame shall be able to withstand the loads inflicted by the weight of all the components connected to it.
D14. The brackets supporting the duct shall be able to withstand the loads inflicted by the weight of the duct.
S87. All structural parts of the system shall be able to handle the loads associated with the flow from the turbine.
D15. It shall be possible to lock the pipes in position that withstands the load from the flow.
D16. The flexible membrane connection shall not be in direct contact with the flow.

A2. Access

U10. User Requirement **Origin: D-R** **Priority: A** The turbine and its components shall be accessible through the four existing man sized doors.

U11. User Requirement **Origin: D-R** **Priority: A** The maintenance doors shall not be moved.
System Requirement **S16.** D-R shall approve it when the bleed system requires the four inspection doors to be moved.

U12. User Requirement	**Origin: D-R**	**Priority: C**
No bleed lines shall be mounted below the inlet center of the turbine within the enclosure.		

~~**U13. User Requirement**~~	~~**Origin: D-R**~~	~~**Priority: A**~~
~~The new bleed line system shall ensure the availability.~~		

U59. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall have such a configuration that contributes to good access for service personnel.		
System Requirement **S81.** There shall be room enough for a standard service person to access every part of the turbine needed for service.		
D17. The duct shall be positioned high enough for a standard service person to fit underneath it.		

A3. Safety

U14. User Requirement	Origin: Government	Priority: A
The bleed system shall meet all HSE requirements and regulations.		

System Requirements

S17. Parts of the bleed system manual lifted by the crew during service shall not exceed 25kg (Norsok Standard R-002, Sep 2012).

S18. The maximum temperature released from the housing through the ventilation shall not exceed 70 degrees celsius.

S19. The parts of the bleed system from valve 43, 44 and 51 shall withstand [redacted] degrees celsius during the whole operation time.

S20. The parts of the bleed system from valve 42 shall withstand [redacted] degree celsius during the whole operation time.

S21. The backpressure in the bleed system valve 43, 44 and 51 together shall be maximum 70 kPa.

S22. The back pressure from valve 42 shall be maximum 24 kPa.

S23. It shall not be possible to reach parts of the bleed system with temperatures exceeding 70 degrees celsius (Norsok Standard S-002, Aug 2004).

S24. It shall not be possible to reach parts of the bleed system with temperatures below -10 degrees (Norsok Standard S-002, Aug 2004).

S25. The individual employee's maximum exposure to noise during a 12 hours working day is 83 db (Norsok Standard S-002, Aug 2004).

S26. The maximum allowable noise level in any situation is 130 dB.

S27. All edges of the system shall be be rounded.

S28. All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person.

a. All parts lighter than 25 kg, and with geometry difficult to lift shall have handles, grip points etc.

S29. All parts of the system lighter than 25 kg shall be reachable for a person from the operation area.

U15. User Requirement **Origin: D-R** **Priority: B**

The system shall be delivered with risk assessment for possible injuries on working crew during installing/removing of bleed system.

~~**U16. User Requirement** **Origin: D-R** **Priority: A**~~

~~Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).~~

U17. User Requirement **Origin: D-R** **Priority: A**

Installation of low noise equipment shall be the primary noise control measure (Norsok Standard S-002, Aug 2004).

U18. User Requirement **Origin: D-R** **Priority: A**

For piping systems, selection of low noise valves and other components with low noise shall be given priority (Norsok Standard S-002, Aug 2004).

U53. User Requirement **Origin: D-R** **Priority: A**

There shall be heat resistant material between duct and enclosure.

S74. The parts the pipeline from bleed system touches from valve 43, 44 and 51 shall withstand transferring heat at [redacted] degree celsius.

S75. The parts the pipeline system touches from valve 42 shall withstand transferring heat at [redacted] degree celsius.

S76. The material used between pipes and enclosure shall withstand [redacted] degree celsius.

U54. User Requirement **Origin: D-R** **Priority: A**

Parts of the bleed system outside of enclosure shall be personal protected.

S77. Piping and ducts reachable external shall be protected with physical blocking, like fence, isolation etc, to prevent anyone to touch.

U58. User Requirement **Origin: D-R** **Priority: A**

The enclosure walls shall withstand the forces from bleed system attached to them.

S78. The walls shall withstand the maximum load of …..N.

A4. Economy

U19. User Requirement **Origin: D-R** **Priority: A**

The cost of the system shall be within budget

System Requirement

S30. The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost

U20. User Requirement **Origin: D-R** **Priority: A**

The bleed system maintenance cost shall be within budget.

System Requirement

S31. The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours

U21. User Requirement **Origin: D-R** **Priority: B**

The bleed system shall meet all cost impact targets.

System Requirement

S32. Cost of transportation shall not cost more than for the current system.

A5. Producing

U22. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall have parts possible to produce.		
System Requirement **S33.** The bleed system shall have parts regulated in international standards.		

U23. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall follow guidelines from D-R		
System Requirement ~~**S34.** Valve 42 shall have its own bleed line.~~		

U24. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall be suitable for turbine package with crane attached to both sides.		
S35. The bleed system can be designed for left side crane, but shall then also be designed for right hand side.		
S36. The bleed system can be designed for right hand side crane, but shall then also be designed for left side.		

U25. User Requirement	**Origin: D-R**	**Priority: A**
~~The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.~~		

~~**U26. User Requirement**~~	~~**Origin: D-R**~~	~~**Priority: B**~~

~~The bleed lines can share the same sound muffler.~~

A6. Maintenance

U27. User Requirement **Origin: D-R** **Priority: A** The bleed system shall allow the use of the gas turbine maintenance crane.
System Requirement **S37.** The crane shall move freely of parts of the bleed system left after disassembly in the enclosure.

U28. User Requirement **Origin: D-R** **Priority: A** The bleed system total removing and installing time shall be below 4,2% of the total service time of the turbine.
System Requirements **S38.** The bleed system shall take not more than 30 min to remove.
D18. It shall be possible to let the duct hang on the wall during maintenance.
D19. V band connections shall be used.
D20. The pipe straights and bends shall be welded together.
S39. The bleed system shall take not more than 30 min to install.
D18. It shall be possible to let the duct hang on the wall during maintenance.
D19. V band connections shall be used.
D20. The pipe straights and bends shall be welded together.
~~**S40.** The Fastening method shall always be the fastest possible.~~

U29. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall be fitted with fixtures possible to remove and install with standard tools.		
System Requirement **S41.** The bleed system shall use the metric system		

U30. User Requirement	**Origin: D-R**	**Priority: A**
Removal of the bleed system shall be possible without removing any other components unless components needs to be removed in the maintenance service.		

U31. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall cool down during cooldown period of turbine.		
System Requirement **S42.** The bleed system shall cool down to 70 degrees celsius within 240 minutes.		

U32. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall have manuals with instructions		
System Requirement **S43.** The bleed system shall have instructions in standards of material received from Dresser-Rand for disassembly during maintenance.. **S44.** The bleed system shall have instructions in standards of material received from for assembly during maintenance..		

U56. User Requirement	**Origin: D-R**	**Priority: A**
There shall be considered using solutions preventing service personnel to climb freestanding ladders.		

A7. Operation

U33. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not contribute to lower efficiency in turbine while turbine is working on maximum load.		

U34. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not contribute to lower efficiency during start-up.		

U35. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall not contribute to efficiency losses during partial loading of the turbine.		

U36. User Requirement	**Origin: D-R**	**Priority: B**
There shall be delivered risk assessment for component failure.		
System Requirement ~~**S45.** The system shall have risk assessment for at least two critical components in the bleed system.~~		

U37. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall last without failing between main service of the turbine.

System Requirement

S46. The system shall sustain 26280 hours without maintenance.

U38. User Requirement **Origin: D-R** **Priority: A**

The bleed system shall be able to handle the excess air from the turbine.

System Requirement

S47. The bleed system outlet shall in total be able to handle bleed air in amounts of [redacted] kg/s.

S48. The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s.

S49. The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s.

S50. The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.

~~**U39. User Requirement**~~ ~~**Origin: D-R**~~ ~~**Priority: A**~~

~~All the pipes from bleed valves shall not be connected together.~~

~~**S51.** The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.~~

U40. User Requirement **Origin: D-R** **Priority: A**

~~The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.~~

U41. User Requirement **Origin: D-R** **Priority: A**

The bleed line system shall withstand fully developed turbulence within the piping during the whole operation time.

U42. User Requirement **Origin: D-R** **Priority: A**

The bleed line system shall withstand the strong flow created in the enclosure by the ventilation system ([redacted] kg/s).

U43. User Requirement **Origin: D-R** **Priority: A**

All bolts and nuts shall have bursting discs to prevent them to loosen under operation.

.

U52. User Requirement **Origin: D-R** **Priority: A**

Gaskets in the bleed system shall withstand the heat and pressure from the air.

System Requirement

- **S70.** Gaskets in the bleed system from valve 43, 44 and 51 shall withstand [redacted] degree celsius.
- **S71.** Gaskets in the bleed system from valve, 43, 44 and 51 shall withstand pressure of 70 kPa.
- **S72.** Gaskets in the bleed system from valve 42 shall withstand [redacted] degree celsius.
- **S73.** Gaskets in the bleed system from valve 42 shall withstand 24 kPa.

U61. User Requirement	**Origin: D-R**	**Priority: A**
The bleed system shall be able to withstand the high temperatures from the flow.		
System Requirement **S83.** all components in touch with the flow of the (A43, A44, A51) part of the bleed system shall be able to handle [redacted] degrees celsius.		

A8. Materials

U44. User Requirement	**Origin: D-R**	**Priority: C**
There shall be proper materials to handle different environments.		
System Requirement **S52.** There shall be considered using the stainless steel SS-316 in the bleed system. **S53.** There shall be considered using the stainless steel SS-316L if there is weldings in the material. ~~**S54.** The material used shall withstand vibrations from the turbine.~~		

A9. Administrative

U45. User Requirement	**Origin: D-R**	**Priority: A**
There shall be developed at least two alternative concepts to handle the bleed air.		
System Requirement **S55.** The solutions shall be presented in the form of a 3D model. **S56.** The 3D model shall have supporting documentation. **S57.** The concept shall have manuals for service. **S58.** The concept shall have understandable manuals for installation and use. ~~**S59.** The time it takes to assemble the system is prioritized above the cost of the system.~~ ~~**S60.** The time it takes to disassemble the system is prioritized above the cost of the system.~~		

U46. User Requirement	**Origin: USN**	**Priority: A**
The model shall be available by may 24th 2017.		

U47. User Requirement	**Origin: D-R**	**Priority: A**
When developed this priority shall be considered.		
S61. The 1st priority is safety **S62.** The 2nd priority is technical requirements **S63.** The 3rd priority is time **S64.** The 4th priority is cost		

A10. Recycle

U48. User Requirement	**Origin: Government**	**Priority: A**
The system shall have environmental care.		
System Requirement **S65.** All the materials are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003). **S66.** All the substances are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).		

A11. Life Time

U49. User Requirement	**Origin: D-R Priority: A**
The bleed system shall last the lifetime of the turbine package.	
System Requirement **S67.** The bleed system shall last for minimum 25 years.	

A12. Transport

U50. User Requirement	**Origin: D-R Priority: A**
The bleed system shall not conflict with any of the existing transportation procedures.	
System Requirement **S68.** The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.	

U51. User Requirement	**Origin: D-R Priority: A**
The fixtures holding the bleed system shall be constructed to withstand loads associated with transportation.	
System Requirement **S69.** The fixtures shall be able to withstand 0,98G during transportation.	
D21. It shall be possible to strap the duct to fix it completely during transportation.	
D22. The straps shall be able to withstand the forces from the duct inflicted by transportation.	
D23. The brackets holding the duct shall be able to withstand the forces inflicted by transportation.	

U57. User Requirement	**Origin: D-R Priority: A**
The external parts of bleed system on top of roof shall be possible to dismantle.	

A13. Deleted requirements

D1. Cooldown of external bleed system to 70 degrees celsius takes no more than …. minutes.(demontere det før de 240 minuttene er gått)
Approved by: Dresser-Rand **Why deleted:** It is not relevant since the system is inside the package.

D2. Disassembly of external bleed system takes no more than …. minutes.
Approved by: Dresser-Rand **Why deleted:** It is not relevant since the system is inside the package.

U13 The new bleed line system shall ensure the availability.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.59

U16. Major noise and vibration sources are localized (Norsok Standard S-002, Aug 2004).
Approved by: Dresser-Rand **Why deleted:** The noise is already localized in the specification from dresser rand, and there is no vibration analysis in the thesis.

U25. The bleed line system shall be mounted in the turbine package from the center line and up from the turbine.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.12

U26. The bleed lines can share the same sound muffler.
Approved by: Dresser-Rand **Why deleted:** It is not a requirement

U39. All the pipes from bleed valves shall not be connected together.
Approved by: Dresser-Rand **Why deleted:** Rewritten to U.7

U40. The hot air injected in the intake air shall be registered by the sensors registering heat flowing into the turbine.
Approved by: Dresser-Rand **Why deleted:** It is not valid. Based on a misunderstanding.

S12. The bleed system does not have restrictions on the distance to the turbine, as long as it doesn't touch any components.
Approved by: Dresser-Rand **Why deleted:** Rewritten requirement to U.6

S34. Valve 42 shall have its own bleed line.
Approved by: Dresser-Rand ok **Why deleted:** Written two times, valid is U7

S45. The system shall have risk assessment for at least two critical components in the bleed system.
Approved by: Dresser-Rand ok **Why deleted:** Rewritten to U36.

S51. The bleed valve oriented in the center on top of turbine shall be connected to the hot air exit in a pipe without any connection points to other part of the bleed system.
Approved by: Dresser-Rand **Why deleted:** Written to U7.

S63. The time it takes to assemble the system is prioritized above the cost of the system.
Approved by: Dresser-Rand **Why deleted:** It is written into the evaluating criterias under stakeholders and concerns.

S64. The time it takes to disassemble the system is prioritized above the cost of the system.
Approved by: Dresser-Rand **Why deleted:** It is written into the evaluating criterias under stakeholders and concerns.

S79. It shall be possible to move the turbine in vertical direction during removal without touching the bleed system.
Approved by: Dresser-Rand **Why deleted:** Written to S82.

S80. The strip wound hose shall be able to swing around the turbine.
Approved by: Dresser-Rand (ok) **Why deleted:** Moved to D53.

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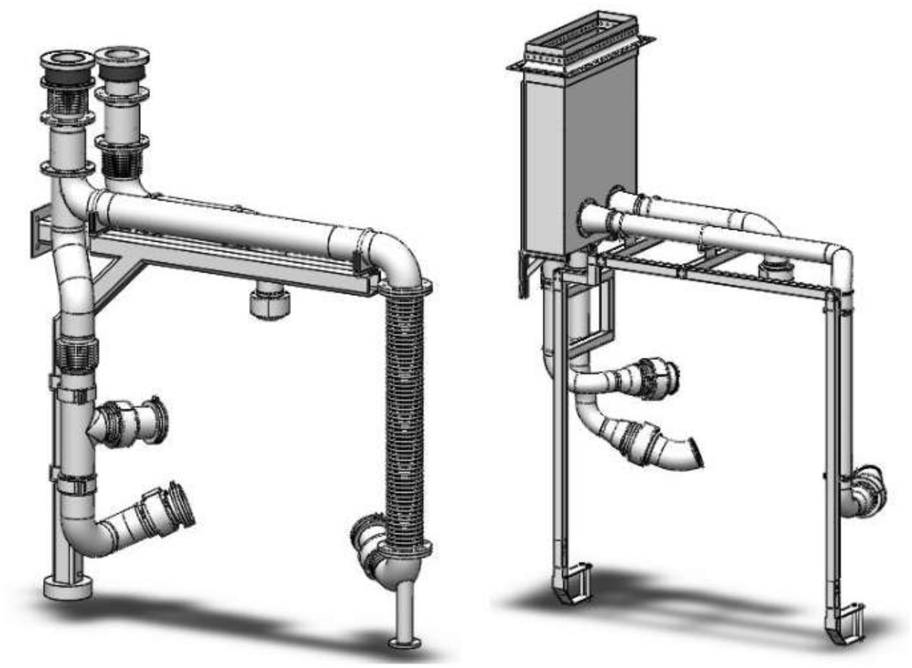
DRESSER-RAND

HSN University College of Southeast Norway

Test Specification

Gas Turbine Bleed System



Gruppe 19

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22.05.2017

Document History

Date	Version	Changes	Approved by
26.01.17	0.0	Created	Kristian
31.01.17	1.0	Approved for publication	Øystein
29.03.17	2.0	Created	Kristian
08.04.17	2.1	New tests	Kristian
11.04.17	2.2	New tests	Daniel
08.05.17	2.3	New tests	Svenn
12.05.17	2.4	New tests	Kristian
16.05.17	2.5	Changed tests/Correction tests	Kristian
20.05.17	2.6	Correction	Kristian
22.05.17	2.7	Correction	Svenn
22.05.17	3.0	Approved for publication	Svenn

Table of Contents

Abbreviations

- FEM - Finite element method
- CFD - Computer assisted fluid dynamics
- Etc. - And so on
- USN - University college of South-East Norway
- E.g. - For example

1. Introduction

Testing is a very important aspect of a development process. It is the primary method to prove that the system is performing the way it was specified in the requirements. There are various forms of testing. During the development of the product testing part by part is important to see if the requirements are met. Later in the process an assembly testing is more appropriate to see if the assembly still meets the requirements. This will be important and more relevant closer to a completion of the product (Buede, 2009).

This document explains how we will approach the testing of the system, the methods we're going to use, the resources involved in the testing, the tests themselves and how we are going to document the results.

2. Test Strategy

2.1 Origin of Tests

To verify and validate the product, one of the activities is to do testing of the product (Department of Defense, 2001). Tests in the test specification are all based on a specific requirement traceable back to the original need from a stakeholder.

To do testing we need to know the purposes of the test. What do we want to test, and what is the most appropriate form of testing the requirement(s). To get any useful results out of testing we must have test methods that meet the requirements properly. When doing this, we get answers that are valid and we can use these results in the development of the product (Department of defense, 2001).

2.2 Approach

The strategy of testing is more a general approach to the process of testing rather than testing methods. Depending on the development process, different testing strategies may be adapted. Two strategies available are top down testing and the bottom up testing methode. Top-down testing will be testing the high-level requirements before going to more detailed testing of single components. Bottom-up testing is doing the opposite. It involves testing at the lower levels in the hierarchy and ending up with final product testing (HN Computing, 2006).

Different types of testing are needed. It is possible to do testing of one component alone to see if it achieves the desired results, and to do testing with components together to see the behavior in an assembly. An assembly testing is important to see if the components are carried in individual testing still meets the requirements in an assembly. Assembly testing will be when the product is near completion.

The progress in the testing is important to get good results. We therefore want to base the test plan on the importance of the tests. The first tests will be among the essential requirements from our user, like a top-down testing. This will be combined with bottom-up testing methods, since sometimes it is important to do testing of components on a lower level to see if it is capable to meet user requirements on a higher level. So, we need to map the low-level testing of components and find the appropriate testing methods, and then find methods for the high level priority testing. This will be the progress of testing our system against the requirements.

2.3 Risk

When building a concept, it is often limited by the time and cost. When doing testing in the development process this is something that can surpass both deadlines and budget. If you get an answer that you are not satisfied with, or that’s not accurate enough, you may need to reevaluate the test method, make adjustments or even change the test method. This can cost both time and money. For our part, it is the time that is most vulnerable to making errors in testing.

Sometimes it is difficult to interpret answers from testing and it may partly lead to new problems or require new solutions with new choice of materials. It is therefore important to avoid delay of testing until the product is almost finished. The risk for surpassing deadlines and budget rises the longer we are into the development process. This is because it is demanding to make changes to the design later in the project.

2.4 Credibility

For a test to be credible there must be an appropriate test for the requirements it will test. The whole reason for testing is to get useful results that can verify the related requirements. To increase the credibility and reliability of a test, trials can be done several times or the test can be done with other test equipment and then compared to make sure that this results is quality assured and we can take them further in the development process.

The equipment used during testing is also of importance when creating credible results. If the equipment is inaccurate, inappropriate, incomplete, or not in good condition this will weaken the result and might make it invalid. In this context, it will be possible to run FEM analysis several times to make sure the results and testing is correct. Time will limit the extent of testing and we must minimize the sources of errors so that the answer is reliable. For FEM analysis, another factor is whether you understand all the necessary inputs and have an idea about what the result is. It can otherwise be easy to conclude incorrectly. The computer assisted simulation programs are only useful if the user understands how to use them correctly.

2.5 Levels of Testing

2.5.1 Design Level Testing

Unit Test Plans are developed during module design phase. These tests are executed to eliminate problems at part level or unit level. The parts are the smallest entity of our system. Part testing verifies that the smallest entity can function correctly when isolated from the rest of the system.

2.5.2 Sub-System Testing

Sub-system Tests ensures that expectations of functionality are met. Every test is testing the sub-system for its functionality, interdependency, and communication. Load and performance testing, stress testing, regression testing, etc., are subsets of system testing.

2.5.3 System Testing

The system as a whole should be tested in a complete state. This includes integration testing, interface testing, operational testing, maintenance testing. These tests will be the ones that verify the top-level requirements of the system and making sure it can be implemented to the parent system.

2.5.4 Validation and Verification

Validation tests are intended to answer the question of whether the system being built is what is needed and expected by the customer. This will therefore be widely based on whether the desired function of the system is achieved, and will test whether we have understood what the customer is looking for. This is done often using functionality tests and field tests. It is only natural that these tests have larger focus on top level requirements. It is important that the validation of requirements happens in the early stage, and in addition much validation occurs in the integration stages of testing.

Verification tests will test whether the system we have created is working as we intended it to do, according to the requirements. We check whether the system and design requirements are met as they should. The result answers whether we build the system correctly based on how we understand our customer. We perform these tests by measurements and calculations on quantifiable objects. These tests are carried out during the entire test period.

3. Test Methods

The methods we will be using to validate and verify are mostly theoretical and computer assisted. This is based on the goal we have in our project. Which consist of a fully functional model rather than a physical system. Our main methods are as follows:

3.1 Finite element method

Finite Element Method (FEM) is a method numerical technique to approximate solutions to boundary value problems for partial differential equations. In our project, we will use a program called SolidWorks (SW), provided by University College of Southeast Norway (USN), which is a computer software capable of doing FEM on system and component level. This is not the most advanced simulation program, but it is usable for basic testing of deformation, flow, vibrations, and temperature. We will use SW as our main tool for testing the system and its parts during the project period. Components, subsystems, and the system will be designed using SW, then tested using the simulation feature. This way we get a good view of the quality of the design and it is easy to find weak spots.

There are some downsides to using FEM software. The most significant is that the accuracy of the results obtained by FEM. It is a function of mesh and nodal setup. By increasing the mesh resolution and/or number of nodes in each mesh element, one can obtain more accurate results, but it will take a larger amount of time to finish each test. To obtain accurate results while saving time, a refined mesh can be applied on areas of the model with concentrated stress, while a coarser mesh is applied to the rest of the model. It is desirable to validate the results using different mesh and node settings and a second software.

3.2 Calculation by Hand

Hand calculation can be used in verifying FEM, to check that the results obtained by the software is realistic, and to get a better understanding of the test compared to FEM analysis. Many physical tests can be simulated with calculation by hand. Examples of these are flow, stress, bending, combined loading, vibration, pressure, fatigue, and heat conductivity testing. We plan to use hand calculations for solving smaller problems and to verify FEM results that appear wrong. We don't expect to solve the problem better than the FEM software, but it can give us an understanding of the correctness of the FEM test. If there are big differences between the FEM test and the hand calculation, it indicates that one of them have been conducted incorrectly, and a revision of both is needed.

Limitations are the complexity of the part/system that is to be analyzed, and also the accuracy of the test. There are many simplifications in the formulas, e.g. perfect conditions of crystal structure of metals, and we are only able to perform calculations on simplified versions of the models, because the true model would present a very complicated and time consuming task.

3.3 Visual Inspection

Visual inspection is one of the most common and most powerful means of non-destructive testing. Visual testing requires adequate illumination of the test surface and proper eye-sight of the tester. To be most effective visual inspection does however, merit special attention because it requires training (Trinity DNT, 2012). In our case the visual inspection will be done on the 3D model of the system. To ensure that all measures and tolerances are in coherence with the requirements.

4. Testing

The test specification bases the test on the system requirements. If a test is satisfied the system requirement is satisfied and all subordinate design requirements are also satisfied. If all the systems requirements originating from a specific user requirement are satisfied the user requirement also is satisfied.

4.1 Instructions for Testing

Each test will be written into the test template as shown below. On the upper row, you have the general information about the test. First the test identification number, next you have identification of the requirement(s) the test is based upon. Furthermore, there is information about what type of test it is, and what priority it has.

In the open cell below we have more specific information about the particular test. It states the requirement which is to be tested, how the test will be performed, what should be satisfied to approve the test, the equipment that must/can be used, and notes about the test.

Test ID	**Req ID**	**Test type**	**Priority**
Requirement to test: **Test procedure:** **Acceptance criteria:** **Equipment:** **Note:**			

Table: Test template (made by bachelor group in google disk).

The testID is based on the reqID. They are the same but for the testID the first letter and number indicate which specific test with concern to the requirement it tests. E.g. T1.S1 is test number one which tests requirement S1, and T2.S1 is test number two that tests the same requirement.

The priority of the tests is based on the priority of the user requirements (same method, A, B or C). Given the scale of the project we knew early on that we would not be able to perform all the tests in the test specification. We have instead focused on the tests D-R is most interested in getting answers to. All requirements has a written test, but we have not performed all of them.

4.2 Test Schedule

Testing is scheduled to take place in the design/testing phase. Intermediate design periods and test periods will occur repeatedly in this phase. This is to get the most feedback from testing as soon as possible throughout the designing phase. So, we do not spend too much time on areas of the task that turn out not working. There will be 2 test periods in the design/testing phase, a and b. After the first rough designing phase of a week test period a is performed. Test period b will take place in parallel with designing on a more detailed level. Tests that require more details on the model will be performed during this period.

4.2.1 Test Phase a

This period will last for a week. And the focus will be to get a rough feedback to the first 3D-design which we will build on in the following week. We will have 4 design concepts to test in this test phase. The test which we will focus on in this test period are the ones that are important for the configuration of the systems, and which provide a solid foundation to build on. We will not have time to conduct all the tests that are lucrative for this stage, so the most valuable are selected. Some of the tests are aimed only at certain concepts, we will only have to perform these on the specific concepts. We will during this test and design period end up with the final two concepts we will be working with till the end of the project, so during testing we will be evaluating if there are grounds to reject two of the concepts.

4.2.2 Test Phase b

In this phase we will perform testing in more detail on the remaining two concepts. We want to achieve results that will ensure the progress in developing of our bleed system. During this test period we want to do some parallel testing simultaneously with designing the system on a detailed level. Some of the tests will consist of parts being tested together to see if subsystems will have the functionality needed and if it meets the requirements. During the period we will try to get approved acceptance criterias for all the most important tests for the system. The final specification of the system will then be based on this test period.

4.3 Test Reports

Each test will be documented briefly in the test status template. The more complicated tests will need more explanation, included in a test report. This will be found in a separate test report document. This test report will follow a standard science experiment report template. This includes purpose of test, hypothesis of outcome, list of equipment, approach, results, discussion/sources of error, and conclusion.4.4. Test Overview

The tests included in this version of the test specification are the ones we as a group have the resources and plan to do. A whole variety of other methods to verify the requirements exist, but they will require physical parts to test, and since it is not part of our goal with this project, they are not included in the list of possible tests. The list below includes tests for all the provisional requirements in the project. Therefore, at this point we have mainly planned validation and verification methods for the top level user requirements and system requirements.

4.4.1 Test Phase a

Test ID	Req ID	Test type	Priority
T1.S3	S3	visual	A

Requirement to test:
The bleed system shall not load the bleed valves A51, A43, A44 and A42 in radial direction with more than 15 kg.
Test procedure:
There shall be evaluation of an actual metal to metal contact between the turbine and the bleed system
Acceptance criteria:
There shall be no metal to metal contact.
Equipment:
Solidworks - measurement
Note:
If testing is doing separately, it needs to be T1 and T2 within S3.

Concept 16 **Status:** completed **Results:** satisfying **Result note:** More detailed results in report.	**Concept 30** **Status:** Completed **Results:** Not satisfying **Result note:** More detailed results in report. In later stages this requirement have been satisfied.
Concept 29 **Status:** Not completed **Results:** Not satisfied **Result note:**	**Concept 31** **Status:** Not completed **Results:** Not satisfied **Result note:**

Test ID	Req ID	Test type	Priority
T1.S4	S4	visual	A

Requirement to test:
The bleed system shall not load the bleed valves A51, A43, A44 and A42 in axial direction with more than 15 kg.
Test procedure:
There shall be evaluation of an actual metal to metal contact between the turbine and the

bleed system
Acceptance criteria:
There shall be no metal to metal contact.
Equipment:
Solidworks - measurement
Note:
If testing is doing separately, it needs to be T1 and T2 within S4

Concept 16 **Status:** completed **Results:** satisfying **Result note:** More detailed results in report.	**Concept 30** **Status:** Completed **Results:** Not satisfying **Result note:** More detailed results in report. In later stages this requirement have been satisfied.
Concept 29 **Status:** Not completed **Results:** Not satisfying **Result note:**	**Concept 31** **Status:** Not completed **Results:** Not satisfying **Result note:** More detailed results in report.

Test ID	Req ID	Test type	Priority
T1.S5	S5/D2	FEM	A

Requirement to test:
External bleed system outside blocking the maintenance door in the housing shall be removable during cooldown.
Test procedure:
With the use of FEM software analyse heat convection in the part outside the housing is analysed.
Acceptance criteria:
The whole subsystem that is located outside the turbine housing should be sufficiently cooled with time to spare to disassemble within the 4 hours of turbine cooldown.
Equipment:
SolidWorks

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 has no external parts blocking the maintenance door.	**Concept 30** **Status:** not needed **Results:** not needed **Result note:** Concept 30 has no external parts blocking the maintenance door.
Concept 29	**Concept 31**

Status: not needed **Results:** not needed **Result note:**	**Status:** not needed **Results:** not needed

Test ID	Req ID	Test type	Priority
T1.S7	S7	Visual	A

Requirement to test:
External bleed system shall be clear of other components on top of housing.
Test procedure:
With the use of CAD software a visual interaction test is performed.
Acceptance criteria:
No interaction of components does occur.
Equipment:
SolidWorks
Note:

Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**	**Concept 30** **Status:** Completed **Results:** Satisfying **Result note:**
Concept 29 **Status:** Completed **Results:** The clearance it NOT sufficient, and changes in the design must be made. **Result note:** Changes in the thickness of the outer wall in the sound muffler, shorter pipes from the turbine or some components on the	**Concept 31** **Status:** Completed **Results:** Satisfying **Result note:**

inlet of the ventilation have to be moved.	

Test ID	Req ID	Test type	Priority
T1.S8	S8	Integration Test	A

Requirement to test:
External bleed system shall not make the height of existing turbine package higher.
Test procedure:
With the use of CAD software a visual measurement is performed.
Acceptance criteria:
External constructions attached to the housing shall not conflict with any other components in the package.
Equipment:
SolidWorks
Note:

Concept 16 **Status:** Completed **Results:** Satisfying **Result note:** The clearance is sufficient enough to get the result without measuring.	**Concept 30** **Status:** Completed **Results:** Satisfying **Result note:** The clearance is sufficient enough to get the result without measuring.
Concept 29 **Status:** Completed **Results:** satisfying **Result note:** The bleed system is based on elevating it, and will make the package higher when the 3 years service is executed, but still the inlet of the ventilation will be slightly higher.	**Concept 31** **Status:** Completed **Results:** Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S9	S9	Integration Test	A

Requirement to test:
External bleed system shall not build out more sideways then the width of the maintenance doors, 1870 mm.
Test procedure:

With the use of CAD software a visual measurement is performed. **Acceptance criteria:** The external system on the side of the turbine housing should not block for a turbine to be placed beside the housing. **Equipment:** Solidworks

Concept 16 **Status:** completed **Results:** satisfying **Result note:**	**Concept 30** **Status:** completed **Results:** satisfying **Result note:**
Concept 29 **Status:** Completed **Results:** Satisfying **Result note:**	**Concept 31** **Status:** Completed **Results:** Satisfying **Result note:**

Test ID	**Req ID**	**Test type**	**Priority**
T1.S10	S10	Visual	A

Requirement to test:
The bleed system shall be clear of wiring and piping within the housing.
Test procedure:
Use the 3D model received from D-R and se that the bleed system clears the structures inside the housing.
Acceptance criteria
No interaction of components does occur.
Equipment:
Solidworks

Concept 16 **Status:** not performed **Results:** not performed **Result note:** We do not have a 100% accurate 3D-model to test it.	**Concept 30** **Status:** not performed **Results:** not performed **Result note:** We do not have a 100% accurate 3D-model to test it.
Concept 29 **Status:** not performed **Results:** not performed **Result note:** We do not have a 100% accurate 3D-model to test it.	**Concept 31** **Status:** not performed **Results:** not performed **Result note:** We do not have a 100% accurate 3D-model to test it.

Test ID	Req ID	Test type	Priority
T1.S11	S11	SolidWorks	A

Requirement to test:
The bleed system must use the existing access point to the exhaust if leaded to the exhaust.
Test procedure:
Must see that these access points is possible to use when working on a concept that uses the exhaust as an outlet of the bleed system.
Acceptance criteria:
The access points to the exhaust must be available.
Equipment:
SolidWorks

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 does not dump the bleed air into the exhaust.	**Concept 29** **Status:** not needed **Results:** not needed **Result note:** concept 29 does not dump the bleed air into the exhaust.
Concept 30 **Status:** not needed **Results:** not needed **Result note:** concept 30 does not dump the bleed air into the exhaust.	**Concept 31** **Status:** not needed **Results:** not needed **Result note:** concept 31 does not dump the bleed air into the exhaust.

Test ID	Req ID	Test type	Priority
T1.S13	S13	Solidworks	A

Requirement to test:
If the bleed line A42 is led to the exhaust it needs to be connected to the outlet with the check valve.
Test procedure:
Check the 3D model that it contains a check valve.
Acceptance criteria:
A check valve must be installed to prevent back pressure from exhaust.
Equipment:
Solidworks

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 does not dump the bleed air into the exhaust.	**Concept 29** **Status:** not needed **Results:** not needed **Result note:** concept 29 does not dump the bleed air into the exhaust.
Concept 30 **Status:** not needed **Results:** not needed **Result note:** concept 30 does not dump the bleed air into the exhaust.	**Concept 31** **Status:** not needed **Results:** not needed **Result note:** concept 31 does not dump the bleed air into the exhaust.

Test ID	Req ID	Test type	Priority
T1.S15	S15	Visual	A

Requirement to test:
Valve A42 leaded out of the enclosure within the pipe of valve A43, A44 and A51 shall not have any leakage between them.
Test procedure:
See if there is openings between connection points in bleed system.
Acceptance criteria:
After visual check and no openings is found.
Equipment:
Solidworks
Note:

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 does not dump the bleed air into the exhaust.	**Concept 29** **Status:** Completed **Results:** Satisfying **Result note:**
Concept 30 **Status:** not needed **Results:** not needed **Result note:** concept 30 does not dump the bleed air into the exhaust.	**Concept 31** **Status:** not needed **Results:** not needed **Result note:** concept 31 does not dump the bleed air into the exhaust.

Test ID	Req ID	Test type	Priority
T1.S16	S16	D-R approval	A

Requirement to test:
D-R shall approve it when the bleed system requires the four inspection doors to be moved.
Test procedure:
When working on a concept that needs the inspection doors to be moved, we must contact D-R for approval.
Acceptance criteria:
An approval from D-R.
Equipment:
D-R.
Note:

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 does not require a inspection door to be moved	**Concept 29** **Status:** not needed **Results:** not needed **Result note:** concept 29 does not require a inspection door to be moved
Concept 30 **Status:** not needed **Results:** not needed **Result note:** concept 30 does not require a inspection door to be moved	**Concept 31** **Status:** not needed **Results:** not needed **Result note:** concept 31 does not require a inspection door to be moved

Test ID	Req ID	Test type	Priority
T1.S17	S17	Weight measurement	A

Requirement to test:
Parts of the bleed system manual lifted by the crew during service shall not exceed 25kg.
Test procedure:
With SolidWorks' mass property feature the weight of all parts that need to be disassembled is measured.
Acceptance criteria:
All parts that are needed to be disassembled manually during maintenance are within 25kg.
Equipment:

SolidWorks **Note:**	
Concept 16 **Status:** completed **Results:** satisfying **Result no te:**	**Concept 29** **Status:** completed **Results:** satisfying **Result note:**
Concept 30 **Status:** Completed **Results:** Satisfying. **Result note:**	**Concept 31** **Status:** completed **Results:** satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T2.S21	S21	Hand calc	A

Requirement to test:
The backpressure in the bleed system valve A43, A44 and A51 together shall be maximum 70 kPa.
Test procedure:
A hand calculation of back pressure in the system shall be performed.
Acceptance criteria:
The configuration and specifications of the system allows for the maximum flow without creating a pressure above 70 kpa.
Equipment:

Note: The test method used is not correct.

Concept 16 **Status:** Complete **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.	**Concept 29** **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.
Concept 30 **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report	**Concept 31** **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.

Test ID	Req ID	Test type	Priority
T1.S22	S22	Hand calculation	A

Requirement to test:
The back pressure from valve 42 shall be maximum 24 kPa.
Test procedure:
A hand calculation shall be performed to measure back pressure.
Acceptance criteria:
The configuration and specifications of the system allows for the maximum flow without creating a pressure above 24 kpa.
Equipment:

Note: **The test method used is not correct.**

Concept 16 **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.	**Concept 29** **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.
Concept 30 **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.	**Concept 31** **Status:** Completed **Results:** Was Satisfying, but has been invalidated due to a wrong test method. **Result note:** More detailed results in report.

Test ID	Req ID	Test type	Priority
T1.S29	S29	Visual	A

Requirement to test:
All parts of the system lighter than 25 kg shall be reachable for a person from the operation area.
Test procedure:
Measurementation of dimensions and weight, and placement for the relevant parts shall be taken, and evaluated for the purpose of reaching.
Acceptance criteria:
The measurements shall make the parts convenient to reach.
Equipment:

Solidworks

Concept 16 **Status:** completed **Results:** satisfying **Result note:** Removal of some parts of the system require a ladder in an allowable height.	**Concept 29** **Status:** Not completed **Results:** Not satisfying **Result note:**
Concept 30 **Status:** completed **Results:** satisfying **Result note:** Removal of some parts of the system require a ladder in an allowable height	**Concept 31** **Status:** completed **Results:** satisfying **Result note:** Removal of some parts of the system require a ladder in an allowable height.

Test ID	Req ID	Test type	Priority
T1.S33	S33	Standard analysis	A

Requirement to test:
The bleed system shall have parts regulated in international standards.
Test procedure:
An analysis of which standard parts of the system shall be performed with the help of DIN
Acceptance criteria:
As many parts as possible should be used from DIN as possible.
Equipment:
DIN

Concept 16 **Status:** Completed **Results:** acceptance criteria met **Result note:** This is the case where possible.	**Concept 29** **Status:** Completed **Results:** Not satisfying. **Result note:** Some of the pipes in the manifold does not have standardized bends. Special order parts is recommended.
Concept 30 **Status:** Completed **Results:** Not satisfying **Result note:** Some bends are not standardised. Also size of pipes must be controlled with NS standards.	**Concept 31** **Status:** Completed **Results:** Not satisfying **Result note:** The manifold has to be custom made.

Test ID	Req ID	Test type	Priority
T1.S35	S35	Visual inspection	A

Requirement to test:
The bleed system can be designed for left side crane, but shall then also be designed for right hand side.
Test procedure:
A visual inspection of the space inside the housing shall be performed concerning the possibility of a mirrored system.
Acceptance criteria:
There shall be the possibility of a mirroring version of the system.
Equipment:
Solidworks.

Concept 16 **Status:** not needed **Results:** not needed **Result note:** The system is designed for a right side crane.	**Concept 29** **Status:** Not needed **Results:** Not needed **Result note:** Concept 29 is a center based system.
Concept 30 **Status:** Completed **Results:** The system can be designed for right side crane. **Result note:** It might be necessary to move inspection doors ref req. T1S16.	**Concept 31** **Status:** not needed **Results:** not needed **Result note:** The system is designed for a right side crane.

Test ID	Req ID	Test type	Priority
T1.S36	S36	Visual inspection	A

Requirement to test:
The bleed system can be designed for right hand side crane, but shall then also be designed for left side.
Test procedure:
A visual inspection of the space inside the housing shall be performed concerning the possibility of a mirrored system.
Acceptance criteria:
There shall be the possibility of a mirroring version of the system.

Equipment:
Solidworks.

Concept 16 **Status:** Completed **Results:** The system can be designed for left side crane. **Result note:** will require another solution for supporting bends, and there will be more back pressure build up because the combined flow from A51 and A43 will have a longer flowpath	**Concept 29** **Status:** Not needed **Results:** Not needed **Result note:** Concept 29 is a center based system.
Concept 30 **Status:** Completed **Results:** The system can be designed for left side crane	**Concept 31** **Status:** Completed **Results:** Approved **Result note:** Works for both sides

Test ID	Req ID	Test type	Priority
T1.S37	S37	Integration test	A

Requirement to test:
The crane shall move freely of parts of the bleed system left after disassembly in the enclosure.
Test procedure:
With the use of CAD software a visual measurement is performed.
Acceptance criteria:
There is no collision between the bleed system and the maintenance crain.
Equipment:
Solidworks

Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**	**Concept 29** **Status:** Completed **Results:** Satisfying **Result note:**
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:**	**Concept 31** **Status:** Completed **Results:** Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S47	S47	Hand calc	A

Requirement to test:
The bleed system outlet shall in total be able to handle the combined air in amounts of [redacted] kg/s.
Test procedure:
Hand calculations to calculate the outlet flow in the system shall be performed.
Acceptance criteria:
The configuration of the bleed system shall not allow for a pressure build up of more than 24 kPa.

Concept 16 **Status:** not needed **Results:** not needed **Result note:** concept 16 does not combine all the flows.	**Concept 29** **Status:** Not complete **Results:** Not satisfying **Result note:**
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:**.More detailed results in report.	**Concept 31** **Status:** Not complete **Results:** Not satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S49	S49	Hand calc	A

Requirement to test:
The bleed system shall handle bleed air from valves combined A43, A44, and A51 in amount of [redacted] kg/s.
Test procedure:
Use hand calculations to calculate the forces created by the flow.
Acceptance criteria:
See that no force from air flow destroys the bleed system.
Equipment:

Concept 16 **Status:** not completed **Results:** not satisfying **Result note:** Not prioritised	**Concept 29** **Status:** not completed **Results:** not satisfying **Result note:** Not prioritised

Concept 30 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in report.	**Concept 31** **Status:** not completed **Results:** not satisfying **Result note:** Not prioritised

Test ID	Req ID	Test type	Priority
T1.S50	S50	Hand calc	A

Requirement to test:
The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.
Test procedure:
Use hand calculations to find forces created by the flow.
Acceptance criteria:
See that no force from air flow destroys the bleed system.
Equipment:

Concept 16 **Status:** not performed **Results:** not satisfying **Result note:** Not prioritised	**Concept 29** **Status:** not performed **Results:** not satisfying **Result note:** Not prioritised
Concept 30 **Status:** not performed **Results:** not satisfying **Result note:** Not prioritised	**Concept 31** **Status:** not performed **Results:** not satisfying **Result note:** Not prioritised

Test ID	Req ID	Test type	Priority
T1.S69	S69	Hand calc/FEM	A

Requirement to test:
The bleed system shall be able to withstand the loads associated with shipping.
Test procedure:
Need to do hand calculations and simulations in solidworks on the prosedure shipping. During shipping forces acts on the already mounted parts of the bleed system and it needs to be properly secured
Acceptance criteria:

The secured method withstands the forces that arises when shipped. **Equipment:** Data sheet with information from forces occurring during shipping, Solidworks simulations and hand calculations. **Note:** Not performed

Test ID	Req ID	Test type	Priority
T1.S81	S81	Visual Test	A

Requirement to test:
There shall be room enough for a standard service person to access every part of the turbine needed for service.
Test procedure:
A visual test shall be performed on the 3D model. The clearance and room around the bleed system shall be measured.
Acceptance criteria:
The room in any direction around the floor based boom vertical beam shall be more than 225mm.
Equipment:
Solidworks

Concept 16 **Status:** Test completed **Results:** satisfying **Result note:**	**Concept 29** **Status:** Test completed **Results:** satisfying **Result notes:**
Concept 30 **Status:** Test completed **Results:** satisfying **Result notes:**	**Concept 31** **Status:** Test completed **Results:** satisfying **Result notes:**

Test ID	Req ID	Test type	Priority
T1.S82	S82	Visual Test	A

Requirement to test:
There shall not be any collision between parts of the bleed system and the turbine during removal of the turbine.
Test procedure:

A visual test will be performed by a visual test. The distance between the turbine and the closest parts of the bleed system will be mesures. For this test the turbine needs to be in the position it is in after it has been lifted up, but before it is removed from the turbine enclosure.
Acceptance criteria:
There is 200mm between the turbine and the bleed system.
Equipment:
Solidworks

Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**	**Concept 29** **Status:** Not completed **Results:** Not satisfying **Result notes:**
Concept 30 **Status:** Completed **Results:** Satisfying **Result notes:**	**Concept 31** **Status:** Not completed **Results:** Not satisfying **Result notes:**

Test ID	Req ID	Test type	Priority
T1.S86	S86 - D13	Hand calculation	A

Requirement to test:
All structural parts of the system shall be able to handle the loads associated with weight.
Test procedure:
A hand calculation will be performed.
Acceptance criteria:
The booms shall be rigid enough to handle the stress.
Equipment:
Pen
paper
literature: statikk og fasthetslære (vollen), Mechanics of materials (Hibbeler)

Concept 16 **Status:** Only partly completed **Results:** Not satisfying **Result note:** A test is performed to analyse the loading in one part of the system. The rest remains. See test report for complete analysis.	**Concept 29** **Status:** Not completed **Results:** Not satisfying **Result notes:**
Concept 30	**Concept 31**

Status: not performed **Results:** not satisfying **Result note:** Not prioritised	**Status:** Not completed **Results:** Not satisfying **Result notes:**

4.4.2 Test Phase b

Test ID	Req ID	Test type	Priority
T1.S1	S1	FEM	A

Requirement to test:
The gas generator interface shall move during expansion with at least 4 mm radial.
Test procedure:
With the use of FEM software, analyse radial heat expansion of the interface part.
Acceptance criteria:
No external forces, stress or moments imposed to the gas generator interface.
Equipment:
SolidWorks
Note:

Concept 16
Status: Not needed
Results: Not Needed.
Resnote: Acceptance criteria satisfied by T1.S88, T1S84, and T1.S85.

Concept 30
Status: Completed
Results: Satisfying
Result note: Interface joint is designed with a 10mm radial gap.

Test ID	Req ID	Test type	Priority
T1.S2.	S2.	FEM	A

Requirement to test:
The gas generator interface shall move during expansion with at least 8 mm axial.
Test procedure:

With the use of FEM software analyse axial heat expansion of the interface part. **Acceptance criteria:** No external forces - Stress or moments imposed to the gas generator interface. **Equipment:** SolidWorks **Note:**
Concept 16 **Status:** Not needed **Results:** Not Needed. **Result note:** Acceptance criteria satisfied by T1.S88, T1S84, and T1.S85.
Concept 30 **Status:** Completed **Results:** Not satisfying **Result note:** More detailed results in report.

Test ID	**Req ID**	**Test type**	**Priority**
T2.S7	S7	FEM	A
Requirement to test: External bleed system shall be clear of other components on top of housing. **Test procedure:** With the use of FEM we test if heat expansion is sufficient to make components collide. **Acceptance criteria:** No interaction of components does occur. **Equipment:** SolidWorks **Note:**			
Concept 16 **Status:** Not needed **Results:** Not needed **Result note:** The clearance was sufficient. It was therefore no need for the test.			
Concept 30 **Status:** Not needed **Results:** Not needed **Result note:** The clearance was sufficient. It was therefore no need for the test.			

Test ID	Req ID	Test type	Priority
T1.S19	S19	FEM thermal properties	A

Requirement to test:
The parts of the bleed system from valve 43, 44 and 51 shall withstand [redacted] degrees celsius during the whole operation time.
Test procedure:
With FEM the an thermal analysis is performed to control the properties of the materials and configuration of the system during a high temperature.
Acceptance criteria:
The whole system keeps its necessary properties for function during [redacted] degrees celsius.
Equipment:
Solidworks
Note:

Concept 16
Status: Not Needed
Results: Not Needed
Result note: All materials can withstand over [redacted] degrees celsius.

Concept 30
Status: Not Needed
Results: Not Needed
Result note:. All materials can withstand over [redacted] degrees celsius.

Test ID	Req ID	Test type	Priority
T1.S20	S20	Data from supplier	A

Requirement to test:
The parts of the bleed system from valve A 42 shall withstand [redacted] degree celsius during the whole operation time.
Test procedure:
Collect current data from supplier.
Acceptance criteria:
Shown data that accept the thermal limit value and duration.
Equipment:
Data sheet from supplier.
Note:

Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S21	S21 - D48, D54, D55	FEM Fluid analysis	A
Requirement to test: The backpressure in the bleed system valve A43, A44 and A51 together shall be maximum 70 kPa. **Test procedure:** A fluid dynamic analysis with solidwork simulation will be performed. **Acceptance criteria:** The configuration and specifications of the system allows for the maximum flow without creating a pressure above 70 kpa. **Equipment:** Solidworks **Note:**			
Concept 16 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in test report			
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in report.			

Test ID	Req ID	Test type	Priority
T2.S22	S22	FEM	A
Requirement to test: The back pressure from valve 42 shall be maximum 24 kPa. **Test procedure:**			

A fluid dynamic analysis with solidwork simulation will be performed. **Acceptance criteria:** The configuration and specifications of the system allows for the maximum flow without creating a pressure above 24 kpa. **Equipment:** Solidworks simulation. **Note:**
Concept 16 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in report.
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in report.

Test ID	Req ID	Test type	Priority
T1.S23	S23	visual	A
Requirement to test: It shall not be possible to reach parts of the bleed system with temperatures exceeding 70 degrees celsius. **Test procedure:** Using FEM relevant components are located and the accessibility for humans to the parts are analysed. **Acceptance criteria:** All parts accessible to humans with temperatures over 70 degrees celsius during operation shall be located. **Equipment:** Solidworks **Note:**			
Concept 16 **Status:** completed **Results:** Satisfying **Result note:**			
Concept 30 **Status:** completed			

Results: Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S24	S24	visual	A

Requirement to test:
It shall not be possible to reach parts of the bleed system with temperatures below -10 degrees
Test procedure:
Using FEM relevant components are located and the accessibility for humans to the parts are analysed.
Acceptance criteria:
All parts accessible to humans with temperatures under -10 degrees celsius during operation shall be located.
Equipment:
Solidworks
Note:

Concept 16
Status: completed
Results: satisfying
Result note:

Concept 30
Status: completed
Results: satisfying
Result note:

Test ID	Req ID	Test type	Priority
T1.S25	S25	Sound analysis	A

Requirement to test:
The individual employee’s maximum exposure to noise during a 12 hours working day is 83db.
Test procedure:
Analysis with an hand calculation of sound levels in the intersection between the system and the environment.
Acceptance criteria:
The sound levels coming from the bleed system with the input of stable operation of the turbine should not exceed 83db.

Equipment: Unknown Software. **Note:**
Concept 16 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritised, and too complicated.
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritised, and too complicated.

Test ID	Req ID	Test type	Priority
T1.S26	S26	Sound Analysis	A
Requirement to test: The maximum allowable noise level in any situation is 130 dB **Test procedure:** Analysis with a hand calculation of sound levels in the intersection between the system and the environment. **Acceptance criteria:** The sound levels coming from the bleed system of all inputs of operation of the turbine should never exceed 130dB. **Equipment:** Unknown Software. **Note:** Not completed			

Test ID	Req ID	Test type	Priority
T1.S27	S27	Visual inspection	A
Requirement to test: All edges of the system shall be be round **Test procedure:** A visual inspection shall be performed on the 3D model of the system **Acceptance criteria:** All edges of the system are within the limit. **Equipment:**			

Solidworks **Note:**
Concept 16 **Status:** Completed **Results:** Satisfying **Result note:** 3D-model does not include this, to be easier to work with.
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:** 3D-model does not include this, to be easier to work with.

Test ID	Req ID	Test type	Priority
T1.S28	S28	Visual/mockup	A
Requirement to test: All parts of the system lighter than 25 kg shall be manageable to lift without causing strain on the person. **Test procedure:** Measurementation of dimensions and weight for the relevant parts shall be taken, and evaluated for the purpose of lifting. A mockup model of the part may be made representing the dimensions and weight of the part, and the possibility of lifting can be tested in a physical test. **Acceptance criteria:** The measurements shall make the parts convenient to lift. There shall be a possibility of picking up the mockup without straining the body. **Equipment:** Solidworks **Note:**			
Concept 16 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritised			
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritised			

Test ID	Req ID	Test type	Priority

T1.S30	S30	Financial analysis	A

Requirement to test:
The total cost of the bleed system cannot exceed 20 000 dollars without the maintenance cost
Test procedure:
A financial budget is to be produced for the whole system. Using relevant part catalogues and industry standards.
Acceptance criteria:
The sum of cost for production and assembly of all the parts in the system is under 20 000 dollars.
Equipment: Part cataloges, industry standards
Note:

Concept 16
Status: completed
Results: Not Satisfying
Result note: Se technology document for detailed cost analysis.

Concept 30
Status: completed
Results: Satisfying
Result note: Se technology document for detailed cost analysis.

Test ID	Req ID	Test type	Priority
T1.S31	S31	Financial analysis	A

Requirement to test:
The bleed system shall cost maximum 1000 dollars in maintenance parts cost every 26280 hours
Test procedure:
A financial budget is to be produced for changeable parts of the system during maintenance (if any). Using relevant part catalogues and industry standards.
Acceptance criteria:
The sum of cost for Parts that need to be changed during maintenance (if any) shall not exceed 1000 dollars
Equipment:
Part cataloges, industry standards
Note:

Concept 16
Status: Not completed

Results: Not satisfying **Result note:** Not prioritised
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritised

Test ID	Req ID	Test type	Priority
T1.S32	S32	Financial analysis	B

Requirement to test:
Cost of transportation shall not cost more than current system.
Test procedure:
A financial budget for transportation is to be produced for the whole system. Using information from suppliers of D-R-
Acceptance criteria:
The total amount for transportation of all parts included in the bleed system does not exceed the amount for the existing system.
Equipment:
Supply catalogs
Note:

Concept 16
Status: Not completed
Results: Not satisfying
Result note: Not prioritised

Concept 30
Status: Not completed
Results: Not satisfying
Result note: Not prioritised

Test ID	Req ID	Test type	Priority
T1.S38	S38	Assembly simulation	A

Requirement to test:
The bleed system shall take not more than 30 min to remove.
Test procedure:
With CAD software a motion study will be performed to simulate the assembly time. This study will be based on knowledge from actual service employees.

Acceptance criteria: The duration of the motion study shall not exceed 30 min. **Equipment:** Solidworks **Note:**
Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S39	S39	Assembly simulation	A
Requirement to test: The bleed system shall take not more than 30 min to install. **Test procedure:** With CAD software a motion study will be performed to simulate the assembly time. This study will be based on knowledge from actual service employees. **Acceptance criteria:** The duration of the motion study shall not exceed 30 min. **Equipment:** Solidworks **Note:**			
Concept 16 **Status:** Completed **Results:** Satisfying **Result note:**			
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:**			

Test ID	Req ID	Test type	Priority

T1.S42	S42	FEM	A
Requirement to test: The bleed system shall cool down to 70 degrees celsius within 240 minutes. **Test procedure:** With FEM we perform a thermal conductivity test together with the gas turbine. **Acceptance criteria:** The resulting time of cool down from the gas turbine input is below 240 minutes. **Equipment:** Solidworks **Note:**			
Concept 16 **Status:** Not completed **Results:** Not satisfying **Result note:** This test was not prioritised.			
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** This test was not prioritised.			

Test ID	Req ID	Test type	Priority
T1.S43	S43	Checkup	A
Requirement to test: The bleed system shall have Instructions in the standard of … for disassembly during maintenance. **Test procedure:** A third party member will be asked to read the instructions for feedback. **Acceptance criteria:** Every section of the instructions shall be understood by the reader. **Equipment:** **Note:**			
Concept 16 **Status:** Not completed **Results:** not satisfying **Result note:** A service manual is not made for C16, due to a request for only C30.			
Concept 30			

Status: Completed
Results: Satisfying
Result note:

Test ID	Req ID	Test type	Priority
T1.S46	S46	FEM/hand calc	A

Requirement to test:
The system shall sustain 26280 hours without maintenance.
Test procedure:
An fatigue test will be performed using FEM, and hand calculation (if possible)
Acceptance criteria:
The configuration and materials used in the system are not critically affected by working conditions after 26280 hours.
Equipment:
Solidworks
Note:

Concept 16
Status: Not completed.
Results: Not satisfying.
Result note:

Concept 30
Status: Not completed.
Results: Not satisfying.
Result note:

Test ID	Req ID	Test type	Priority
T2.S47	S47	FEM fluid analysis	A

Requirement to test:
The bleed system in total shall be able to handle bleed air in amounts of [redacted] kg/s.
Test procedure:
An FEM fluid will be performed.
Acceptance criteria:
The configuration of the bleed system shall not allow for a pressure build up of more than 24 kPa.
Equipment:
SolidWorks

Note:
Concept 16 **Status:** Not needed **Results:** Not needed **Result note:** Consept 16 does not combine all of the flows.
Concept 30 **Status:** Completed **Results:** Satisfying **Result note:** More detailed results in report.

Test ID	Req ID	Test type	Priority
T1.Fs	S48	FEM	A

Requirement to test:
The bleed system shall handle bleed air from valve A42 in amount of [redacted] kg/s.
Test procedure:
Use solidworks simulation to check that the bleed system withstands the given amount of flow.
Acceptance criteria:
See that no force from air flow destroys the bleed system.
Equipment:
Solidworks simulation.
Note:
Not completed

Test ID	Req ID	Test type	Priority
T2.S50	S50	FEM	A

Requirement to test:
The part of the bleed system connected to valve A43 shall handle flow of [redacted] kg/s.
Test procedure:
Use solidworks simulation to check that the bleed system withstands the given amount of flow.
Acceptance criteria:
See that no force from air flow destroys the bleed system.
Equipment:
Solidworks simulation.
Note:

Concept 16 **Status:** only partly completed **Results:** not satisfying **Result note:** More detailed results in report.
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritized.

Test ID	Req ID	Test type	Priority
T1.S52	S52	SolidWorks	C
Requirement to test: There shall be considered using the stainless steel SS-316 in the bleed system **Test procedure:** Choose SS-316 Steel form the material list in solidworks. **Acceptance criteria:** Use of SS-316 Steel when possible. **Equipment:** Solidworks **Note:** It is possible to use other materials but the choice must be justified.			
Concept 16 **Status:** completed **Results:** Satisfying **Result note:**			
Concept 30 **Status:** completed **Results:** Satisfying **Result note:**			

Test ID	Req ID	Test type	Priority
T1.S53	S53	SolidWorks	C
Requirement to test: There shall be considered using the stainless steel SS-316L if there is weldings in the material. **Test procedure:**			

Choose SS-316L Steel form the material list in solidworks. **Acceptance criteria:** Use of SS-316L Steel when possible. **Equipment:** Solidworks **Note:** It is possible to use other materials but the choice must be justified.
Concept 16 **Status:** completed **Results:** Satisfying **Result note:**
Concept 30 **Status:** completed **Results:** Satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S55	S55	SolidWorks	A
Requirement to test: The solutions shall be presented in the form of a 3D model. **Test procedure:** Use solidworks to draw the 3D models. **Acceptance criteria:** Finished 3D models designed in solidworks. **Equipment:** SolidWorks. **Note:**			
Concept 16 **Status:** completed **Results:** Satisfying **Result note:**			
Concept 30 **Status:** completed **Results:** Satisfying **Result note:**			

Test ID	Req ID	Test type	Priority
T1.S56	S56	Visual	A

Requirement to test:
The 3D model shall have supporting documentation.
Test procedure:
Check that requirements are fulfilled and the accompanying documentation exists.
Acceptance criteria:
All the needed documentation exists.
Equipment:
Data produced in this thesis.
Note:

Concept 16
Status: completed
Results: Satisfying
Result note:

Concept 30
Status: completed
Results: Satisfying
Result note:

Test ID	Req ID	Test type	Priority
T1.S57	S57	Checkup	A

Requirement to test:
The concept shall have manuals for service.
Test procedure:
Making manuals that shows the installation step by step.
Acceptance criteria:
Manuals that are understandable and shows the information needed for proper assembly and disassembly and the correct use of the system.
Equipment:
Use Word to write the manuals and use Solidworks to make explode pictures of assembly and disassembly
Note:

Concept 16
Status: not completed

Results: not satisfying **Result note:** there was a request from D-R for service manuals only for C30.
Concept 30 **Status:** completed **Results:** satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S58	S58	checkup	A
Requirement to test: The concept shall have understandable manuals for installation and use. **Test procedure:** A third party member will be asked to read the manual for feedback. **Acceptance criteria:** Every section of the manual shall be understood by the reader. **Equipment:** **Note:** Not completed			

Test ID	Req ID	Test type	Priority
T1.S65	S65	Norsok Standard S-003	A
Requirement to test: All the materials are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003). **Test procedure:** Information on proper handling of the various materials for the concept's life. **Acceptance criteria:** Understandable guide on handling the material in a proper way that follows Norsok Standard S-003. **Equipment:** Norsok Standard S-003, environmental care. **Note:** Not needed. We did not work with any physical parts or substances during the project.			

Test ID	Req ID	Test type	Priority
T1.S66	S66	Norsok Standard S-003	A

Requirement to test:
All the substances are treated properly in accordance with Norsok (Norsok Standard S-003, Des 2003).
Test procedure:
Information on proper handling of the various substances for the concept's life.
Acceptance criteria:
Understandable guide on handling the substances in a proper way that follows Norsok Standard S-003.
Equipment:
Norsok Standard S-003, environmental care.
Note:
Not needed. We did not work with any physical parts or substances during the project.

Test ID	Req ID	Test type	Priority
T1.S67	S67	FEM/hand calc	A

Requirement to test:
The bleed system shall last for minimum 25 years.
Test procedure:
An tension test will be performed using FEM, and hand calculation (if possible)
Acceptance criteria:
The configuration and materials used in the system are not critically affected by working conditions after 25 years of operation. Besides changeable parts during main service.
Equipment:
Solidworks
Note:
Not satisfying, too complicated.

Test ID	Req ID	Test type	Priority
T1.S83	S83	Control datasheets	A

Requirement to test:
All components in touch with the flow of the (A43, A44, A51) part of the bleed system shall be able to handle [redacted] degrees celsius.
Test procedure:

The different components used in the system shall be controlled by looking at data sheets from the producers of the components. **Acceptance criteria:** All parts used can withstand more than [redacted] degrees celsius. **Equipment:** Datasheets **Note:**
Concept 16 **Status:** completed **Results:** satisfying **Result note:**
Concept 30 **Status:** completed **Results:** satisfying **Result note:**

Test ID	Req ID	Test type	Priority
T1.S84	S84 - D35,D34	Fem Analysis	A
Requirement to test: Parts of the system that are fixed shall be able to withstand the stresses from the heat expansion. **Test procedure:** A thermal stress analysis will be performed in solidworks simulation. **Acceptance criteria:** The expansion for fixed features shall not lead to stresses above the the yield strength of the material, and stretches utilizing expansion joints shall be within the limits of properties for buyable expansion joints. **Equipment:** Solidworks - Thermal analysis solidworks - static analysis **Note:**			
Concept 16 **Status:** completed **Results:** satisfying **Result note:** See test report for complete analysis.			
Concept 30 **Status:** Not completed **Results:** Not satisfying			

Result note: Not prioritized

Test ID	Req ID	Test type	Priority
T1.S85	S85 - D32	Fem Analysis	A
Requirement to test: parts of the system that are partly free to move shall be able to expand enough to not cause stresses above yield strength of the material. **Test procedure:** A thermal stress analysis will be performed in solidworks simulation. **Acceptance criteria:** The expansion of the relevant parts shall not exceed yield strength of the material. **Equipment:** Solidworks - Thermal analysis Solidworks - static analysis **Note:**			
Concept 16 **Status:** completed **Results:** satisfying **Result note:** See test report for complete analysis.			
Concept 30 **Status:** Completed **Results:** Not satisfying **Result note:** See test report for complete analysis.			

Test ID	Req ID	Test type	Priority
T1.S87	S87	Flow analysis + static analysis	A
Requirement to test: All structural parts of the system shall be able to handle the loads associated with the flow from the turbine. **Test procedure:** A fluid analysis will be performed to find the force acting on the piping system, and then a static analysis will determine the stress in the structural system. **Acceptance criteria:** The safety factor against yielding of the material is below 2,5 **Equipment:** Solidworks - thermal analysis			

solidworks - static analysis **Note:**
Concept 16 **Status:** only partly completed **Results:** not satisfying **Result note:** See test report for complete analysis.
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritized.

Test ID	Req ID	Test type	Priority
T1.S88	S88	Thermal analysis and static analysis	A
Requirement to test: the A42 part of the system shall be able to handle a heat expansion of 2mm/meter pipe. **Test procedure:** A thermal stress analysis will be performed in solidworks simulation. **Acceptance criteria:** The expansion for fixed features shall not lead to stresses above the the yield strength of the material, and stretches utilizing expansion joints shall be within the limits of properties for buyable expansion joints. **Equipment:** Solidworks - thermal analysis solidworks - static analysis **Note:**			
Concept 16 **Status:** completed **Results:** satisfying **Result note:** See test report for complete analysis.			
Concept 30 **Status:** Not completed **Results:** Not satisfying **Result note:** Not prioritized.			

4.4.4 Deleted tests

Along the way many of the planned tests have been deleted. This is in accordance to the deleted requirements, which will be found in the requirements specification.

Test ID	Req ID	Test type	Priority
T1.S14	S14	Checkup	?-A
Requirement to test: If the bleed valve 42 opens simultaneously with valve 51, 43 and 44 the bleed air can not be led into the housing ventilation duct.			

Test ID	Req ID	Test type	Priority
T1.S6	S6	Visual	c-?
Requirement to test: External bleed system outside blocking the maintenance door shall be mounted with fixtures with quick release.			

Test ID	Req ID	Test type	Priority
T1.S18	S18	FEM thermal fluid sim	b-A
Requirement to test: The maximum temperature released from the housing shall not exceed 70 degrees.			

Test ID	Req ID	Test type	Priority
T1.S45	S45	FEM	c-
Requirement to test: The system shall have risk assessment for at least two critical components in the bleed system.			

Test ID	Req ID	Test type	Priority
T1.54	S54	FEM/hand calc	
Requirement to test: The material used shall withstand vibrations from the turbine.			

Test ID	Req ID	Test type	Priority
		Visual/mockup	b-A
Requirement to test: All parts of the system lighter than 25 kg shall be manageable to carry without causing strain on the person.			

Test ID	Req ID	Test type	Priority
T1.S40	S40	Research	
Requirement to test: The Fastening method shall always be the fastest possible.			

Test ID	Req ID	Test type	Priority
T2.S40	S40	FEM	
Requirement to test: The Fastening method shall always be the fastest possible.			

Test ID	Req ID	Test type	Priority
T1.S68	S68	Visual/measurements	
Requirement to test: The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.			

Test ID	Req ID	Test type	Priority
T1.S40	S40	Research	
Requirement to test: The Fastening method shall always be the fastest possible.			

Test ID	Req ID	Test type	Priority
T1.S59	S59	Data produced	
Requirement to test: The 1st priority is safety			

Test ID	Req ID	Test type	Priority
T1.S60	S60	Data produced	
Requirement to test: The 2nd priority is technical requirements			

Test ID	Req ID	Test type	Priority
T1.S61	S61	Data produced	
Requirement to test: The 3rd priority is time			

Test ID	Req ID	Test type	Priority
T1.S62	S62	Data produced	
Requirement to test: The 4th priority is cost			

Test ID	Req ID	Test type	Priority
T1.S68	S68	Data produced	
Requirement to test: The Bleed system shall not be in the way of any anchoring points for lifting of the turbine housing.			

Test ID	Req ID	Test type	Priority
T1.S76	S76		
Requirement to test: The material used between pipes and enclosure shall withstand [redacted] degree celsius.			

Test ID	Req ID	Test type	Priority
T1.S44	S44	Checkup	b-A
Requirement to test: The bleed system shall have instructions in standards of … for assembly during maintenance.			

5. References

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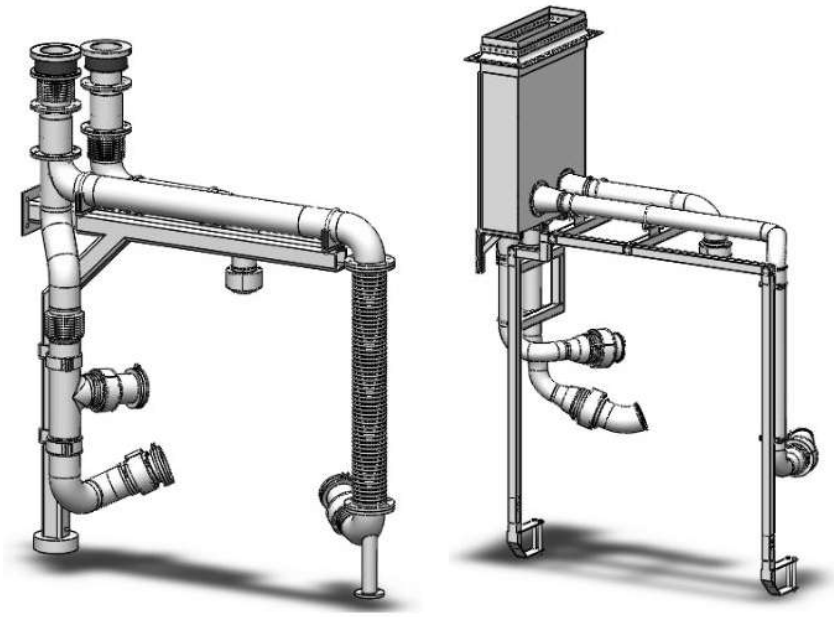
DRESSER-RAND

HSN University College of Southeast Norway

Concept Document

Gas Turbine Bleed System



Gruppe 19

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22.05.2017

Document History

Date	Version	Changes	Approved by
17.02.17	0.0	Created	Daniel
21.03.17	1.0	Approved for submission	Daniel
22.05.17	1.1	Small fixes	Kristian
22.05.17	2.0	Approved for publication	Kristian

Table of Contents

1. Introduction

The concept phase is a very important phase in this project. It is crucial that the we end up with some good concepts, so that we don't go through the whole project, only at the end discovering that the existing solution is better than the chosen concepts. Therefore a lot of time is spent inventing and developing concepts, to get the best foundation to choose the concepts to take into the next phase.

This document describes the process of inventing and selecting concepts, how we used the requirements during the process, the concepts under development and why they got selected or discarded. Much of the document is based on the concept phase, like the "Concept Selection Rounds" described later in the document. The concept development and selection continued in the design/test phase and is described in design/test phases, based on the a and b system from the test specification. The detailed development on the two final concept is then described in the technologi documents for each of the two concepts.

2. Concept Development Process

2.1 Invention of Concepts

To invent concepts the student group needed some basic information. The task itself, who should be involved in the project, and what guidelines would to be followed. This is where the requirements came in. The project is about the requirements, and all of the concepts have to fit the requirements set. In the beginning of the project many requirements are missing, and with the brainstorming of new ideas, the very same ideas are taken to D-R for evaluation. This meant some of the concepts would be excluded, both partly and total. And at the same time new problems where enlightened which lead to new requirements. In this way, the requirements were used and updated actively through the development.

The task of developing concepts has been an equally shared responsibility by the group members. In the beginning everyone took their ideas and brought them to the table in a brainstorming activity. The group focused on how to get the air away from the enclosure in the first round, which was followed by refinery of the concepts. Selection of the right concepts the group intertwined the information from D-R, with requirements, and picked out concepts with the best solutions. The invention of totally new concept ideas happened mainly in the beginning, with a lot of modification on these concepts through the rounds. There were some new concepts invented in the end of the selection round though that period was based mainly on developing the existing concepts.

2.2 Selection of Concepts

The concept selection work began at 9th of February lasted all the way to 9th of April, when we selected the final 2 concepts we recommend our company to use.

The selection rounds where intermediate stages in the Concept development phase, during which we brainstormed for concept ideas, and solutions, evaluate the ideas, and finally choose the concepts which show the most promise for the next selection round.

2.2.1 Concept Selection Round 1

This selection round took place during iteration round 2 of the project (09.02.2017-15.02.2017). The main purpose of the round was to create as many concepts as possible to have a variety of concepts to show Dresser-Rand, thereby getting more information on possibilities and limitations for the system. This made it easier to make new concepts and to develop existing concepts further.

Early in the first selection round the group found that many of the 18 initial concepts would be impossible to design to work in a functional way, so many concepts were discarded early in the round and were not described in detail in the concept overview because there were done very little development on them in that stage. Some of the initial concepts were developed further, and quite a lot of new concepts were made after the initial bunch. The preview showcase with Dresser-Rand marked the end of selection round 1, were we had a total of 16 concepts to show. After the preview showcase meeting (Not to be confused with the actual showcase, which is a milestone in the project) we had acquired new information about the turbine package that helped in the shortening of the number of concepts in round 2.

2.2.2 Concept Selection Round 2

This selection round happened during iteration round 3 of the project (16.02.2017-22.02.2017). Here it was important to develop the existing concepts further to make it easier to compare them in the end of the round. Some concepts were also made, because of the better understanding acquired and the new requirements generated during round 1, it was simpler to make relevant concepts.

In round two the group developed the concepts further and sketched several new ones before they compared them in a simple Pugh matrix. Essentially a Pugh matrix is a complex pros and cons diagram to compare different aspects of concepts in a quantitative way. The purpose was to shorten the concepts down before the actual showcase with Dresser-Rand (the milestone concept showcase). We managed to get down to 9 concepts. During the showcase the group got feedback on how feasible the concepts were. Right away after the showcase the concepts were shortened down to 7.

Underneath is the Pugh matrix we used in round 2. It shows how the concepts score on the different criteria we chose. There is given a weight between 2 and 5 on each criteria, based on how important they are to the system. Each concept is then given a score, -1, 0 or 1 depending on how well they scored on the criteria. The importance of the criteria is then multiplied with the scores of the concept and finally all the scores are added to each other and summed in the cell at the bottom. The concepts marked in red is concepts that did not make it to round 3, but everything is not discarded completely, some aspects have been taken further to another concept. As can be seen; a part of concept 20 is used in concept 34.

Simple Pugh Matrix																								
Criterias	Importance of Criteria	CON2 -Wall runner	C4	C11	CON16 - F1 pit stop	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	CON29 - Verical lift double pipe	CON30 - Truck duct	CON31 - F1 pit stop front vent	CON32 - F1 pit stop front vent with pipes	CON33 - Walk on duct	CON34 - Rise and Shine v2	CON35 - Floor pipe
Safety	5	1			1													0	0	1	0	1	0	1
Tecnical requirments	4	0			1													1	1	1	1	0	1	1
Time of maintanince	4	0			1													1	0	1	1	1	1	1
Affects space/accesabilety in housing	3	1			1													1	1	1	1	1	1	1
Cost of production*	2	1			−1													−1	0	0	0	0	−1	0
Consept scores		10	Fail	To 34	14	Fail	Fail	Fail	To 34	Fail	Fail	To 34	To 33	Fail	Fail	Fail	To 29	9	7	16	11	12	9	16

* Cost still needs to be within the cost requirments.

Diagram 1: Simple Pugh Matrix (Made in google disk by bachelor group).

2.2.3 Concept Selection Round 3

This selection round happened during iteration round 4 of the project (23.02.2017-08.03.2017). Here it was important to develop the concepts further and test them briefly so that they were easier to compare in a more detailed Pugh matrix that was performed in the end of the round, to be able to shorten down further on the selection. The goal was to get down to three concepts at the end of the round.

In this round the we focus more on the details of the concepts to find out which concepts had the advantages. We conducted a hand calculated pressure drop test on all the concepts using simplified formulas, there were many assumptions used, especially on the calculation of pipe, tube and hose bends. The results were that all the concepts were within the allowable range, but this must be tested more in detail later on to secure a reliable result

In the end, we ended up with four concepts. Even though the goal we set earlier was to go down to three. There were more concepts that could have followed to the next phase, but we had to make a choice, because we have limited time to finish the design on the final concepts. The idea of picking four was that we could design all simultaneously, with one concept for each group member to draw thereby saving time.

Detailed Pugh Matrix									
Criterias	Importance of Criteria	CON2 -Wall runner	CON16 - F1 pit stop	CON29 - Verical lift double pipe	CON30 - Truck duct	CON31 - F1 pit stop front vent	CON32 - F1 pit stop front vent with pipes	CON34 - Rise and Shine v2	CON36 - Twin duct
Maintainance time	32,50%	1	3	3	1	3	2	2	1
Lifespan*1	17,50%	2	1	3	3	2	3	2	3
Space/accessibilety*2	15,00%	2	3	3	2	3	3	3	1
Safety*3	10,00%	2	3	2	2	3	2	2	2
User fiendliness	10,00%	2	3	3	1	3	2	2	2
Cost of production/maintainance*4	7,50%	2	2	1	3	2	1	1	3
adaptabilety for both sides*5	5,00%	2	2	3	2	3	3	3	3
Recyclabilety	2,50%	2	1	2	3	1	3	2	3
Consept scores		1,675	2,475	2,725	1,85	2,7	2,325	2,125	1,315
		7	3	1	6	2	4	5	8
*1.) can it lead to unplaned production stop.									
*2.) Safety is weightet so low since all concepts are safe enough.									
*3.) Volume has to be considered along with location.									
*4.) maintenance cost conserns cost of spare parts.									
*5.) All have to have the possibility, but how difficult is it?									

Diagram 2: Detailed Pugh Matrix (Made in google disk by bachelor group).

The score of the detailed Pugh wasn't the only factor taken into consideration when we picked the final concepts. As can be seen above concept 30 is going to the next phase, even though it got a lower score than some of the concepts that were discarded. In addition to the score of the Pugh matrix the technical risk of the concepts was also taken into consideration when choosing the concepts. After the Pugh, we discussed the results and decided which concepts to take further with both the results of the Pugh and the discussion in mind.

2.2.3 Design/Testing Phase a

This period lasted for 2 weeks. And the focus was to get a rough feedback from the first 3D-designs which we built on in the following design phase. We had 4 design concepts to test. The test which we focused on in this test period were the ones that ware important for the configuration of the systems, and which provided a solid foundation to build on. Details of the designing were determined by the tests in the first test phase. We did not have time to conduct all the tests that were lucrative for this stage, so the most valuable were selected. In the End of this phase we had enough information gathered from the whole project to determine the 2 concepts we worked with towards the end of the project.

3. Concept Development

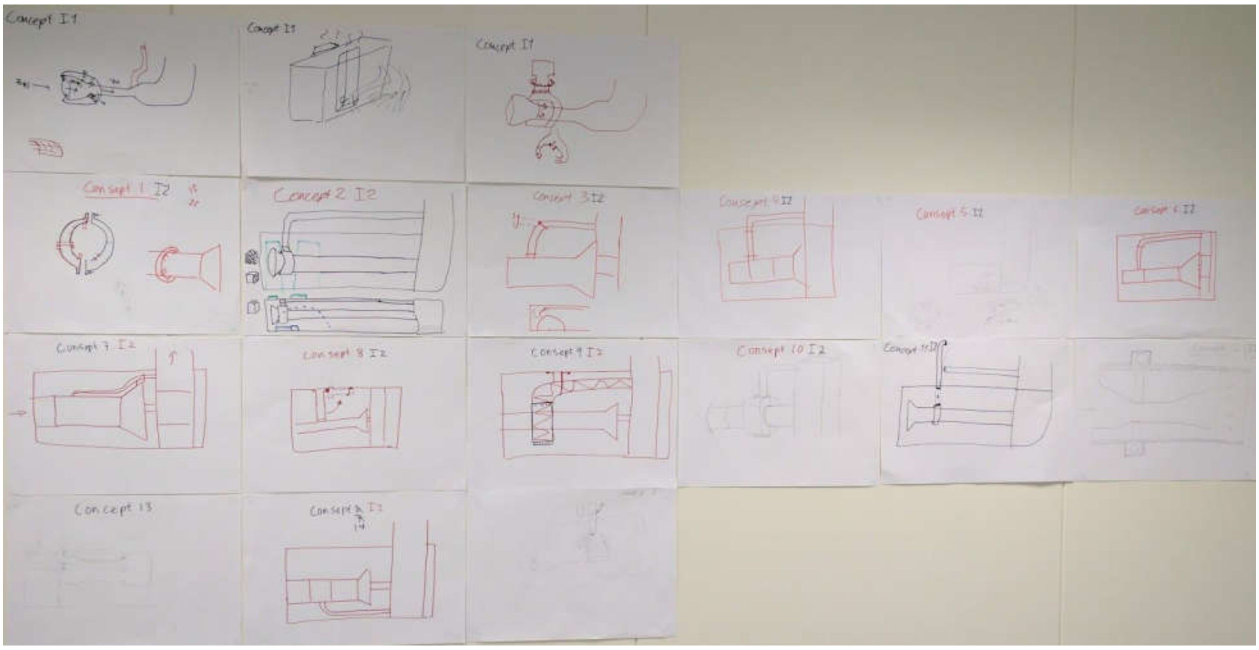
Under the concepts are discussed, divided into the selection rounds. Where the goal was to find the concepts to take into the design/test phase. Additionally, there was a possibility of coming up with new concepts in each selection round.

Below is an overview of the selection rounds. Row one is round 1, row two is round 2 and row three is round 3. Each row/round consists of all the concepts that was worked on that round. When a concept is marked in green it means it made it further to the next round, and the green ones in row/round three are the ones that went further to the design/test phase. The round where a concept is marked in red, is the round which it was discarded.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28								
	C2		C4							C11					C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	
	C2														C16													C29	C30	C31	C32	C33	C34	C35	C36

Diagram 3: Concept Selection through the Selection Rounds(Made in google disk by bachelor group).

3.1 Initial Concepts



Picture: Initial selection of concepts (sketches made by bachelor group).

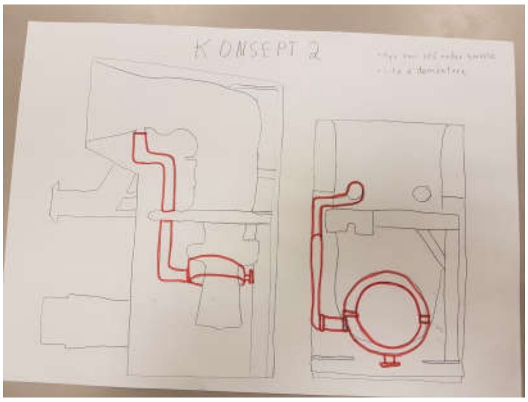
We started by brainstorming a lot of concepts during selection round 1, as planned in iteration 2. Several of these were not relevant and was discarded early on. Some, however, were developed further and is described in detail below. The ones that were discarded are not described in detail, because there wasn't done any development on them before they were discarded. The selection of pictures above.

3.2 Concept Overview

Underneath the functions of the concepts is described in detail together with the development they went through in the different selection rounds and when they were discarded or taken further and the reason for it.

3.2.1 Concept 2 - Wall Runner

Selection Round 1:

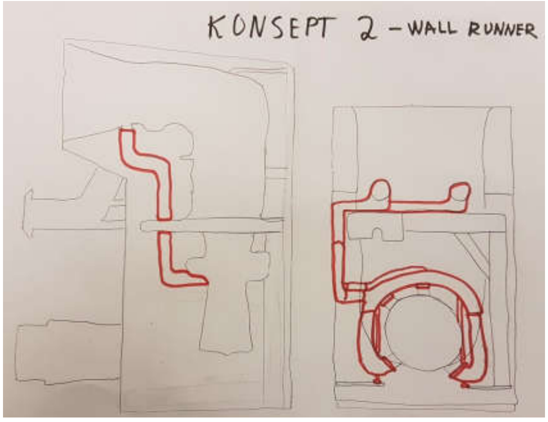


Picture: Concept 2, first sketch

Concept 2 consist of piping drawn from the bleed outlet straight towards the sidewall, and then along the wall towards the exhaust on the inside of the Turbine casing. It would be possible to disassemble just the one piping stub from the turbine to the wall. This allows many of the parts of the system to stay in place while maintenance is performed.

Concept 2 made it through round 1. It is one of the simpler. It is still considered feasible, has little complexity, and shows promise of little maintenance time.

Selection Round 2:



Picture 3: Concept 2, second sketch

The interface part has been developed further, now consisting of a curved duct, with the possibility to have either pipes or hoses connecting to the turbine interfaces. The air is now led inside the housing back to the exhaust, but that can easily be changed to either straight up into a sound muffler or into the ventilation duct.

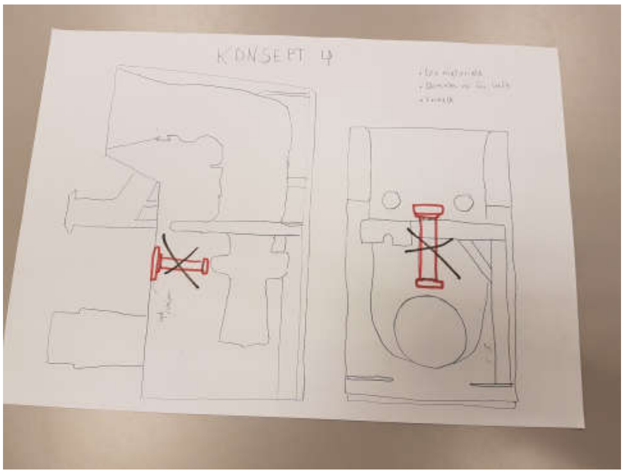
The concept made it through round 2. It still has benefits considering maintenance time, there is just needed to remove the interface subsystem and the pipe connecting it to the wall. There must be conducted more in depth studies on the concept in the next selection round to find out if the system is realistic and as beneficial as it seems on paper.

Selection Round 3:

After more in depth studies on the concept, we found that the curved duct on top of the turbine will have a weight greater than the allowed manual lifting weight. In other words, the duct has to be made in several parts or be lifted by the maintenance crane. This together with the fact that the duct would need a support structure to not cause forces on the turbine interface led to a severe increase in maintenance time. As can be seen in the detailed Pugh diagram, this had a big impact on the total score of the concept. After discussing the score of the concepts the Wall Runner was discarded.

3.2.2 Concept 4

Selection Round 1:



Picture: Concept 4, first sketch

Concept 4 is a simple solution. The thought was to lead the bleed air straight upwards from the turbine and out of the Housing consisting of only one pipe stub. Above the stub there would have to be a silencer between the inside and outside of the turbine housing. During disassembly, there would only be need to remove the one stub.

Selection Round 2:

A silencer was added on top of the housing in this round. This concept was not included among the ones going through to the next round. What we did not consider at first was that the pipe would be in a difficult position to be reached by a maintenance crew. The procedure would require a ladder to disconnect, which is undesirable. It would also probably be too heavy to lift manually.

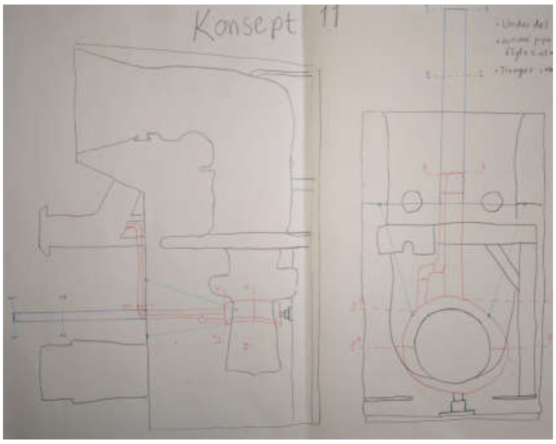
3.2.3 Concept 11

Selection Round 1:

In this concept the bleed pipes is lifted up through the roof by an electrical motor (look at picture in round 2). The thought behind it is to reduce assembly and disassembly time drastically without worrying too much about the cost of the design. There is possible to lift up the pipes, or the pipes and the upper part of the ring duct, to the roof of the housing, where it will slide into a supporting structure. The bleed system is now not blocking the path of the crane anymore, and the turbine can be removed for maintenance. When the maintenance is done the bleed system is lowered down onto the turbine, and is ready to go.

This solution can save a lot of downtime on an oil rig, thereby saving the customer's profits and it makes it possible to have a low amount of fastening solutions inside the housing. It is therefore a candidate that will be looked further into in the next selection round.

Selection Round 2:



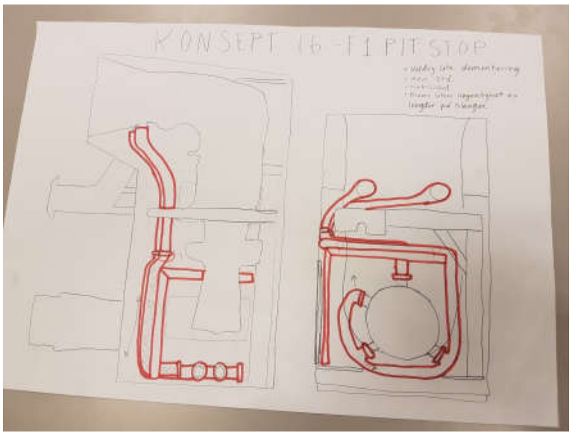
Picture: Concept 11, second sketch

There has been decided that not only the pipes but also the upper duct can be lifted, while the bottom part sits on a rack or hangs in wires. This will require a bigger hatch in the roof which again leads to the need of strengthening the housing to add up for the loss of supporting structure. The goal is that the turbine can be lifted out without the removal of the bottom duct. The interface duct lies tight into the turbine, with a gasket between, so that the bleed air is dropped straight into the duct, without piping.

We found out that the interface solution in this concept not was possible because of all the smaller pipes running along the turbine. The concept was therefore discarded, but the lifting solution was brought further on in concept 34.

3.2.4 Concept 16 - F1 Pit Stop

Selection Round 1:

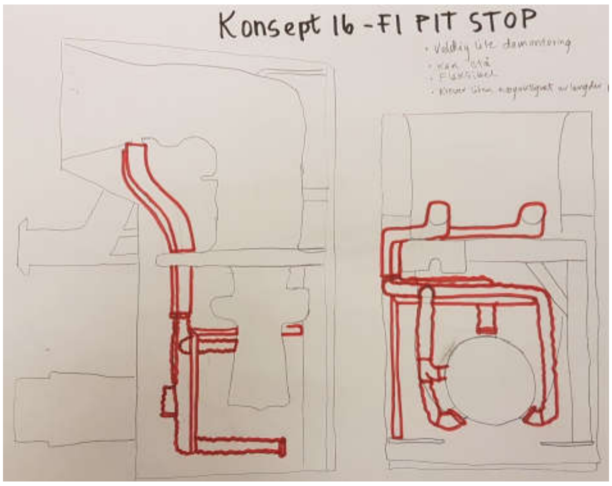


Picture: Concept 16, first sketch

Concept 16 makes use of a flexible corrugated metal hose. The idea was that the hoses would be suspended from a swing arm placed above the turbine. During service the hose ends could easily be disconnected and the swing arm be swung up against the wall out of the way. The rest of the air channel towards the exhaust could in theory be piping or metal hose. The advantage of using hoses is the increased flexibility and not needing to be very accurate when constructing the air channel. And with this concept the service time would be low. The inspiration for the concept comes from formula 1. During the fast pit stops, some of the gear for maintenance of the cars is suspended in the same manner on a swing arm which in the same way can be swung over the cars and back.

It was among the concepts we took through to the next round. The concept shows great promise, but only if we can find a hose sufficiently flexible. Not knowing whether that exist we took it with us to the next round and are going to research whether it will be a feasible solution.

Selection Round 2:



Picture 7: Concept 16, second sketch

After a discussion with the costumer we found that there was no room under the turbine were we originally drew a single bleed line combining the flows of the tree bottom air outlets. Therefore, the new version of the concept slits the air from these outlets allowing flow from the lower right outlet to flow in a separate hose, while the two on the left side flow together. Another concern was that the bend from the upper left outlet would be to sharp. With the new configuration, this problem was also eliminated. We found out that metal hoses offer very little flexibility, and started to look for hoses made of other materials. We found several interesting options made from composite.

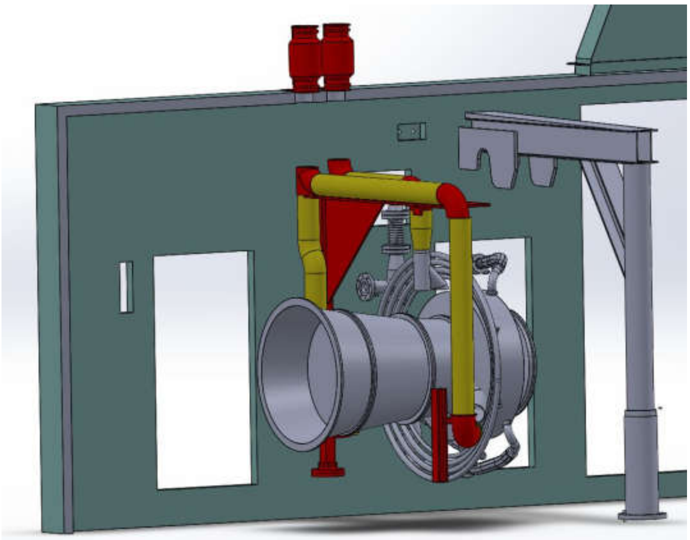
This concept was selected to move on to round 3. The problems found with the original version of the concepts were minor ones which we easily could fix. This concept is still among the ones with the lowest maintenance time, but there is still need to find out more about the specifications of the hoses. We have found hoses in the right dimensions that handles the high temperature, but we don't have any numbers considering maximum stresses, so this have to be solved.

Selection Round 3:

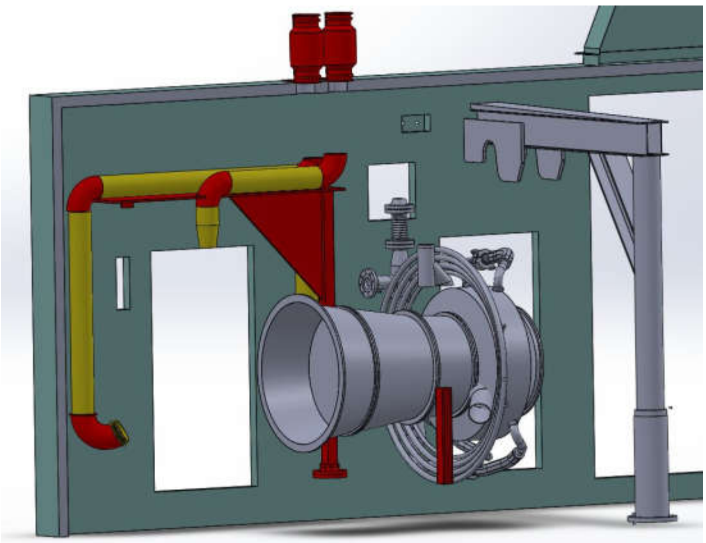
It was taken further to the design/test phase. That is because it still gives the possibility to minimize the maintenance time while making it simple to assemble and disassemble the bleed system. The research on the maximum allowable stresses in the hoses has still not given any results, but will be continued in the next phase.

Design/Test Phase a:

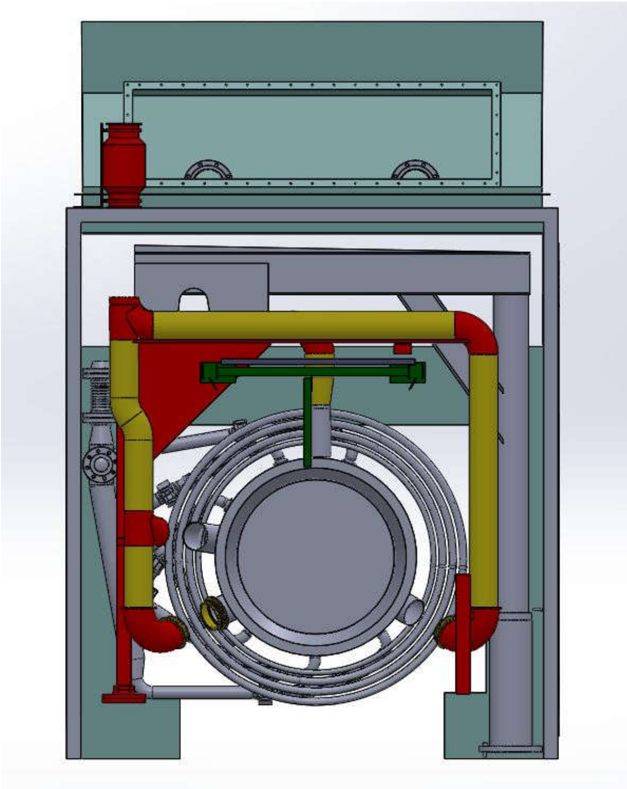
In designing the rough first 3D-model of the concept (shown below) we ran into some troubles as could be foreseen when starting to look at the concepts in more detail. Fortunately, none of the problems were any deal breakers for the function of the system. There was a problem with finding attachment for the pipe bends to take the forces from the flow right after the outlet of the turbine, but the solution was to attach the bends to the swing arm on the one side, and to a beam sticking up from the floor on the other side. Another problem discovered was that the swing arm needed to swing around a center point that was in line with the holes in the roof of the housing, so there wouldn't be too much twisting in the hoses when the system is turn towards the wall.



Picture: 3D model of concept 16 in operational position.
(Designed in SolidWorks by bachelor group)



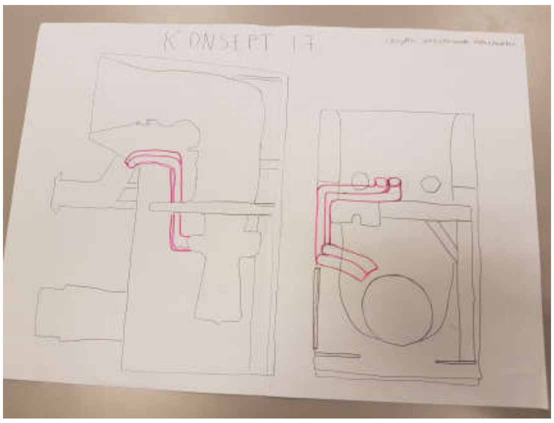
Picture 9: 3D model of concept 16 in maintenance position
(Designed in SolidWorks by bachelor group) .



Picture: Bleed system from the front in operational mode, showing how the
bends on the left side are attached to the swing arm (Designed in SolidWorks by bachelor group).

3.2.5 Concept 17

Selection Round 1:



Picture: Concept 17 sketch (drawn by bachelor group).

Concept 17 demonstrates how the bleed air can be led into the ventilation output of the turbine housing. At the time, we came up with the solution the advantages we could see was that by dumping the bleed air into the air outlet we wouldn't need a silencer for our system as the air outlet has one. Also, there would not be a need for a check valve to prevent airflow going the opposite way as with all solutions going into the exhaust.

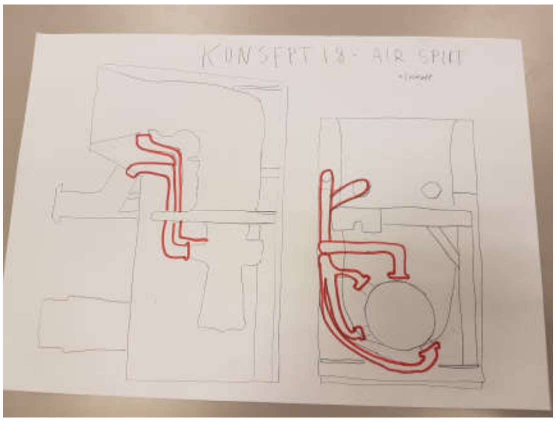
It went on to the next phase. Mainly because we wanted to find out more about the possibility of leading the air to the ventilation duct.

Selection Round 2:

We learned that if we would pursue this kind of solution we would have to enlarge the air outlet duct by an sufficient amount because of the increased airflow. This limits the benefits of this concept and led to the decision to discard it.

3.2.6 Concept 18

Selection Round 1:



Picture: Concept 18 sketch (Drawn by bachelor group).

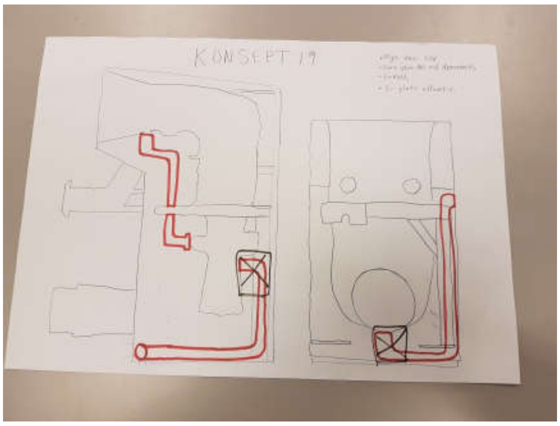
This concept demonstrates the possibility of dividing the bleed line airflow to both the outlet air duct and the exhaust. This could be a solution to constrain the amount of flow to the outlet air duct in an attempt to avoid having to enlarge the duct.

Selection Round 2:

Although this solution can partly solve the problem of having to enlarge the ventilation outlet, because of a smaller amount of air than if both bleed lines were led there, there still has must be done changes to the duct to make it able to handle the larger flow. This limits the benefits of this concept and led to the decision to discard it.

3.2.7 Concept 19

Selection Round 1:



Picture: Concept 19 sketch (Drawn by bachelor group).

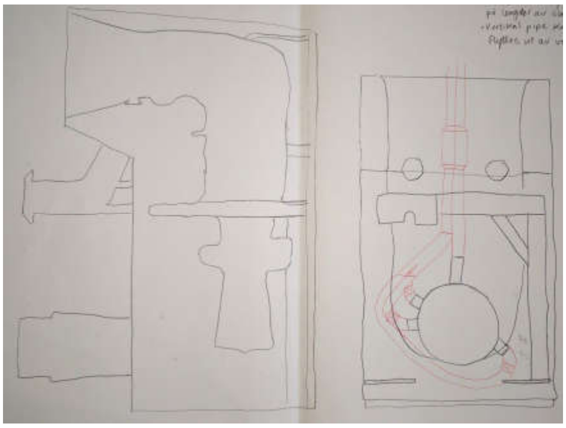
The airflow of the top bleed air outlet and the 3 bottom bleed air outlets is sent in opposite directions. The top air flow will be lead backwards towards the exhaust, and the rest forwards underneath the turbine, towards the wall, and then upwards to a safe height to drop it out into the atmosphere. The hope here was that there would be space for the lines to go under the turbine. This way all the 3 bottom lines would be able to stay in place while maintenance, saving time. there would only be need for disassembling the top bleed line.

Selection Round 2:

We found out, after talking to D-R, that there was a lack of space beneath the turbine, which is a problem for this concept. The simplified 3D model we had been working with did not show all these components. Therefore, this wasn't a possible solution.

3.2.8 Concept 20

Selection Round 1:



Picture: Concept 20 sketch (Drawn by bachelor group).

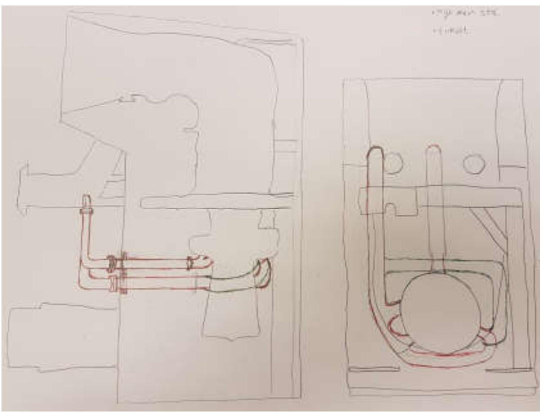
In this concept, we used pipes, going the way we thought was the easiest from A to B. The flow from the three lower interfaces is gathered in one big pipe and led upwards, while the top one is led up in a separate pipe. It is possible to unfasten the pipes at the top interface after the three lower pipes is gathered, so that the vertical pipes can be lifted. The concept is taken further to investigate the possibility of the design. If possible, it is a huge time saver.

Selection Round 2:

As in concept 19 there not space for the bleed system underneath the turbine. Therefore, it is not possible to have a pipe going from the right side and under the turbine like in this concept, there is simply no space for it. The concept was therefore discarded, but part of is used in the making of concept 34.

3.2.9 Concept 21

Selection Round 1:



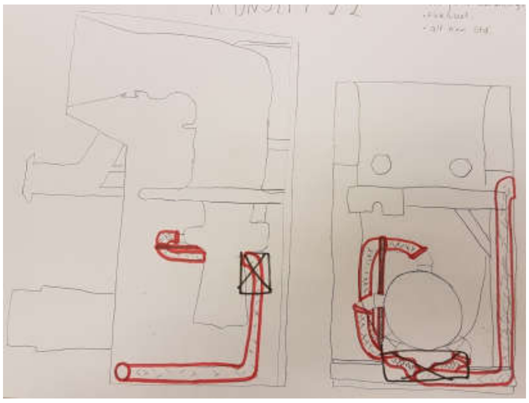
Picture: Concept 21 sketch (Drawn by bachelor group).

Pipes will attach to the turbine from all the valves. To simplify the job for maintenance crew, the pipes will have easy fix solution down by the turbine and up with the roof. The pipes will then be removed. The part on the top of the roof is leaded into the ventilation duct to eliminate the development of a sound muffler.

Selection Round 2:
The ventilation duct has to be redesigned if the amount of air from the bleed valves is leaded through this. Therefore, the concept was discarded.

3.2.10 Concept 22

Selection Round 1:



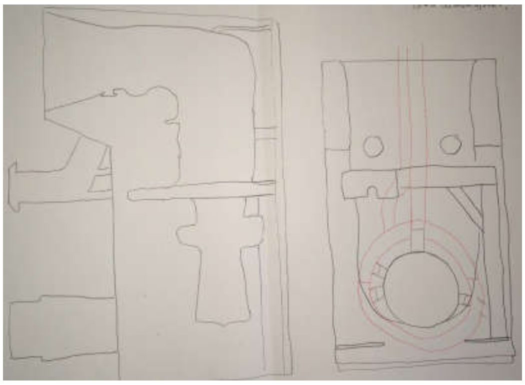
Picture: Concept 22 sketch (Drawn by bachelor group).

The idea here was to use hoses instead of pipes. Hoses stretching from valve A42 (the top one), under the turbine and out through the wall. Valve A43, A44, and A51 was meant to be connected under the turbine, and leaded out the same way as valve A42. The hoses shall be supported by a rack pinning them to the machine, and preventing them to give in for the strong turbulent wind in the hoses and in the enclosure.

Selection Round 2:
There is not possible to gather the hoses under the turbine, and restriction of leading pipes on the floor, but the idea of leading the air forward was approved. The concept was discarded.

3.2.11 Concept 23

Selection Round 1:



Picture: Concept 23 sketch (Drawn by bachelor group).

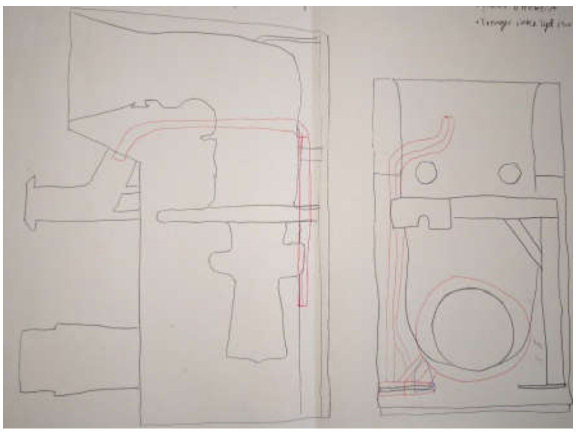
This concept is based on a ring duct solution. Hoses lead the air from the three lower interfaces of the Gas Turbine to the duct, the top interface is led through a pipe that is mounted directly on it, because the air leaves the top interface with a higher pressure and thereby needs separate bleed lines. The lower part of the ring duct can stay where it is, being held up by a rack or wires, while the top can be lifted.

Selection Round 2:

It is not possible to have a duct directly under the turbine, so the concept was discarded. But the some of the ideas from the lifting mechanism and the top duct were used in concept 34.

3.2.12 Concept 24

Selection Round 1:



Picture: Concept 24 sketch (Drawn by bachelor group)

In this concept the air is led into a duct that is the floor. The top interface flow has its own duct, beside the duct shared by the three lower ducts. The air is led backwards and out through the ventilation duct, which has its own sound muffler. A great benefit in this concept is that the floor duct can remain on where it is during maintenance, since it is not blocking the path of the crane or the maintenance crew. The only parts that needs to be disassembled is the two pipes leading the air from the interfaces to the floor duct, thereby saving lots of maintenance time.

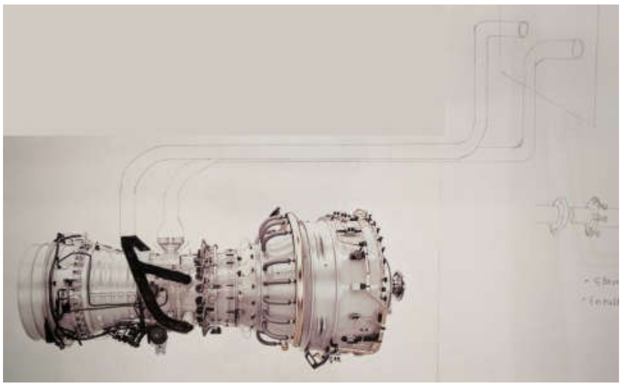
The concept has the possibility to shorten the maintenance time, and can hopefully remain where it is during maintenance. The only concern is accessibility to the parts underneath the duct, but that will have to be investigated further in selection round 2.

Selection Round 2:

In dialog with D-R we found out that there would not be possible to lead the duct past the maintenance crane. The concept was therefore discarded, but the idea of leading the air along the floor is used in concept 33, were the air is led forward instead.

3.2.13 Concept 25

Selection Round 1:



Picture: Concept 25 sketch (Drawn by bachelor group).

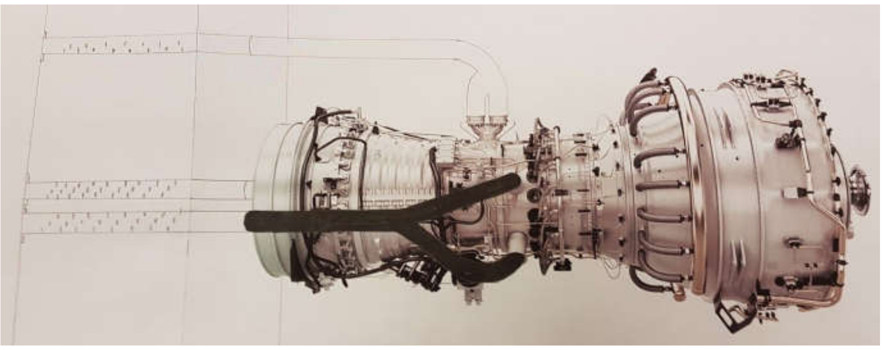
This concept is a simpler version of the original made by Dresser-Rand. The idea was to attach a tripod manifold to the turbine, connecting valve A43, A44 and A51. They are led together to the exhaust in a straight line with the valve A42. This concept offers a reliable solution, because it uses proven methods, and the tripod and straighter piping offers an easier assembly and disassembly.

Selection Round 2:

This concept was impossible because of all obstructions in the path of the pipes. The tripod would be to heavy leaning on the valves and would require some support. This concept was discarded.

3.2.14 Concept 26

Selection Round 1:



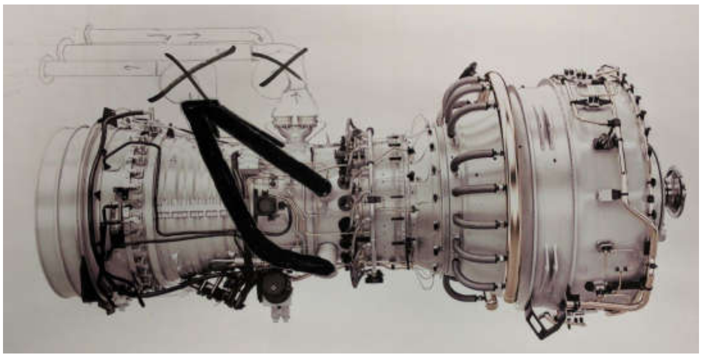
Picture: Concept 26 sketch (Drawn by bachelor group).

The air is blown into the inlet air. The distance is short and the back pressure would be minimal because of the straight lines. The pipes from valve A51 would be supported from the enclosure, and the same would valve A44 and A43 together and A42 alone. The area occupied by the pipes would be small.

Selection Round 2:
There was discovered a requirement; no air shall be mixed with the inlet air. The air shall not either be disturbed to the inlet of the turbine. The concept was excluded.

3.2.15 Concept 27

Selection Round 1:



Picture: Concept 27 sketch (Drawn by bachelor group).

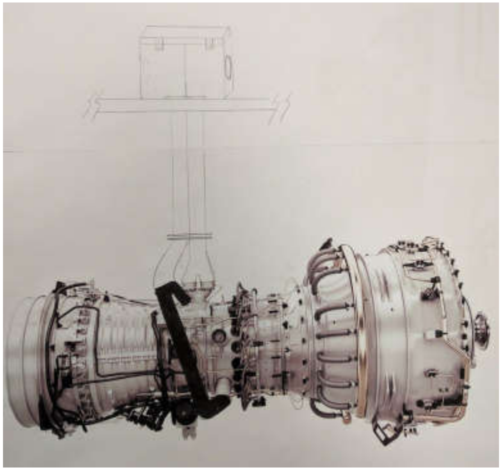
The idea is coming from concept 26. Because of the heat in the outgoing stream, and if it would be to concentrated in the inlet air, it is mounted two turbo's mixing the air from outlet of the valves, with air from inlet of turbine, and mixing them to get the concentration of heat down to a minimum.

Selection Round 2:

The high energy in the air would be the same, and the same conclusion from concept 26 apply. It is not a valid concept and is excluded from the project.

3.2.16 Concept 28

Selection Round 1:



Picture: Concept 28 sketch (Drawn by bachelor group).

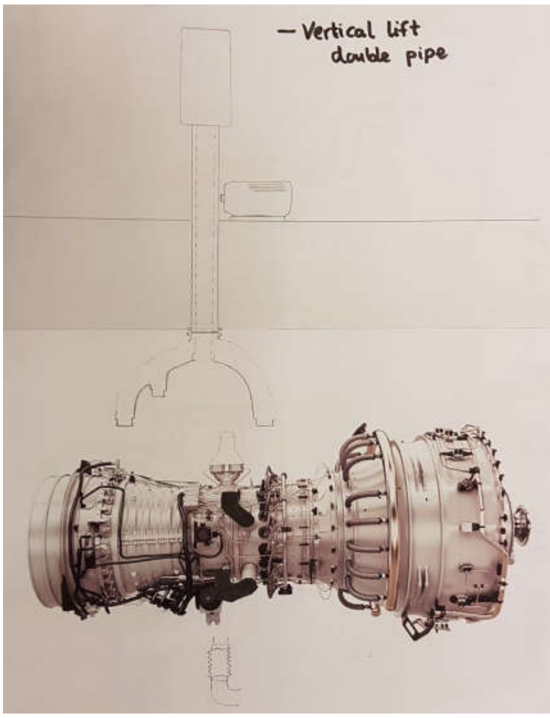
The idea is to have a sound muffler on the top. Short straight pipes leading into the muffler, and a possibility to dismantle the pipes connected to the turbine interface and hoist the pipes under the roof through the sound muffler box. The valves A43, A44 and A51 would be connected to a tripod manifold, and valve A42 to its own pipe. This benefits, like the other systems possible to lift, of a short maintenance time.

Selection Round 2:

The concept was discarded because of the tripod solution. But parts of it was used further in the development of concept 29.

3.2.17 Concept 29 - Vertical Lift Double Pipe

Selection Round 2:

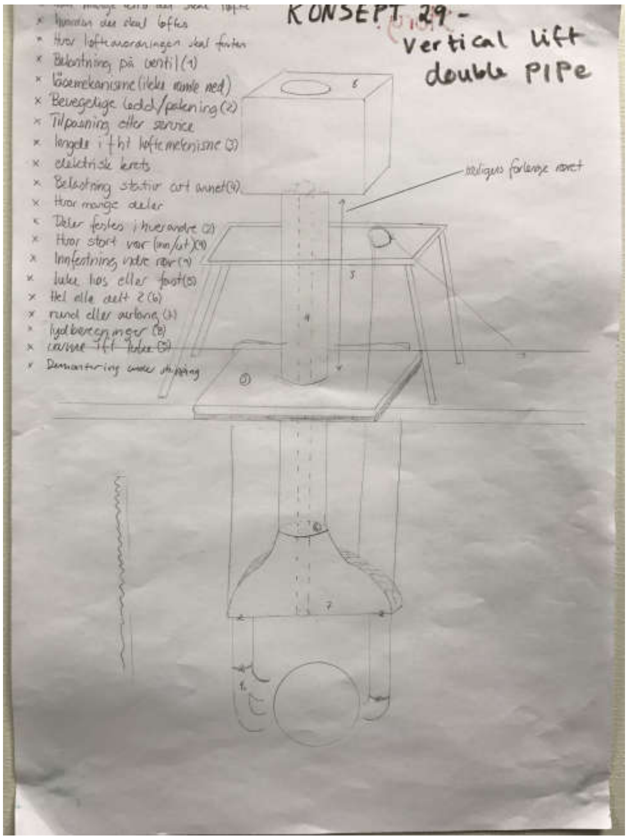


Picture: Concept 29, first sketch (Drawn by bachelor group).

This concept emerged in selection round 2 and is a further developed version of concept 28. It uses the same lifting system, but the interface manifold has changed together with the pipe system, which now is a pipe in a pipe solution. This is to separate the flow from A42 from the other three, because it has a lower pressure and allows less pressure drop through the piping.

It was taken further to round 3. It is a concept that allows for a simple flow path, allows for low maintenance time thanks to the possibility to lift the pipe and the flexible joints between the turbine and the manifold makes it easy to fit, without high precision manufacturing.

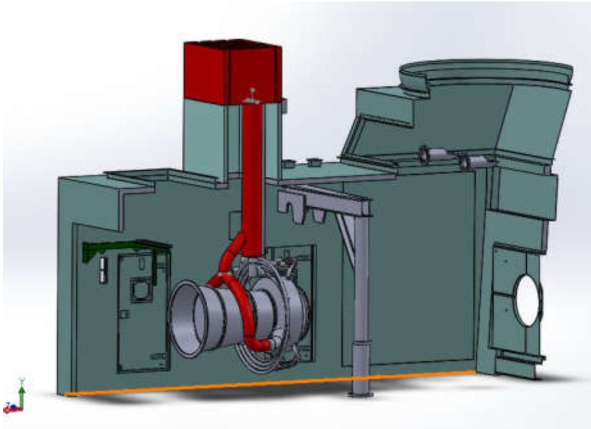
Selection Round 3:



Picture: Concept 29, second sketch (Drawn by bachelor group).

The manifold solution was changed to a more feasible structure and we experimented with different supporting systems for the system that can be lifted up on the roof. Both boxes and supportive stands. The concept was taken further to the design/test phase because of the promising maintenance time of the solution and because it is regarded as feasible.

Design/Test Phase a:

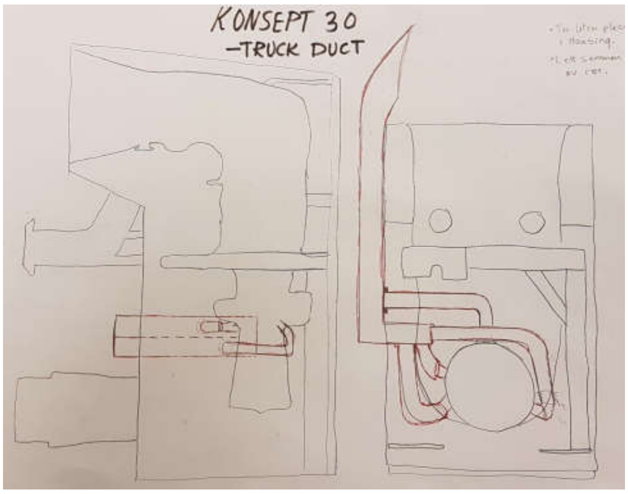


Picture: 3D model of concept 29
(Designed in SolidWorks by bachelor group).

In the design/test phase the concept was drawn in SolidWorks. The original drawing is slimmed down to be easier to work with and is missing a lot of components irrelevant to Concept 29. Vertical pipe concept is noted in red, and the working principle of the concept is a engine on top of housing shall lift the whole construction of the turbine, through the roof, and attach it inside the box on the roof. When the turbine is operating, there will be click-on solution from the valves to the bleed system. And to prevent the forces, if this will be a problem during test phase b, a support rack will be mounted to the bleed system, attached to the floor. The valves will also move freely from the mounted bleed system, because of the gap between valves and bleed system. Valve 42, on top of the turbine have a requirement “bleed valve 42 shall be leaded from the turbine in it’ s own pipe” and is solved by having a pipe within the bigger pipe. The hot excessive air from the turbine compressor is led out of the enclosure and into a sound muffler. This sound muffler will also be lifted together with the bleed system. When compared to the original sketch the lifting system is changed to a box. The original model would be too high when being at the maximum height. Another change is the manifold solution. The manifold in the original would be too big, and would obstruct both the ventilation flow and the ventilation inlet had to be moved further to the front of the package.

3.2.18 Concept 30 - Truck Duct

Selection Round 2:



Picture: Concept 30 sketch (Drawn by bachelor group).

The concept was introduced in selection round 2. We figured that we hadn't had enough focus on solutions using ducts. One clear benefit of this is the dumping effect you get when channeling all the flow paths into a big duct, thus not having to worry about back pressure in the system. This concept was an attempt to include more ducted based concepts. It simply collects all the flow paths from the turbine into a duct. At this stage the duct was supposed to be on the outside of the housing, not to take up too much of the space on the inside of the enclosure.

It was among the concepts that made it through to selection round 3, because it was the only concept at the time based on using a duct. We wanted to explore this feature more, as we understood from D-R that there had previous experience with too much backpressure. It also was among the more simpler concepts.

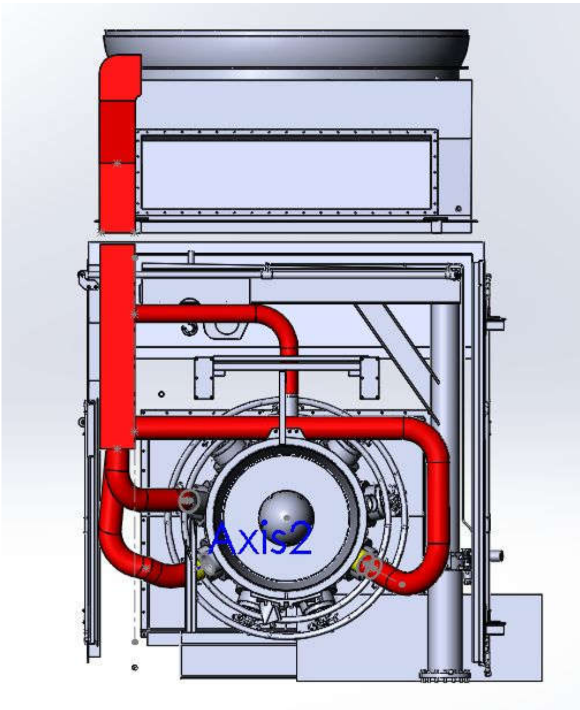
Selection Round 3:

We found out that there was no need for a separate compartments for the air from valve A42 and the others to be dumped in the duct. It was also decided that it would be better if the duct would be placed inside the housing hoping that if made in the right dimensions it could be left hanging on the wall during service.

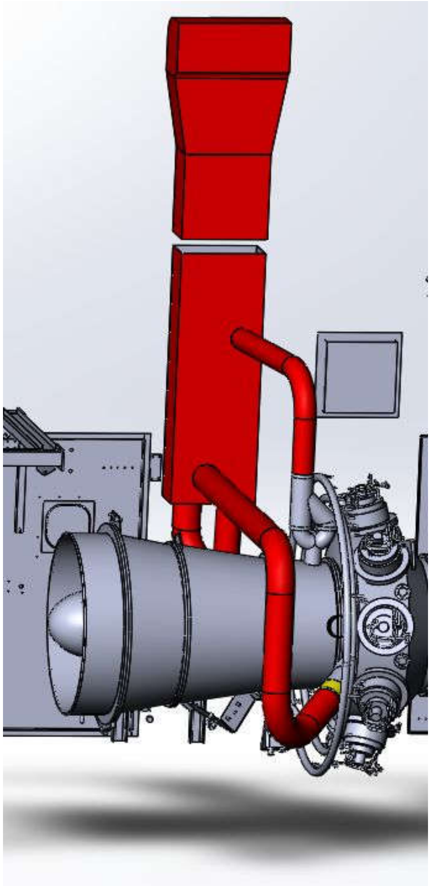
It was selected among the 4 concepts to be worked on in the design/testing phase. It was not among the highest scores on the Pugh, but to minimize the technical risk we decided to bet on different solutions, because some of the best scores had the same technical risks. But if our estimations about pressure in the other concepts would turn out to be wrong, we did at least have a safe bet with this one.

Design/Test Phase a:

This concept is a kind of straightforward without much technical surprises. The pipes from the turbine leads the air to the duct hanging on the wall. The duct must be designed so it will not build up backpressure. The duct leads the air threw a sound muffler on the roof and out in the open air. When designing this concept we want to use standard parts like pipe bends with same radius as diameter. But one problem is that the valves A51, A43 and A44 is pointing out with an angle that not fits with these standards. The solution might be using flexible connection points so we still can use standard parts.



Picture: 3D model of concept 30. The parts in red shows how the concept basically will look like. (Designed in SolidWorks by bachelor group)



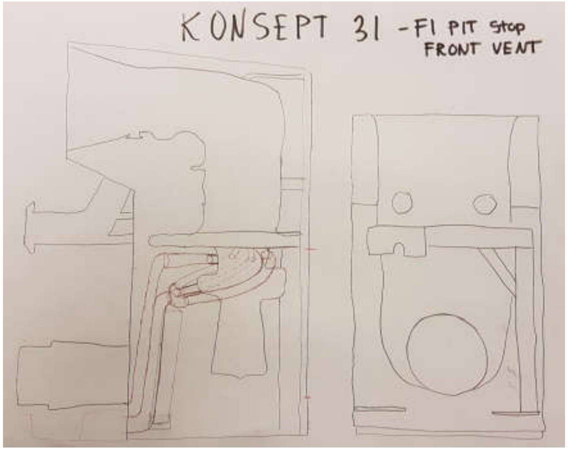
Picture: 3D model of concept 30. Shows righthand side view.
(Designed in SolidWorks by bachelor group)

This version of the model is only a picture of how the concept will look like. Details such as flexible couplings, fastening methods for pipes and interconnections are not included in this model. On picture 28 it shows a yellow detail and it is only intended to show where the flexible connection is thought to be.

Although this is a minor technical concept, there are some challenges that emerge when designing. One of the challenges ahead is how to disassemble/assemble this system when the weight of the components are heavier than allowed for manual lifting, as it might appear that it will be. Here we can use the crane available, but it will increase the time required to disassemble and reassemble. Other challenges is the temperature that will appear in the pipes and ducts during operation and the fastening method for these parts must allow expansion of the material when heated.

3.2.19 Concept 31 - F1 Pit Stop Front Vent

Selection Round 2:



Picture : Concept 31 sketch(Drawn by bachelor group).

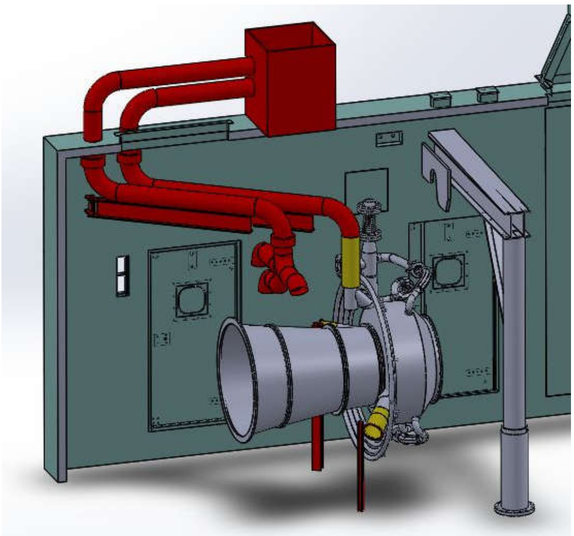
Both concepts 31 and 32 emerged after the first selection round. They are both also based on concept 16. After considering where the most available space in the turbine housing it was decided to make two new versions of concept 16 with the swing arm located in the back rather than in the middle of the housing. The basics principle of the concept is as for concept 16. it Brings the flow from the turbine upwards into channels suspended from a swing arm. During maintenance, the connections are disconnected and the swingarm is swung so it is parallel with the short wall of the housing. The flow is then lead upwards and out of the housing with a separate sound muffler. the difference between the concept 31 and 32 are two things. Concept 32 consists of suspended pipes with flexible joints in the interface between the bleed lines and the turbine, but concept 31 has hoses, concept 32 takes use of a feature from 29, which is placing the pipe containing flow from the top air outlet within the pipe containing the flow from the other air outlets, while 31 has two separate hoses on the swing arm.

This concept made it through to the next round. It showed promise to be a better version of the original concept 16 because of the extra access it provides.

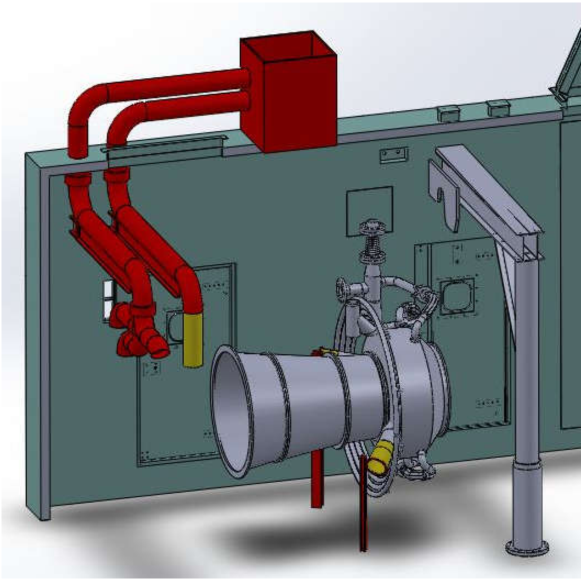
Selection Round 3:

Not a lot of modifications were made to this concept in selection round 3. For the 4 concepts we wanted to work onwards with it was decided that concept 31 and 32 were to be joined into one concept and be among the 4 selected concepts. Then we would have two different configurations of the one concept, giving us the ability to explore the solution with both pipes and houses. Both concepts had good results from the Pugh matrix. Because of the good maintenance time, user friendliness, and the space effectiveness, 32 scored a lower at safety than 31, but 32 has lower technical risk.

Design/Test Phase a:



Picture 30: 3D model of concept 31 showing the operational position of the bleed system. (Designed in SolidWorks by bachelor group)



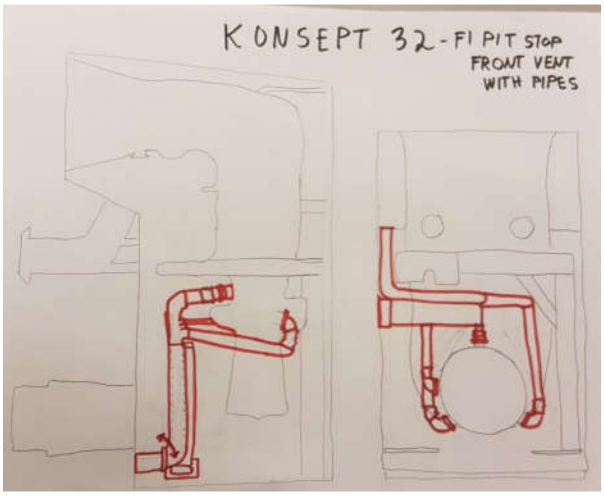
Picture 31: 3D model of concept 31 showing the maintenance position of the bleed system (Designed in SolidWorks by bachelor group).

In this stage the concept was modeled using SolidWorks. The parts in yellow are hoses, while the ones in red is pipes, beams, etc. As can be seen from the pictures the hoses from the manifold is missing. This is because they were not required in the tests in test phase a.

Several new challenges were encountered during the modeling. The pipe to A42 and the pipe to the three others had to be supported on separate beams because they had to be able to swing independently of each other. The design of the manifold have also been changed to offer an easier flow path for the air through the hoses, and a swivel joint was added to make it possible to turn it during maintenance. Without that feature the manifold would not fit, because it would interfere with the front wall. There was also added an interface connection. The idea is that a hose is connected between the turbine interface and a supportive rack, where the rack takes up all forces from the area, and the hose offers a flexible connection. Hoses will connect the interface hoses to the manifold.

3.2.20 Concept 32 - F1 Pit Stop Front Vent with Pipe

Selection Round 2:



Picture: Concept 32 sketch (Drawn by bachelor group)

Both concepts 31 and 32 emerged after the first selection round. They are both also based on concept 16. After considering where the most available space in the turbine housing was it was decided to make two need versions of concept 16 with the swing arm located in the back rather than in the middle of the housing. The basics principle of the concept is as for concept 16. it Brings the flow from the turbine upwards into channels suspended from a swing arm. During maintenance, the connections are disconnected and the swing arm is swung so it is parallel with the short wall of the housing. The flow is then lead upwards and out of the housing with a separate sound muffler. the difference between the concept 31 and 32 are two things. Concept 32 consists of suspended pipes with flexible joints in the interface between the bleed lines and the turbine, but concept 31 has hoses, and concept 32 takes use of a feature of 29, which is placing the pipe containing flow from the top air outlet within the pipe containing the flow from the other air outlets, while 31 has two separate hoses on the swing arm.

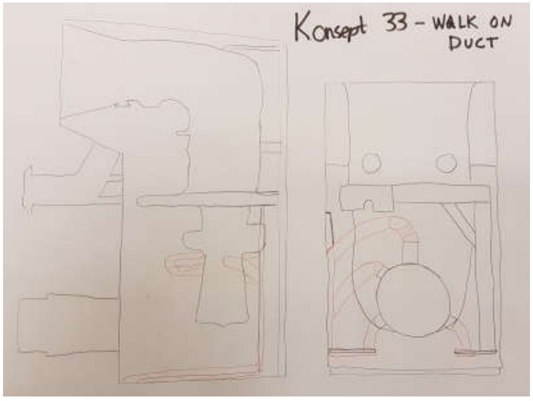
This is one of the concepts we took with us to the next round. The fact that there was still at this point some uncertainty of whether it would be possible to use a house rather than piping, made this solution an attractive replacement of the house based swing arm solutions. This solution also shows great promise for accessibility in the housing.

Selection Round 3:

Not a lot of modifications were made to this concept in selection round 3. For the 4 concepts we wanted to work onwards with it was decided that concept 31 and 32 were to be joined into one concept and be among the 4 selected concepts. Then we would have two different configurations of the one concept, giving us the ability to explore the solution with both pipes and houses. Both concepts had good results from the Pugh matrix. Because of the good maintenance time, user friendliness, and the space effectiveness, 32 scored a lower at safety than 31, but 32 has lower technical risk.

3.2.21 Concept 33 - Walk on Duct

Selection Round 2:



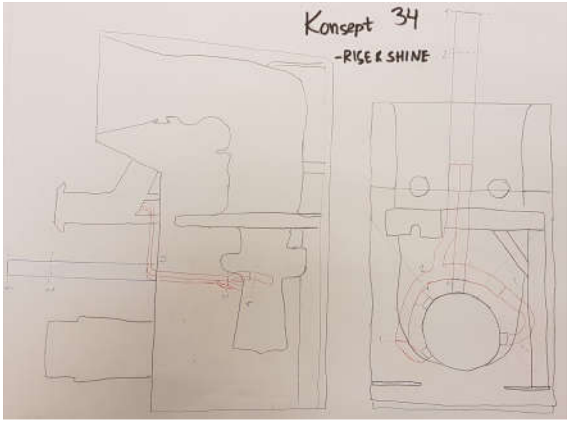
Picture: Concept 33 sketch (Drawn by bachelor group)

When working in the selection round 2 we discovered that all the concepts containing flowlines underneath the turbine turned out to be impossible to implement, we tried to think outside the box about how we could lead the flow forwards by the floor without being right beneath the turbine, but also not in the way while service personnel were working inside the turbine housing. One solution was to lead the streams of air into a duct placed on the floor which would be robust enough for service personnel to walk on. Eventually leading the air all the way towards the front of the housing and then upwards and out with a separate sound muffler. The advantage of this solution is that a big part of the system could be left on while service is performed saving valuable time during maintenance.

It was selected to go through to round 3 in the Pugh because of the space effectiveness of the solution. We thought that it was clever to combine the usability of the bleed line system with the service floor to save space. But in the showcase with D-R we learned that it was impossible to implement because it would hamper the accessibility to the systems beneath the floor and because of safety. The piping would reach a temperature of [redacted]°C which might be a safety issue because the fuel tank of the turbine is placed under the floor. The solution was discarded before the start of round 3.

3.2.22 Concept 34 - Rise and Shine v.2

Selection Round 2:



Picture: Concept 34 sketch (Drawn by bachelor group)

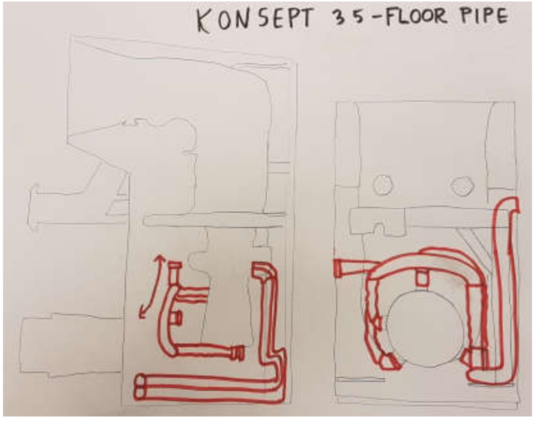
This concept is a further development of the concepts 11, 20 and 23. It have the same benefits as those, but is developed further in the terms of realistic design. The interface manifold is now designed in a way so that it will be possible to lift it up through the roof, or it can be disassembled before the system is lifted, making it possible to have a smaller hatch in the roof. The air is led to the manifold through hoses, making a flexible interface connection. A42 has its separate pipe, going through the manifold.

Selection Round 3:

There wasn't much further development on the concept in this round. In the Pugh it got an average score. The main reason to why it was discarded was that we had another system that could be lifted concept that scored higher, and there was no need to have two of these in the next phase. Concept 29 was therefore taken further instead of this.

3.2.23 Concept 35 - Floor Pipe

Selection round 2:



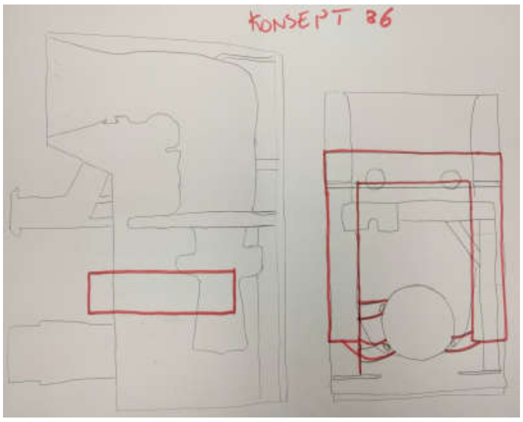
Picture: Concept 35 sketch (Drawn by bachelor group).

As for concept 33 this idea also emerged during selection round 2 as a way of trying to think differently on how we could draw the bleed lines forwarded along the floor. It has the same advantage as 33 allowing a big part of the system to be left on while service is performed saving valuable time while maintenance.

It was among the concepts that, according to the Pugh, should go further to selection round 3, because it would have lots of parts that didn't have to be disassembled during service, and also was quite space effective. But as in concept 33 it was impossible to implement because it would hamper the accessibility to the systems beneath the floor and because of safety. The piping would reach a temperature of [redacted]°C which might be a safety issue because the fuel tank of the turbine is placed under the floor. So it was also discarded before the start of iteration round 3.

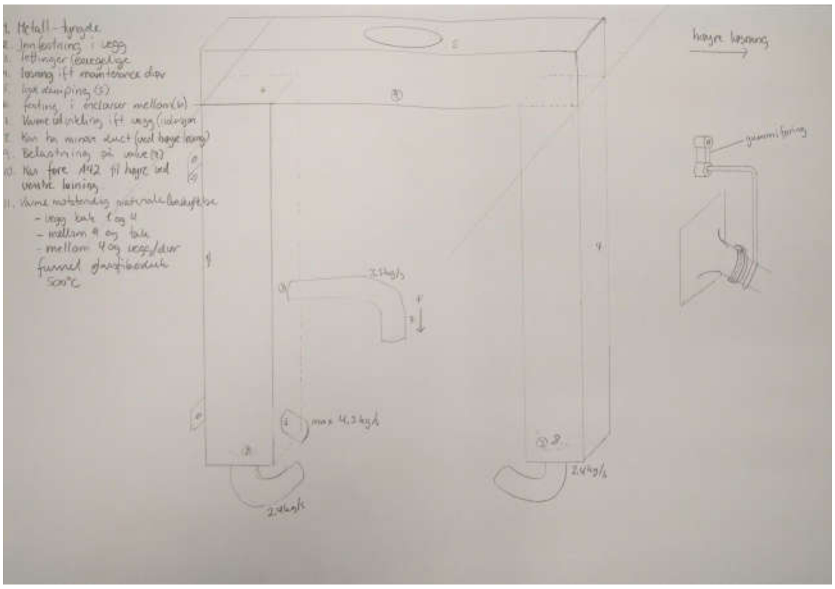
3.2.24 Concept 36 - Twin Duct

Selection round 3:



Picture: Concept 36, first sketch (Drawn by bachelor group)

This concept is mostly based on an idea from D-R. We decided to investigate if it would be beneficial. It consists of two separate big ducts on each side of the turbine, which the bleed air is lead into with either pipes or tubes. Because of the sectional area of the ducts there will be a dumping effect, where we have low pressure drop through the bleed line. That gives us the possibility to lead A42 together with the other outlets. The air is lead upwards from each of the ducts and is combined in a collection duct on the top of the housing. The air the goes through a sound muffler before it is let out in the atmosphere. The concept didn't have any technical risks, it was very simple, and wouldn't cost a lot to produce



Picture: Concept 36, second sketch (Drawn by bachelor group).

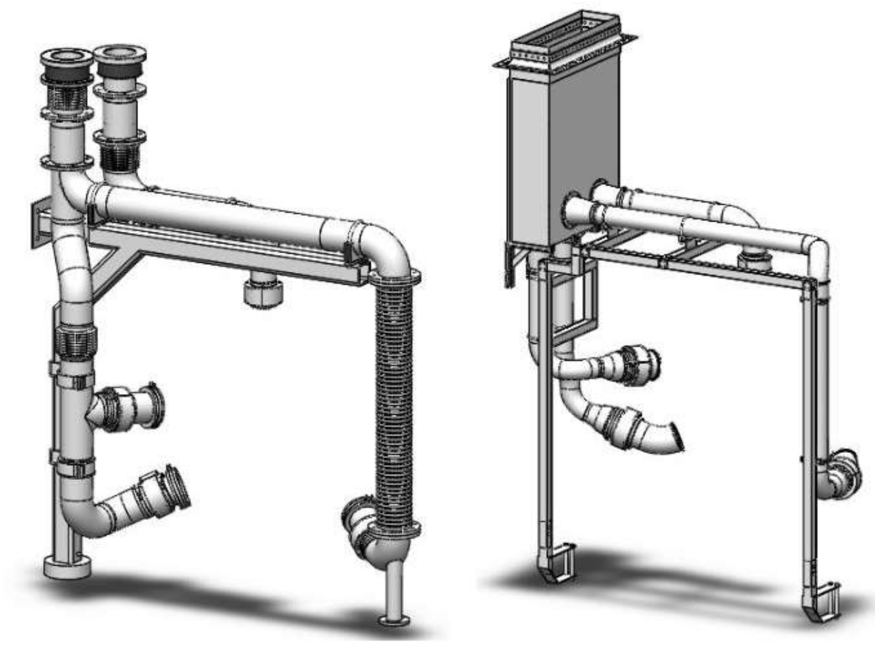
But it didn't score high enough on the stringer weighting criteria of the Pugh matrix because of the low score on maintenance time. The choice was therefore to move further with the possibility of using the dumping effect in concept 30, where the duct is only on one side, thereby saving maintenance time and giving better access in the housing.

DRESSER-RAND

HSN University College of Southeast Norway

Technology Document C16

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
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22.05.2017

Document History

Date	Version	Changes	Approved by
25.04.17	0.0	Created, Layout	Daniel
02.05.17	0.1	3.1, 3.3.1	Svenn
02.05.17	0.2	3.2, 3.3, 3.3.1, 3.3.2, 3.3.3, 2	Kristian
04.05.17	0.3	3.3.3.1, 3.3.3.1.1	Svenn
06.05.17	0.4	3.4, 3.5	Svenn
08.05.17	0.5	3.3.3.2.1, 2.1, 2.2	Svenn
08.05.17	0.6	3.2	Kristian
10.05.17	0.7	3.2, Components	Svenn. Kristian
11.05.17	0.8	3.3, 3.2.1, 3.2.2, 3.23, 3.2.4,3.2.5, components	Svenn, Kristian
12.05.17	0.9	3., components	Svenn, Kristian
15.05.17	0.10	Components, installation, assembly during service, disassembly during service	Svenn
16.05.17	0.11	Introduction	Svenn
16.05.17	0.12	Filled in where needed	Svenn
18.05.17	0.13	Budget, referred to requirements and numbers, strip wound hose	Svenn, Kristian
22.05.17	0.14	Correction and structuring	Kristian, Daniel
22.05.17	1.0	Approved for submission	Daniel

Table of Contents

1. Introduction

Concept 16 is a solution to a new problem. With new owners, Dresser-Rand AS has been commissioned to customize turbines from other suppliers, which brings new challenges. Concept 16 will lead the excess air from the turbine compressor, and out to the environment in a safe way. Group 19 has been assigned the task of designing this concept, working in parallel with two concepts. Concept 30, the other final concept, will be in a document for itself. In this document, we discuss the technological choices we have made. What we have weighed against each other and why exactly the different types of choices have occurred. A careful weighing from contact with suppliers, specifications of materials, concept features and customization has been done, where they are described in detail. The choices extend back to an early stage in the project, where the information from the first sketch to the final concept is included. Also included is a part overview, how to manufacture, which components are to be assembled, who supplies the parts, meter prices, and all other information needed for a good understanding of the product. The main document is easily read and contains the most essential information, while attachments on specific matters will elaborate the information in more detail, and is for the most interested.

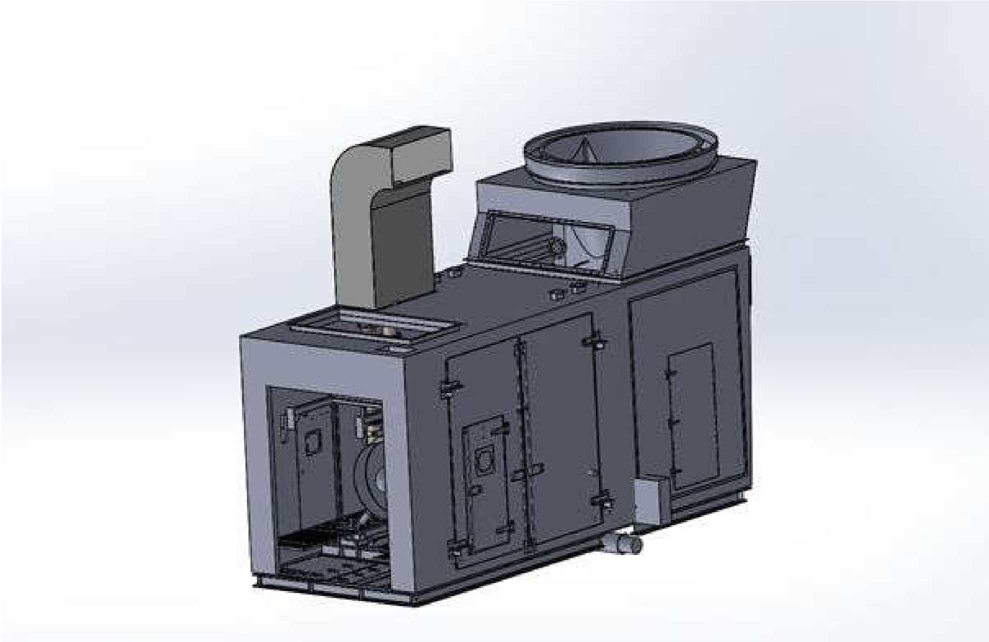
2. Technological Summary

2.1 Problem Statement

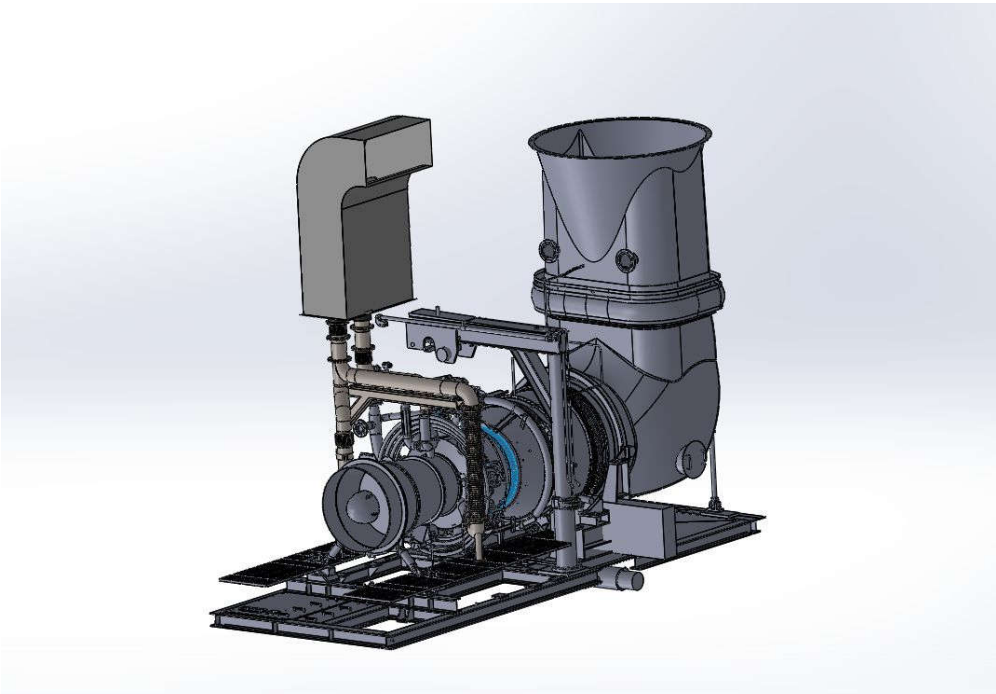
Dresser-Rand needs a new solution to an existing bleed line system made for the turbine package RB211-GT30-DLE. A turbine bleed system's task is to bleed of excess air from the compression stages before it hits the combustion chamber, during the unstable conditions of startup. In the case where the turbine is placed in an enclosure the excess air needs to be leaded from the turbine and out of the enclosure via some kind of a flow channel. The system to be replaced is difficult to disassemble, has components that are complex and that take up too much space inside the enclosure. This means that the time it takes to get it out will be long, it is demanding for technicians to disassemble and it is difficult to get to components under inspection. One of the main areas of focus in the project is the service time. The time of assembly and disassembly is required by the customer to be as low as possible, and shall at least be less than one hour total. (According to requirements S37 & S38)

Solution

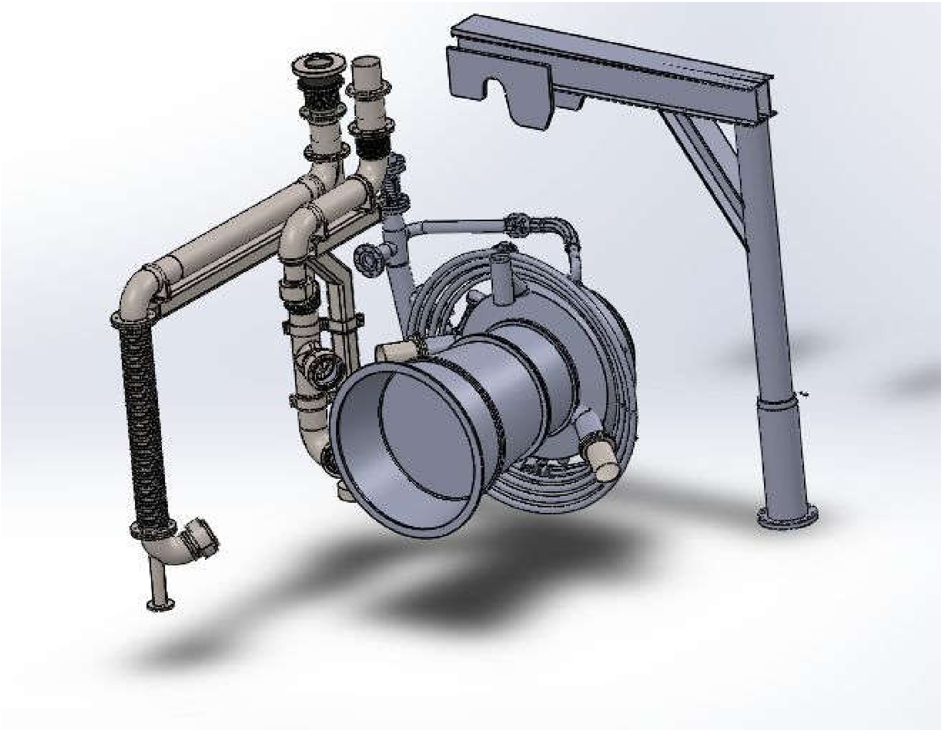
Concept 16 solves this problem by placing the bleed line routing system on two rotating booms located beside the turbine. This pipe routing can be swung out of the way in a short amount of time during service of the gas turbine.



Picture showing the top of the BS sticking out of the turbine enclosure. (lighter gray duct.). (Designed in SolidWorks by the bachelor group).



Picture of the BS in it context without the enclosure. In operational mode. (the lighter gray parts) (Designed in SolidWorks by the bachelor group).



Pictures of the BS in a simplified model, during service mode. (Designed in SolidWorks by the bachelor group).

2.2 Technical Risk

The biggest technical risk associated with this concept in the beginning of this project were related to using flexible hoses instead of pipes. We didn't first know whether there existed a type of flexible hose fitting the application. The properties that were difficult finding in a flexible hose were the ability to handle large amount of stress caused by the powerful flow from the turbine (According to requirements S47, S48, S49), and the ability to withstand the high temperature over a long period without losing its properties. As a minimum it would have to hold the 3 years interval between each service of the turbine. But ideally it shouldn't have to be changed during the life of the system of 25 years.

2.3 Technical Challenges

A difficulty that was a common problem for both final concepts was finding a good solution for connecting the turbine to the bleed line system without transferring “any” loads between them. (According to requirements S1, S2, S3, S4) We had the same problem for this component as we did when trying to find a hose. A lot of the possible flexible sealing solutions between the turbine and the bleed line system would require the use of materials that cannot stand the high temperature over the needed period.

When pursuing this solution for the problem the placement and configuration of the boom was essential. We wanted the boom to be placed in such a way that it would provide an open workspace for the service personnel while working inside the closure. This was no easy task, since the big pipes attached to the boom would swing on the outside of it, sweeping across a large area. We also needed to decide whether we should have one or two booms. Both solutions had their pros and cons where we needed to make compromises between usability and price. On the one hand, we wanted to make the bypassing of the roof with the piping system as easy and standardized as possible but on the other hand we knew it might require more parts and therefore a higher price.

There have been many technological challenges.There have been requests by mail and telephone to countless suppliers. Finding manufacturing methods for components that are specially designed have been difficult, and joining the systems with welding and cutting. Some of the problems have also come during system analysis. Values have on occasion gotten higher than permissible, causing stresses higher than the yielding strength of materials used, and manufacturer can't answer the questions. So basically, there were many of the challenges in gathering information from those who sell the products.

In the project we did for a time misunderstand the method of calculating maximum pressure drop for a pipeline. (According to requirements S20 & S21) This mistake was performed on the two first pressure drop tests of the project. Fortunately we discovered the mistake in time to prevent it from having a large impact on the project. We thought that to find the maximum backpressure in a system with multiple inlets that you would have to add the results for each of the paths. But In reality the pressure for the paths would not be combined. Therefore we got much higher results than they were suppose to be in the two first pressure drop tests. The tests performed using the wrong methode have been marked in both the test specification as well as in the testreports.

3. Technological Aspects

3.1 Concept Functions

The bleed line system shall be independent of the turbine. When the turbine moves because of the expansion created by the heat the bleed line system shall not transfer any forces to the turbine. The interface between turbine and bleed line system connect the two systems which lets the turbine move freely, and seals the connected pipes for hot air streaming to the surroundings of the enclosure. From the valves the air follows pipes to the top of the enclosure, and into a sound muffler. The bleed line system will be exposed to high temperature and will grow in both width and length, and due to this expansion, the bleed line system is equipped with heat expansion joints. The part of the system leading air from valve A43 and A51 is directed vertically, and is attached with one clamp between the valves (Lower C2 on part overview below) to ensure the growth will be equally shared between the two valves. Approximately this growth gives 10 mm movement in the vertical direction. The movement is calculated into the interface, and will be aligned so there is little disturbance in the flow inside the pipes. Above this point there are heat expansion joints which collects all movement (E1, E2 on part overview below), and prevent the system from moving. There is also a clamp (upper C2 on part overview below) which lets the system grow both radial and axial. There are three expansion joint in total, and two separate subsystems leading the air from all the four valves. The air from valve 42 has one expansion joint due to its low complexity and length, while the bleed system from the other valves have two.

3.2 Technological Choices

To reach the final design of the system we have had to decide between many different configurations of the system as well as deciding which parts would best suit the requirements. There is a lot of work done on every aspect of the system and almost no features are coincidental. This section is aimed at documenting the technical process of the system in the making. In this section, we divide the choices made into problems they were meant to solve. Presenting the problems, the options, and the choices here, but the analysis in a separate technical choice attachment for each of the subjects. If the reader wants to know how and why the choices are made it is recommended to read the technical choice attachments for C16.

3.2.1 Bypassing the Enclosure Roof

Swivel Joint vs Rotating Roof Section

For the bypassing of the roof on the enclosure with piping we had to choose between rotating pipes (swivel joint) or a rotating section of the roof.

- Swivel joint - **implemented**
- Rotating roof section

See attachment for the analysis of this technical choice

3.2.2 Routing

Routing Path

For concept 16 there would be several options for the exact routing of the flow path. Both from the turbine on to the boom structures (B1, B2 on part overview below) and from the booms towards the outside of the turbine enclosure.

- Single flow path from the turbine to the boom (Valves A43, A44, A51)
- Separate flow paths from the turbine to the boom - **Implemented**
- Dump flow in the exhaust
- Dump flow directly above the bleed system - **Implemented**
- Dump flow above and in front of the enclosure

See attachment for the analysis of this technical choice.

Hoses vs Pipes

We had the choice between different parts to channel the flow from the turbine to the outside of the turbine enclosure. This selection was divided in two. Considering hoses against pipes, and piping against tubing

- Houses - **Implemented**
- pipes - **Implemented**

See attachment for the analysis of this technical choice

Piping vs Tubes

- Pipes - **Implemented**
- Tubes

See attachment for the analysis of this technical choice

Diameter of Flowpath

The diameter of the flowpath would be altered by the pressure drop in the final design of the concept, and availability of sizes of piping. It would be desirable to use as low of a diameter as possible.

- 200 mm inside diameter - **Implemented**

See attachment for the analysis of this technical choice

Standard bends vs Custom bent elbows

For two of the systems elbows (RB11, RB12 on part overview below) there was a need for a bend with a non-standard elbow degree. This was due to the non-standard angle the outlet valves of the turbine had. For these two elbows, we needed to decide between using a specially made custom bent elbow or cutting a standard elbow to the right size.

- Cut Standard elbows - **Implemented**
- Custom bent elbows

See attachment for the analysis of this technical choice

Flanged vs Buttwelded piping

We needed to decide on the connection method between all the pipes and the one hose in the system. This decision had a lot to do with the weight of the system.

Flanges - **Implemented (mostly)**
Buttwelding **Implemented (on few parts)**

See attachment for the analysis of this technical choice

3.2.3 Support Structure

Configuration, placement and number of booms.

This concerns the configuration of the boom, the number of booms, and its or their placement on the floor or the wall compared to the turbine and other components within the enclosure.

- One boom, two fixed pipe center points
- One boom, two eccentric non-fixed center point pipes
- Two booms, two fixed pipe center points **-Implemented**
- Standing floor based boom **-Implemented (B1)**
- Wall suspended boom **-Implemented (B2)**
- Walking clearance of 225mm **-Implemented**

See attachment for the analysis of this technical choice

3.2.4 Heat Expansion During Operation

Fixing of pipes/hoses
The pipeline needed to be held in place in a manner that would provide good rigid hold, but also it was important to fix it in the places where there was least room for movement due to heat expansion.

- Fixture hindering movement near the interfaces to the turbine **- Implemented**
- Fixture preventing eccentricity of pipe going thru the roof **- Implemented**
- Fixture preventing non linear compression in expansion joints **- Implemented**
- Fixture allowing for elongation of large horizontal pipe **- Implemented**

See attachment for the analysis of this technical choice

The use of expansion joints

In coherence with the fixing of the pipelines we needed to consider if the elongations in the system would cause to great loads on the system. If so we wanted to use expansion joints in the most optimal places possible on the pipeline.

- Compensate for expansion in between upper and lower fixture **- Implemented**
- Compensate for expansion in between roof and system - **Implemented**

See attachment for the analysis of this technical choice

3.2.5 Non-load Transferring Connection to the Turbine

Interface concepts. (Rockwool, below, other)
To comply with requirements concerning connection to the turbine it was important not to transfer more than 150N of forces from the system on to the turbine.

- Rubber bellow
- Rock wool muffler- **Implemented**
- Fabric cloth

See attachment for the analysis of this technical choice

Configuration of interface (Assembly)
- Screws
- Hose Clamps **- Implemented**

See attachment for the analysis of this technical choice

Configuration of interface (Shape)
- Round
- With edges - Implemented

See attachment for the analysis of this technical choice

3.2.6 Sound Isolation

Separate sound silencer vs connected to the exhaust

This concerned whether we wanted to use the sound silencer built in the exhaust system of the turbine package, a sound silencer in the duct or using a separate sound silencer.

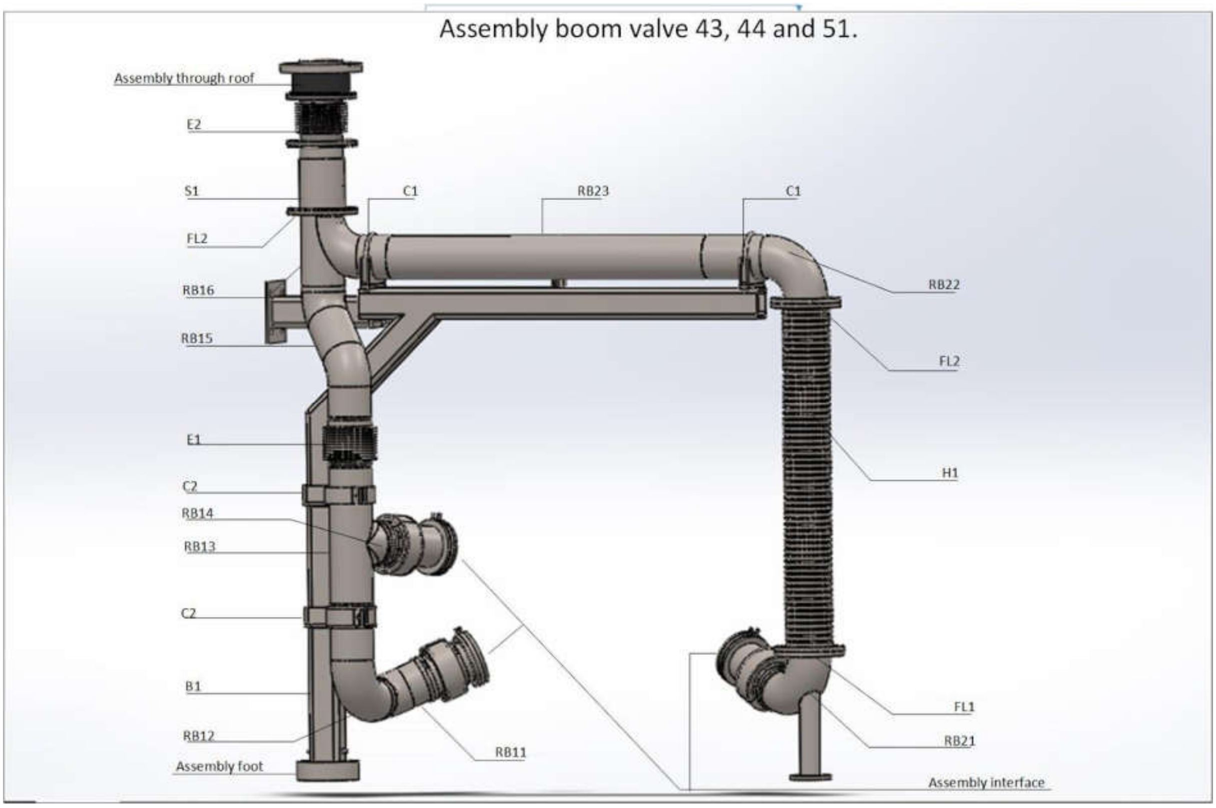
- Sound silencer in exhaust
- Use sound silencer as a duct
- Separate sound silencer - **Implemented**

See attachment for the analysis of this technical choice

3.3 Components

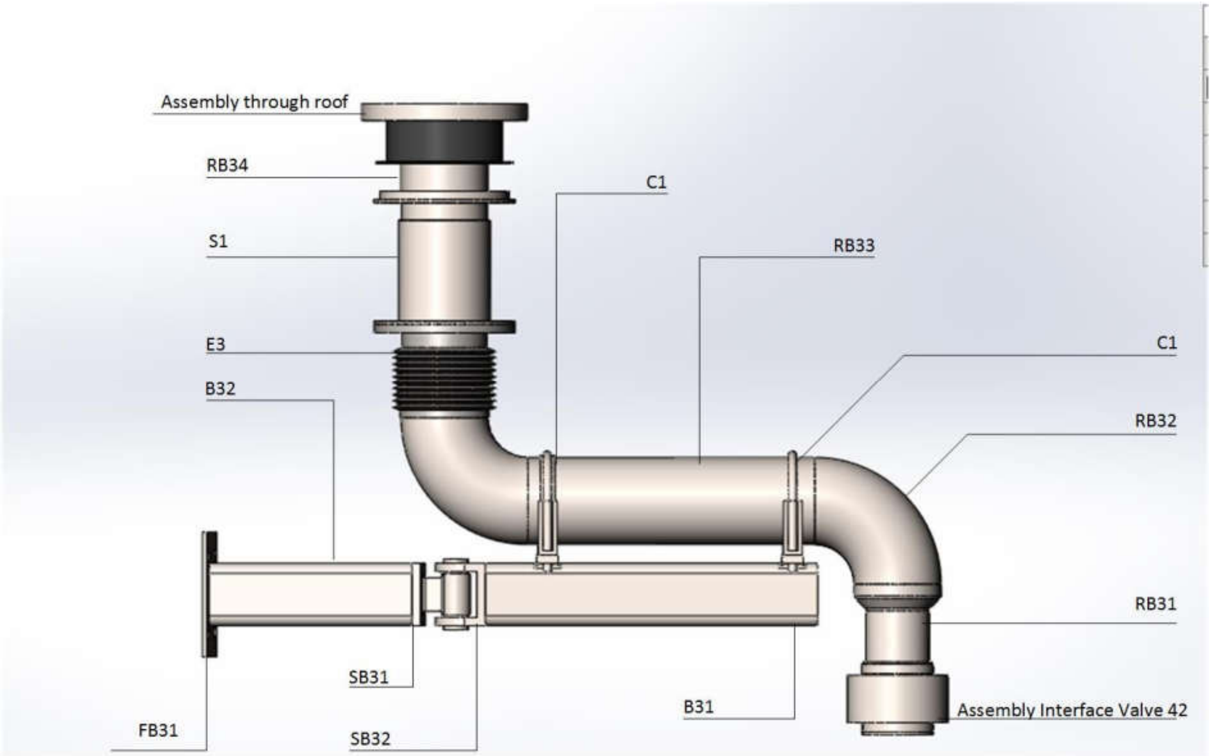
On the final design of the system there are mostly standardized buyable parts. But some parts need to be specially made. During the design, there have been made choices prioritizing standard products possible to buy from suppliers. This section only shows a list and a brief explanation of the components. But for a more detailed explanation, information about supplier, and technical specifications on the components see the separate attachment.

3.3.1 Overview of Components B1



Picture: Assembly through roof consists of parts G1, RB17, TR1
Assembly interface consists of parts I1, RW1 and CL230 (Designed in SolidWorks by the bachelor group).

3.3.2 Overview of Components B2/B3



Picture: Assembly through roof consists of G1, RB34 and TR1.
Assembly interface consists of I1, RW1 and CL230.
(Designed in SolidWorks by the bachelor group).

3.3.3 Specially Designed Components

3.3.3.1 Interface for A43,A44, and A51

Picture: Interface between turbine and bleed system

(Designed in SolidWorks by the bachelor group).

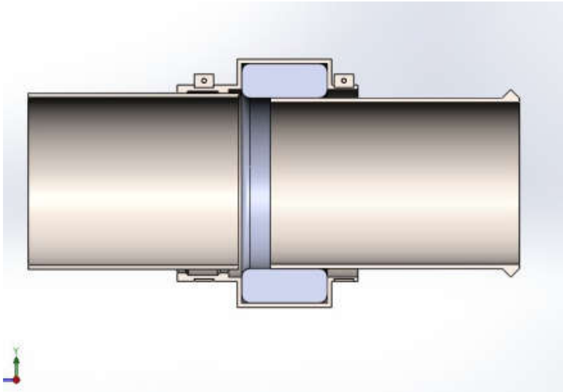
List of parts in the subassembly

Name	# part	Part ID	Material Choice	Order
Interface bowl	2	I1	stainless steel	Special delivery
Rockwool ring	1	RW1	Prorox PS 960	Supplier
Clamp	2	CL230	Standard steel	Supplier

List of specially designed parts in the subassembly:

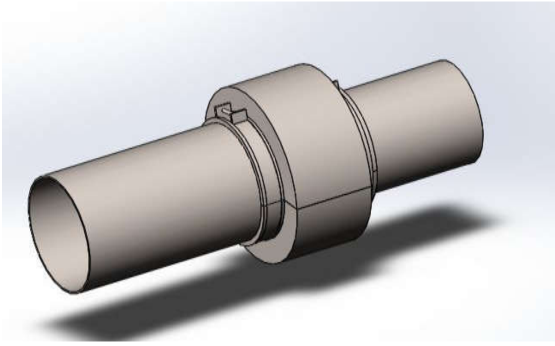
- Interface bowl
- Rockwool ring

The interface joint consists of 5 separate parts. The first picture below shows the two halves that is attached over the pipe, forming the sealing, the rockwool sealant inside, and two clamps on each end to tighten it to the pipe it shall seal. The second picture shows a section view of the concept. For more Information see attachments for components.



Picture: Section view of interface between bleed line and turbine.
(Designed in SolidWorks by the bachelor group).

3.3.3.2 Interface for A42



Picture: Interface valve 42.
(Designed in SolidWorks by the bachelor group).

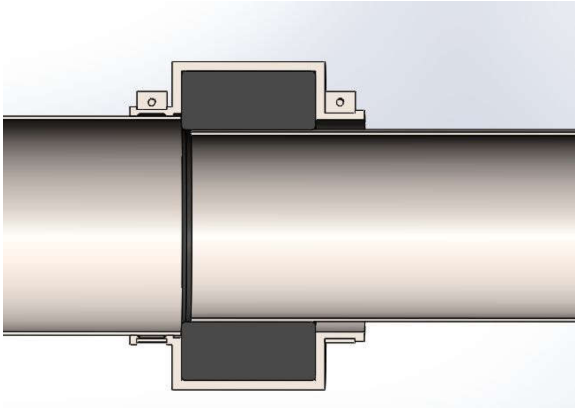
List of parts in the subassembly

Name	# part	Part ID	Material Choice	Order
Interface bowl	2	I2	Stainless steel	Special delivery
Rockwool ring	1	RW2	Prorox PS 960	Supplier
Clamp	2	CL174	Standard steel	Supplier

List of specially designed parts in the subassembly

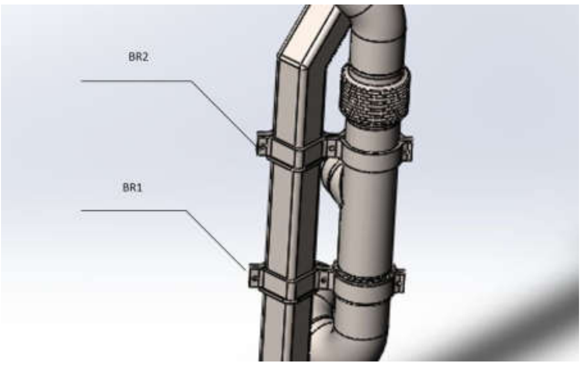
- Interface bowl
- Rockwool

Function of the interface between valve 42 and the the bleed line system is the same as for valve 43, 44 and 51, with the exception of dimensions. See the attachment “interface to valve 42”.



Picture: Section view of interface valve 42.
(Designed in SolidWorks by the bachelor group).

3.3.3.3 Boom Fixing Brackets



Picture: Position of brackets.
(Designed in SolidWorks by the bachelor group).

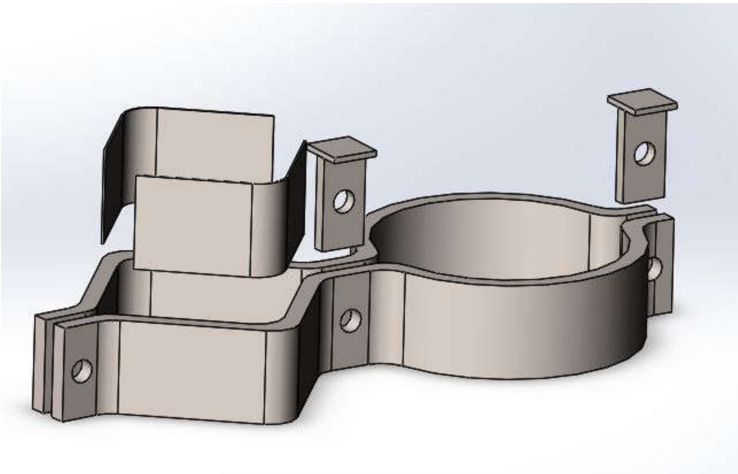
List of parts in the subassembly

Name	# part	Part ID	Material Choice	Order
Bracket	1	C21	Stainless steel	Special delivery
Bracket	1	C22	Stainless steel	Special delivery
Bolt	3	BO60	Stainless steel	Supplier
Nuts	3	NU30	Stainless steel	Supplier
Shims brackets	2	SH1	Stainless steel	Special delivery
Shims boom	2	SH2	Stainless steel	Special delivery

List of specially designed parts in the subassembly

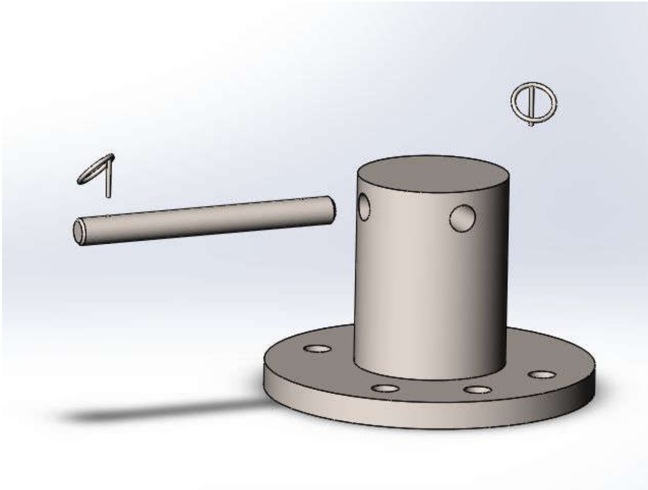
- 2 Brackets
- 3 Bolts
- 3 Nuts
- Shims boom
- Shims bracket

There are two different use of the same brackets. The top bracket on the picture allow the pipe to move due to shims, and are fixed on the boom, while the bottom bracket is fixing the boom and pipe. For more information see attachment to components, Brackets C2.



Picture: Upper brackets with shims.
(Designed in SolidWorks by the bachelor group).

3.3.3.4 Boom Foot



Picture: Boom foot
(Designed in SolidWorks by the bachelor group).

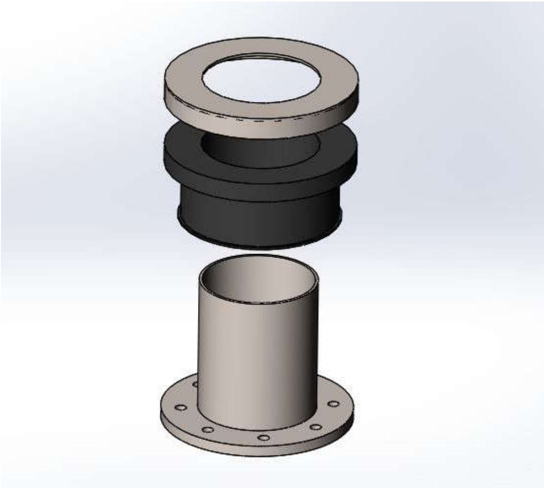
List of parts in the subassembly

Name	# part	Part ID	Material Choice	Order
Bracket	1	C21	Stainless steel	Special delivery
Foot	1	SV1	Stainless steel	Special delivery
Small spline	2	SP1	Stainless steel	Supplier
Large spline	1	SP2	Stainless steel	Supplier

List of specially designed parts in the subassembly
- Bracket
- Foot

The boom (B1) is attached over the foot, and the foot can be locked in service and operation condition of the bleed system. For further information, see “attachment Foot to boom B1”.

3.3.3.5 Roof Seal



Picture: Roof seal
(Designed in SolidWorks by the bachelor group).

List of parts in the subassembly

Name	# part	Part ID	Material Choice	Order
Isolator	1	G1	Prorox PS 960	Supplier
Top pipe	1	RB17(RB34*)	Stainless steel	Special order
Top lid	1	TR1	Stainless steel	Special order

* The roof duct for boom 1, and B1/B3 is similar. The one thing that separates them is the top pipe length.

3.3.4 Standard Buyable Components

3.3.4.1 Expansion Joint type US1F

Picture: Expansion joint type US1F
(Designed in SolidWorks by the bachelor group).

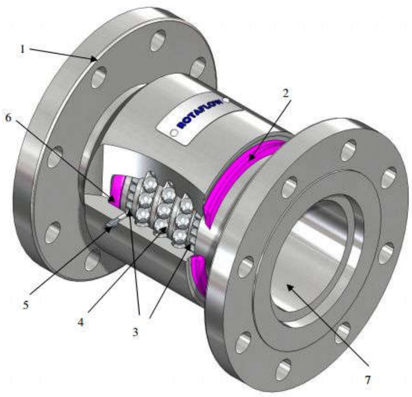
Part ID	E1
Function	Absorb dislocation due to heat expansion
Material	Stainless steel AISI 321
Price w flange	411
Price without flange	201
Weight	N/A
Length	255mm
Inner diameter	200mm
Supplier	United flexible
Additional information	See attachment

3.3.4.2 Isolation between Roof and Pipe

Picture: Isolation between roof and pipe
(Designed in SolidWorks by the bachelor group).

Part ID	G1
Function	Absorb dislocation due to heat expansion, protect from heat
Material	Prorox PS 960
Weight	N/A
Length	139mm
Inner diameter	200mm
Supplier	Glava
Additional information	See attachment “Interface for valve 43,44 and 51”.

3.3.4.3 Swivel Joints



Picture: Boom foot (Eaton Powering business worldwide, 2016).

Part ID	S1
Function	Make bleed system turn
Material	Stainless steel
Weight	85kg
Length	283mm
Inner diameter	200mm
Supplier	Rotaflow
Additional information	See attachment “Swivel joint”

3.3.4.4 Bend Fittings (90, 45, tee)

List of bends.

Type	# part	Part ID	Material Choice	Original	Config
90 degree short	2	RB32	Stainless steel	Yes	-
90 degree	2	RB22/RB12	Stainless steel	No	Length*
45 degree	2	RB15	Stainless steel	No	Length/weld*
Tee joint	1	RB13	Stainless steel	No	Length*

* see 3.3.3

3.3.4.5 U Bolt Clamps

Picture: U bolt (U-BOLTS-R-US, 2017).

Part ID	C1
Function	Secure piping
Material	Stainless steel AISI T304
Price	32 $ per piece
Total price	X4 = 128 $
Weight	N/A
Inner diameter	200mm

Supplier	U bolts r us
Additional information	(bolts online store, 2017)

3.3.4.6 Strip Wound Hose

Picture: Strip wound hose (Pacific Hoseflex, 2017)

Part ID	H1
Function	Flexibility in system
Material	Stainless steel AISI T304
Price	1743 $ per piece
Weight	N/A
Inner diameter	200mm
Supplier	Hoseflex
Additional information	Se attachment for strip wound hose

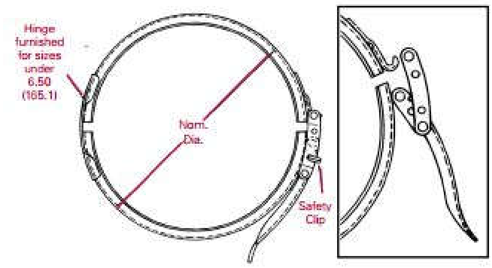
3.3.4.7 Gasket on Tube for Interface

Picture: Copper paste (Mekonomen, 2015).

Function	Smooth assemble
Material	Copper paste
Price	13 $
Weight	N/A
Supplier	Mekonomen
Additional information	(Mekonomen online store)

3.3.4.8 V-band MVT89099B

MVT89099B
Min. Nom Dia: **5.50 in.** (139.7 mm)
Max. Num. Dia.: **24.00 in.** (609.6 mm)



Picture: V-band (Eaton Powering business worldwide, 2016).

Function	Connect tubes
Material	Stainless steel
Price	See budget
Weight	N/A
Supplier	Eaton
Additional information	(Eaton online chart)

3.3.4.9 Boom Bearing (SKF Metal Deep Groove Ball Bearing 6212 60mm I.D, 110mm)

Picture: Boom Bearing (RS-online, 2017).

Function	Make boom turn
Material	Stainless steel
Price	See budget
Weight	N/A
Supplier	See budget
Additional information	(RS-online, 2017)

3.3.4.10 Splints for Boom

Picture of splint. (Wurth online store, 2017)

Function	Secure pin
Material	Stainless steel
Price	7,15 $
Weight	N/A
Supplier	Wurth Norge
Additional information	(Wurth online store, 2017)

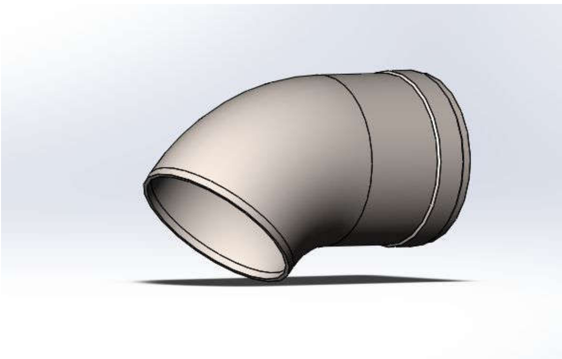
3.3.5 Buyable Parts that need to be Processed.

In the bleed line system there have mostly been chosen parts possible to buy, but many of these parts need to be welded, cut or machined. In this column there will be a detailed view of what parts in the system are processed and given the specific treatment. For extra information about the background of the components, see attachment.

3.3.5.1 Pipes

The bleed line system consists of piping with irregular angles. To get parts to fit without unwanted complexity of geometry, not suited for production, the pipes have been divided into sections. Every part of the sections have geometry from regular standard bends, and need to be cut end welded to the bleed line system in the correct angle. All the pipes are made in stainless steel 316.

3.3.5.1.1 Pipe From Valve 51(RB11)



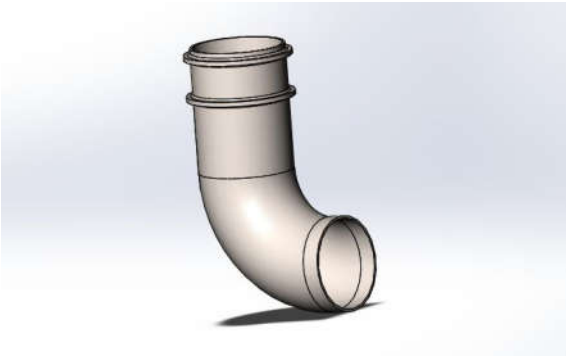
Picture: RB11. (Designed in SolidWorks by the bachelor group).

First section from valve 51 of the bleed line system. See part overview above.

Pipe length	**How to process**	**Estimated time**	**Price per/hour**	**Estimated length**	**Price pr/m**	**Total**
	Cut	0,5 h	116,5 $			58,25 $
	Weld			1,89m	35 $	66,15 $
259mm					See budget	

<u>Total cost:</u> <u>124,3$</u>

3.3.5.1.2 Second Bend From Valve 51(RB12)



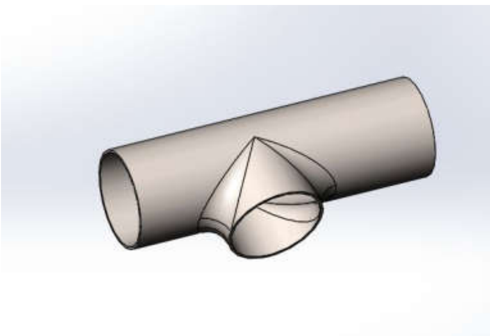
e: Second bend from valve 51
(Designed in SolidWorks by the bachelor group).

Second section of the bleed line system from valve 51. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	0,75 h	116,5 $			87,4$
	Weld			2,849m	35 $	99,7$
646,2mm					See budget	

Total cost 187,1$

3.3.5.1.3 T-bend(RB13)



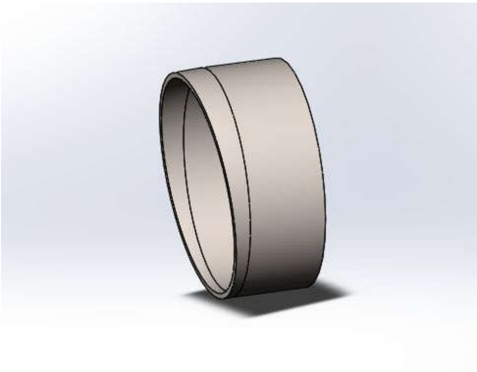
Picture: RB13 (Designed in SolidWorks by the bachelor group).

First section of the collected flow of valve 51 and 43. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	1,0h	116,5 $			116,5$
	Weld			1,98	35 $	69,3$
661,7mm					See budget	

Total cost: 185,8$

3.3.5.1.4 First Bend From Valve 43(RB14)



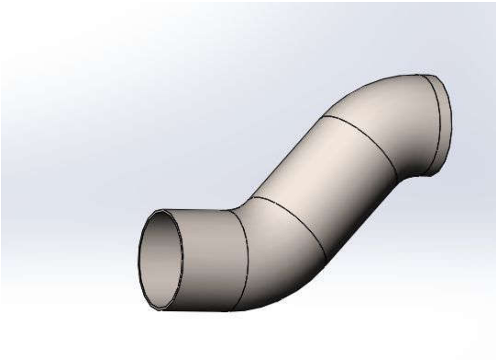
Picture: RB14. (Designed in SolidWorks by the bachelor group).

First and only section from valve 43. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	0,75	116,5 $			87,4 $
89mm					See budget	

Total cost 87,4 $

3.3.5.1.5 Vertical Pipe Along Boom (RB15)



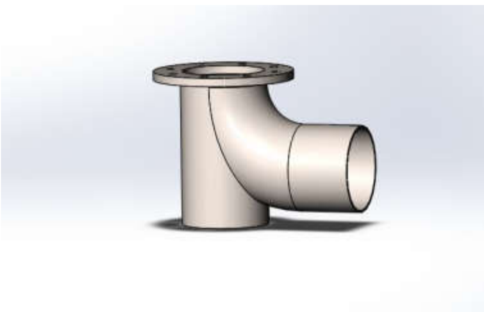
Picture: RB15. (Designed in SolidWorks by the bachelor group).

The pipe is the second section of the connected flow from valve 43 and 51. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	1,5	116,5 $			174,8$
	Weld			1,98m	35 $	69,3$
732,7mm					See budget	

Total cost: 244,1$

3.3.5.1.6 T-bend (RB16)



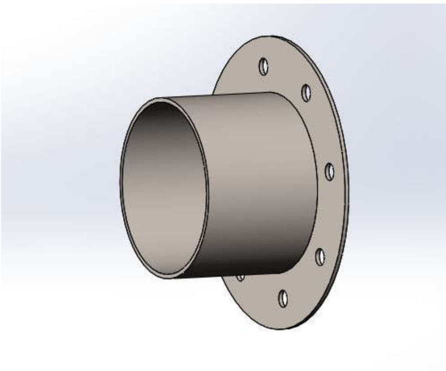
Picture: RB13. (Designed in SolidWorks by the bachelor group).

First connection pipe for flow 43,44 and 51. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	1h	116,5 $			116,5$
	Weld			1,98m	35 $	69,3$
732,7mm					See budget	
	Flange x1					236$

Total cost: 421,8$

3.3.5.1.7 Top Pipe (RB17)



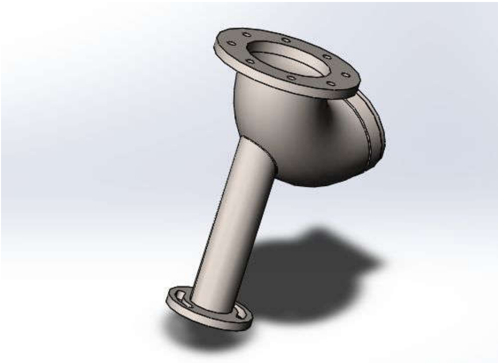
Picture: RB16 (Designed in SolidWorks by the bachelor group).

The last pipe section in the assembly through roof. See part overview above.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	0,5	116,5 $			58,3$
	Weld			1,32	35 $	46,2$
149,4mm					See budget	
	Flange x1					236$

Total cost: 340,5$

3.3.5.1.8 First Bend from Valve 44(RB21)



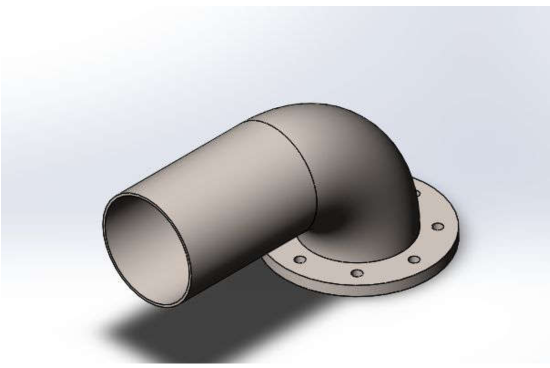
Picture: RB21. (Designed in SolidWorks by the bachelor group).

The bend is welded with a foot with possibility to screw it to the floor.

Pipe length	**How to process**	**Estimated time**	**Price per/hour**	**Estimated length**	**Price pr/m**	**Total**
	Cut	0,75	116,5 $			87,3$
	Weld			2,3m	35$	80,5$
409mm					See budget	
	Flange x1					356$

Total cost: 523,8$

3.3.5.1.9 Bend on Edge of Boom(BR22)



Picture: BR22. (Designed in SolidWorks by the bachelor group).

The flanged 90 degree pipe is attached to the strip wound hose and boom.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Weld			1,98m	35 $	69,3$
300mm					See budget	
	Flange x1					236$

Total cost: 305,3$

3.3.5.1.10 Pipe on boom (RB23)

Picture: B1. (Designed in SolidWorks by the bachelor group).

A standard pipe.

Pipe length	How to process	Estimated time	Price per/hour	Estimated length	Price pr/m	Total
	Cut	0,5			35	58,3$
1600mm					See budget	

Total cost: 58,3 $

3.3.5.1.11 Standing Boom (B1)

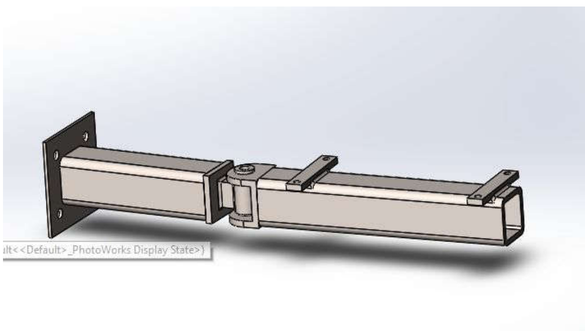
Picture: B1. (Designed in SolidWorks by the bachelor group).

The boom is supporting and allowing the swing function during service. See picture below.

Steel lenght	**How to process**	**Estimated time**	**Price per/hour**	**Estimated length**	**Price pr/m**	**Total**
	Cut	1 h	116,5 $			116,5$
	Weld			4,4m	35 $	154$
3,3mm					See budget	
	Brackets					10$

Total cost: 280,5$

3.3.5.1.12 Wall Suspended Boom (B2)



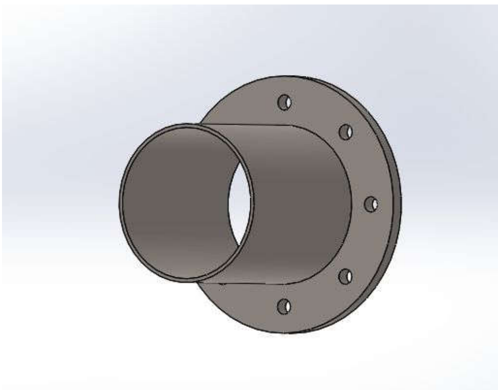
Picture: B2. (Designed in SolidWorks by the bachelor group).

The boom supports bleed line system to valve 42. See picture below.

Steel lenght	**How to process**	**Estimated time**	**Price per/hour**	**Estimated length**	**Price pr/m**	**Total**
	Cut	1 h	116,5 $			116,5 $
	Weld			4,4m	35 $	154 $
3,3mm					See budget	
	Brackets					10 $

Total cost: 280,5$

3.3.5.1.13 Top Pipe Boom 2 and 3 (RB34)



Picture: RB34. (Designed in SolidWorks by the bachelor group).

Pipe length	**How to process**	**Estimated time**	**Price per/hour**	**Estimated length**	**Price pr/m**	**Total**
	Cut	0,5h	116,5 $			58,3$
	Weld			1,32m	35 $	46,2$
1600mm					See budget	
	Flange				See budget	

Total cost: 104,5$

3.4 Installation

The installation (not to be confused with service assembly/disassembly) process for concept 16 is rather comprehensive compared to concept 30 for instance. Due to containing more parts, it has more movable features, and requires more connections. For easy and fast installation of the system it is important to try to avoid tight tolerances and the need for accurately fitted parts. Otherwise the installation might require the use of a jig system to construct the main system. To prevent the need for accuracy the concept has been constructed with a sufficient gap between the bleed system and the turbine with the gap sealed with a large rockwool seal. And to further utilize this gap for fast and easy installation it is recommended that the construction of the interfacing parts between the turbine and the bleed system shall come early in the sequence, Just after the construction of the beams. When the starting points of the pipeline system are established the rest of the routing can be connected all the way to the outside of the enclosure.

3.5 Disassembly During Service

The main service is scheduled every three years, and in this context the turbine will be removed, to be replaced by another turbine. The turbine package will be at the location it is operating on, and the bleed line system must take as little time as possible to move. The concept 16 fulfills this requirement. Although it has a longer installation time than concept 30 due to more parts, and movable sections, it is more effective when it comes to disassembly during service. Compared to C30 It is more than twice as fast to disassemble, with an estimated time around 5-6 minutes. This process is more closely described in the attachment “service description” to assembly during service.

3.6 Assembly During Service

When the turbine and all of it’s other components is installed at the site, the bleed line system has to be assembled. The steps to assemble are more closely described in the attachment “service description”.

3.7 Budget

The budget is made from prices given from the suppliers. In the cases where there has been sufficient information about the product or service on the internet this price is considered, and given a reference to the supplier or workshop. Considering manufacturing cost we have estimated the cost of concept 16 and 30 (the other final concept) differently. Were as concept 30 is less complicated to produce we have actually got real cost estimated of manufacturing, but

Since concept 16 is a more complex solution, the response from many of the workshops contacted have been negative, therefore the price has been difficult getting an exact estimate on. Therefore the price for concept 16 is estimated by ourselves. We have calculated every section of the system based on salaries and material cost. The cost for each section is shown in 3.3.3, with the total manufacturing costs belov in this section. We show the budget in two tables. One with cost for parts, and the other with cost of manufacturing.

Parts			
Parts	**Number of parts**	**Price per part/price per meter ($**	**Price ($)**
8" Pipe, sch 10, buttwelded, SS 316	4,5m	267,5	1205
3" Pipe, sch 10, seamless, SS 316	0,4m	80	32
8" 90 degree elbow, sch 10, SR, buttwelded, SS316	5	104	520
8" 45 degree elbow, sch 10, SR, buttwelded, SS316	5	68	340
8" Equal Tee joint, sch 10, buttwelded, SS316	2	216	432
8" - 6" concentric reduser, sch 10, buttwelded, SS316	1	52	52
slip on flange, 8", SS316	2	118	236
Lap joint flange, 8", SS316	2	178	356
8" expansion joint, with flange, with liner, SS316	2	411	822
8" expansion joint, without flange, with liner SS316**	2	231	231
8" Swivel joint, with flange	2	3213	6426
150mmx150mmx16mm SHS beam, SS316	5,8m	390	2262
8" stripwound hose, SS304, with flanges	1	1743	1743
Isolation	2	N/A	N/A
ball bearing, 240mm OD, 110mm ID, 50 Thickness	1	410	410
sheet metal	N/A	N/A	N/A
200mm Hose clamp, SS 302	8	4,5	36
200mm pipeclamp, SS 316	4	32	128
200mm V-band, SS 316	3	38,5	116
Sound muffler	1	N/A	N/A
		sum cost parts	15347

manufacturing			
manufacturing process	**hourly wage/production/meter cost**	**number of hours/meter needed**	**Price ($)**
Welding	35	26,4	924
Cutting	60	9,75	450
bending	-	Insignificant	insignificant
machining		?	3332
		sum cost manufacturing	4706
*The budget does not include installation.			

Tables showing the estimated cost for production of concept 16.

This results in a total price of about 20'050$. Keeping in mind that the price does not represent the real price Dresser-Rand gets from their suppliers, as well as that the price for installation and the sound silencer is left out. Theoretically this means we do not satisfy the cost requirement of the thesis (20'000$) (According to requirements S30).

4. Conclusion

To get a complete understanding of the concept, how it's produced and how it works this document must be read. The technological aspects are discussed in detail, and combined for a comprehensive overview. In the process, choices have been made and the choices are set against each other to illustrate the benefits of the choice. Included in this are summaries of manufacturing methods, from the production of individual parts, to the construction of the entire system. During the process of developing the product, choices have been made that have proved difficult and expensive but are documented and argued for how and why they have been changed. This document provides a comprehensive overview of the technological challenges, technological choices, costs and details of the smallest component.

5. References

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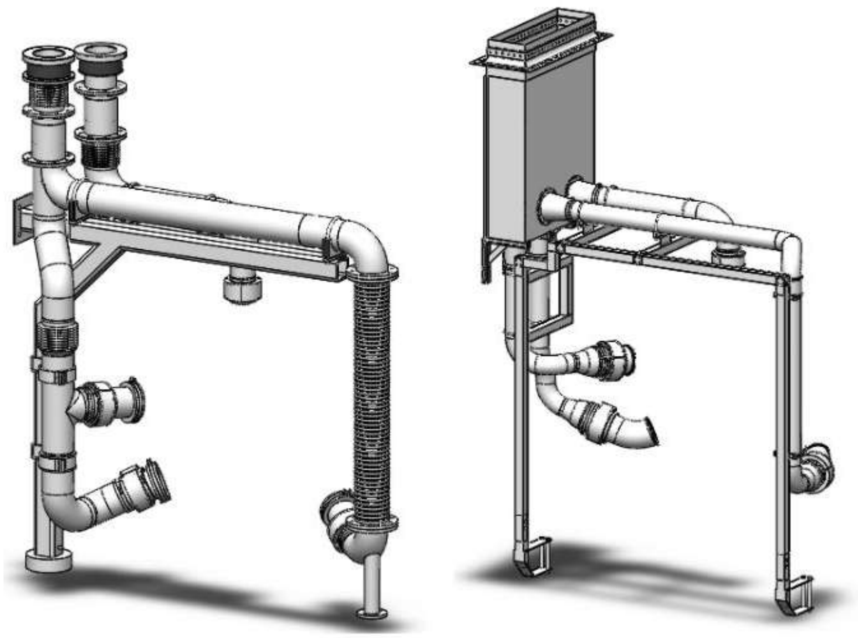
DRESSER-RAND

HSN University College of Southeast Norway

Technology Document C30

Gas Turbine Bleed System



Gruppe 19

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Øystein Botnen
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22.05.2017

Document History

Date	Version	Changes	Approved by
20.04.17	0.0	Created, layout	Daniel
20.04.17	0.1	Silencer, references, layout	Øystein, Daniel
27.04.17	0.2	3.3.1, 3.3.3, 3.3.4	Øystein
01.05.17	0.3	3.3.3	Øystein
04.05.17	0.4	3.1, 3.3.1, 3.3.2, 3.3.3	Øystein
12.05.17	0.5	2.1, 2.3, 2.4, 2.5, 3.1, 3.2, 3.3	Øystein
14.05.17	0.6	3.3	Øystein
15.05.17	0.7	3.3	Øystein
16.05.17	0.8	3.3	Svenn, Daniel
18.05.17	0.9	Assembly/disassembly during service	Øystein
19.05.17	0.10	1, 2.1, 3.1, conclusion	Øystein
20.05.17	0.11	Budget, attachments, finishing	Øystein
22.05.17	0.12	Correction and structuring	Kristian, Daniel
22.05.17	1.0	Approved for submission	Daniel

Table of Contents

1. Introduction

This document explain the main content of technological choices, components, installation, disassembly and assembly for concept 30. It explains what we have weighed against each other and why exactly the different types of choices have been made. The careful weighing is based on contact with suppliers and specifications of materials. Concept features and customization has been done. These are described in detail. The choices extend back to an early stage in the project, where the information from the first sketch to the final concept is included

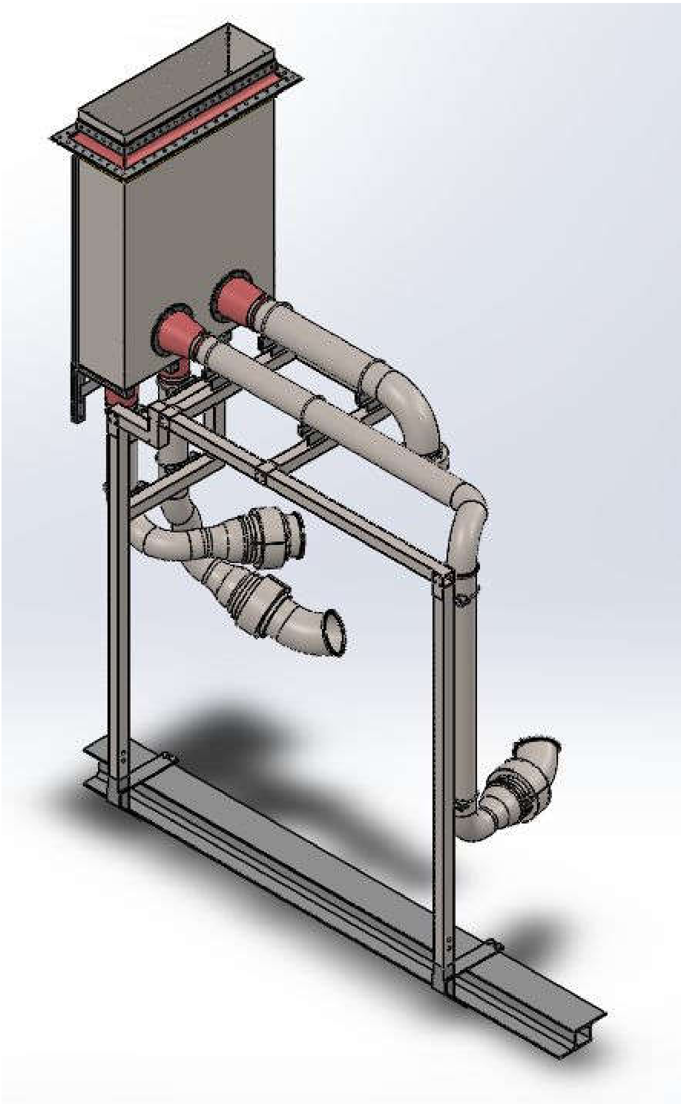
This document is easy to read and contains the most essential information, while the attachments to technological choices and components elaborate more detailed information.. Technological Summary.

2.1 Problem Statement

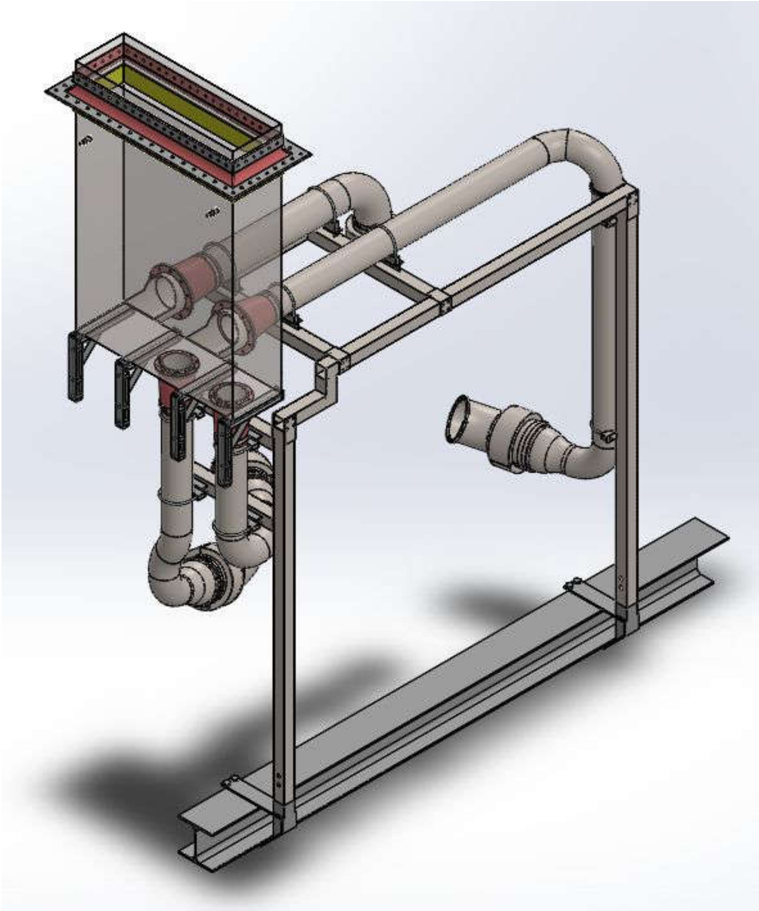
Dresser-Rand needs a new solution to an existing bleed line system made for the turbine package RB211-GT30-DLE. A turbine bleed system's task is to bleed of excess air from the compression stages before it hits the combustion chamber, during the unstable conditions of startup. In the case where the turbine is placed in an enclosure the excess air needs to be leaded from the turbine and out of the enclosure via some kind of a flow channel. The system to be replaced is difficult to disassemble, has components that are complex and that take up too much space inside the enclosure. This means that the time it takes to get it out will be long, it is demanding for technicians to disassemble and it is difficult to get to components under inspection. One of the main areas of focus in the project is the service time. The time of assembly and disassembly is required by the customer to be as low as possible, and shall at least be less than one hour total (According to requirements S37 & S38).

2.2 Solution

This concept consists of bleed lines and duct.The two pictures below shows the system that is designed.



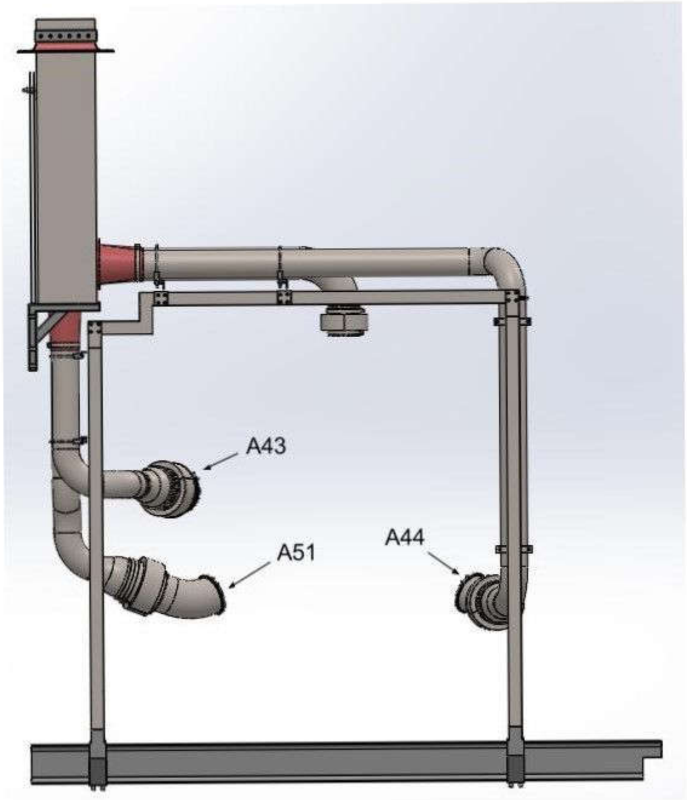
Picture: Here we see the duct, four bleed lines and the frame holding the bleed system in position (Designed in SolidWorks by bachelor group).



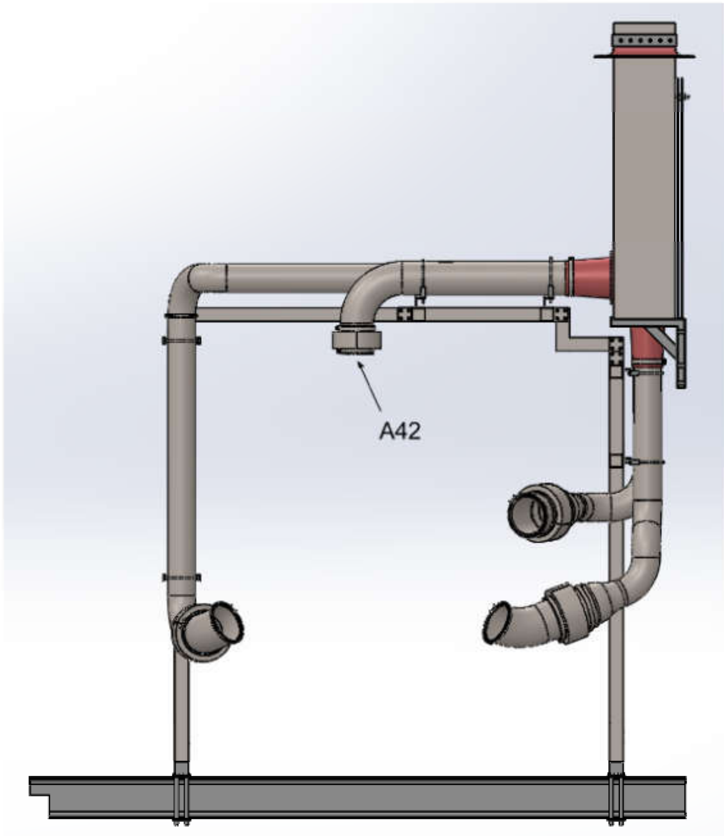
Picture: here the duct is transparent and the 4 entrance points to the duct from the bled lines is shown (Designed in SolidWorks by bachelor group) .

2.3 Overview

The first picture below is a front view and shows where the three interfaces and pipes from A43, A44 and A51 are. The second picture shows a rear view of the bleed system where interface and pipe for valve A42 is clearly shown.



Picture: shows the bleed system front view and the bleed lines from A43, A44 an A51 is marked Designed in (SolidWorks by bachelor group) .



Picture: shows the bleed system rear view and bleed lines from A42 is marked (Designed in SolidWorks by bachelor group).

2.4 Technical risk

The technical risks in this concept is not so many since it basically consists of proven technology. The interfaces between turbine and bleed system is a design from the bachelor group. This is the biggest technical risk in this concept since high temperature is combined with up to 70 kPa pressure and a huge amount of air-flow at the same time.

The flexible connection between bleed system and duct and between duct and roof of the enclosure is another technical risk. In this location we have the same challenging temperature, only with almost no pressure since the air is dumped into the duct. During research and communication with D-R we have found a solution for these risks.

The risks mentioned have not been significant enough to jeopardize the concept, but the desire to improve the already existing methods is something that has been desirable.

2.5 Technical challenges

A difficulty that was a common problem for both final concepts was finding a good solution for connecting the turbine to the bleed line system without transferring “any” loads between them. We had the same problem for this component as we did when trying to find a hose. A lot of the possible flexible sealing solutions between the turbine and the bleed line system would require the use of materials that cannot stand the high temperature over the needed period.

There have been many technological challenges. There have been requests by mail and telephone to countless suppliers. Finding manufacturing methods for components that are specially designed have been difficult, and joining the systems with welding and cutting. Some of the problems have also come during system analysis. Values have on occasion gotten higher than permissible, causing stresses higher than the yielding strength of materials used, and manufacturer can’t answer the questions. So basically, there were many of the challenges in gathering information from those who sell the products.

3. Technological Aspects

3.1 Concept Functions

The function of the bleed system is to lead the air from the compressor part of the turbine to the duct through four pipes, one from each valve. All the four pipes will be connected to the same duct where the air will be dumped. The duct will bring the air up and through the roof of the enclosure where it will be passed through a silencer and out in the atmosphere.

The bleed system will be an independent system that allows the turbine to move freely during heat expansion and will not transfer more forces than accepted to the turbine. The flexible connections to the turbine and to the duct with only one fixing point allows the bleed system to move freely during heat expansion.

3.2 Technological Choices

To reach the final design of the system we had to choose between many different configurations of the system as well as deciding which parts would best suit the requirements. There is a lot of work done on every aspect of the system and almost no features are coincidental. This section is aimed at documenting the technical process of the system. Presenting the problems, options, and the solutions here and analysis in a separate technical choise attachment for each of the subjects. In this section, we divide the choices made into problems they were meant to solve.

3.2.1 Interface

Interface - existing design or new design

The temperature of the air passing through the valve is at [redacted] degrees celsius and the material in the existing design is not working well at this temperature. So we designed a new interface with material that allows temperatures of at least [redacted] degrees celsius.

- Existing design
- New design - **Implemented**

For more information see attachment Technological choices - Interface

3.2.2 Pipes and Routing

Pipes vs tubes

- Pipes - **Implemented**
- Tubes

For more information see attachment Technological choices - pipes vs tubes.

Routing path

This concept have some alternative regarding routing of pipes.

- Separate flowpath, A44 under turbine.
- Separate flowpath A44 over turbine **- Implemented**
- Separate flowpath, A42, A43, A51 to common duct on the left side of turbine and A44 connected to duct on the right side of turbine.

For more information see attachment Technological choices - Routing path

3.2.3 Flexible Connections

Connection to duct

There are several ways of connecting to the duct that allows the movement during heat expansion. Not all of them are equally well suited for this system and the requirements are important when choosing components.

- Metal hose
- Flexible connection EagleBurgmann - **Implemented**
- Flexible joint metal

For more information see attachment Technological choices - Connection to duct

Connection between duct and roof

The connection between duct and roof must allow the movement of the duct during heat expansion.

- Fastening the duct directly to roof with flexible connection points.
- Flexible connection EagleBurgmann - **Implemented**

For more information see attachment Technological choices -Flexible connection between duct and roof.

3.2.4 Heat Protection

Heat shield versus insulation material.

The duct is placed 50 mm from the wall and heat from the duct must be prevented from radiate to the wall of casing.

- Heat shield - **Implemented**
- Insulation material

For more information see attachment Technological choices - Insulation between duct and wall

Insulation material between duct and roof

The duct has a clearance of 10 mm that needs insulation between duct and roof.

- Insulation material - **Implemented**

3.2.5 Sound Silencer

Separate sound silencer vs connected to the exhaust

This concerned whether we wanted to use the sound silencer built in the exhaust system of the turbine package, a sound silencer in the duct or using a separate sound silencer.

- Sound silencer in exhaust
- Use sound silencer as a duct
- Separate sound silencer - **Implemented**

For more information see attachment Technological choices - Sound silencer

3.2.6 Frame

Frame

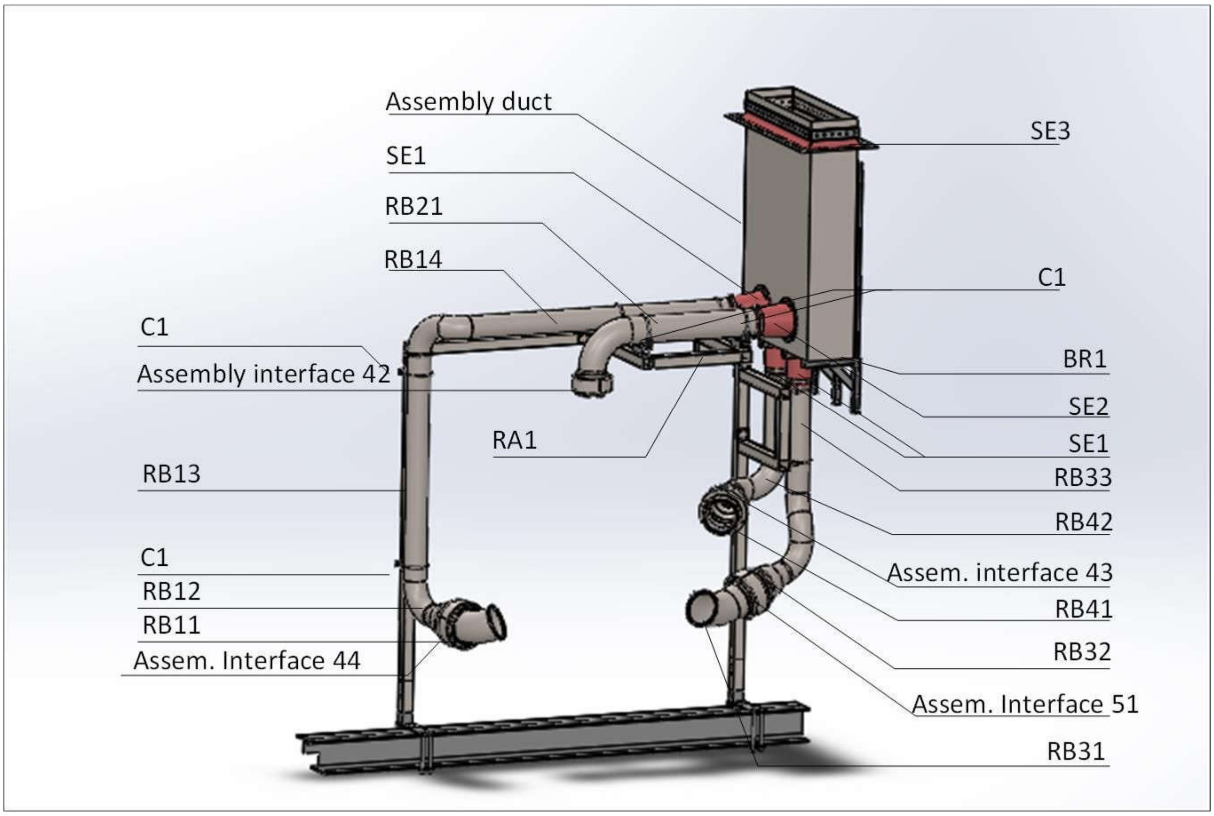
The frame will be built of mostly standard parts.

- Frame built of hollow profile, clamps (fixed and loose), bolts and nuts and some customized distans brackets. - **Implemented**

For more information see attachment Technological choices - Frame

3.3 Components

On the final design of the system there are mostly standardised buyable parts. But some parts need to be specially made. During the design there have been made choices prioritizing standard products possible to buy from suppliers. The picture below shows the parts in the assembly. More advanced parts are described as assemblies, and will be given an overview in the matrix below the picture.



Picture: shows the ID to parts in the whole bleed system (Designed in SolidWorks by bachelor group).

Part name	**Part.Id**
Interface A43,A44 and A51	I1, RW1 and CL230
Interface A42	I2, RW2 and CL174
Duct	RB111, DT1, HS1

3.3.1 Specially Designed Components

3.3.1.1 Interface A43, A44 and A51

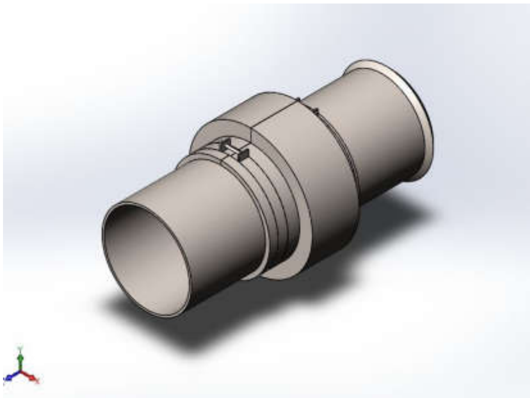
List of parts

Name	# part	Part ID	Material Choice	Order
Interface bowl	2	I1	stainless steel	Special delivery
Rockwool ring	1	RW1	Prorox PS 960	Supplier
Clamp	2	CL230	Standard steel	Supplier

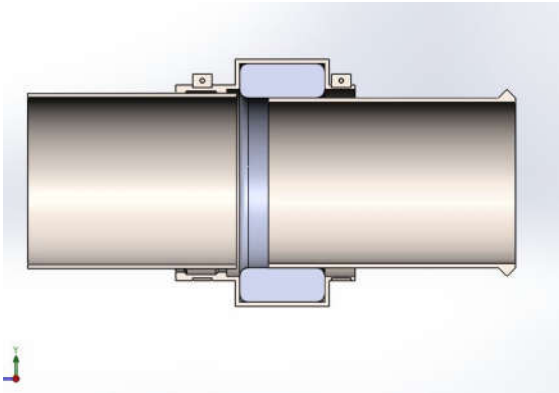
List of specially designed parts in the subassembly:

- Interface bowl
- Rockwool ring

The interface joint consists of 5 separate parts. The first picture below shows the two halves that is attached over the pipe, forming the sealing, the rockwool sealant inside, and two clamps on each end to tighten it to the pipe it shall seal. The second picture shows a section view of the concept.



Picture: Interface between turbine and bleed system
(Designed in SolidWorks by bachelor group).



Picture: Section view of interface between bleed line and turbine
(Designed in SolidWorks by bachelor group).

See component attachment - Interface valve A43,A44 and A51 and rockwool for more information

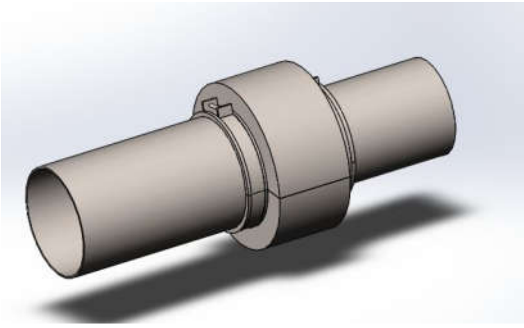
3.3.1.2 Interface for A42

List of parts

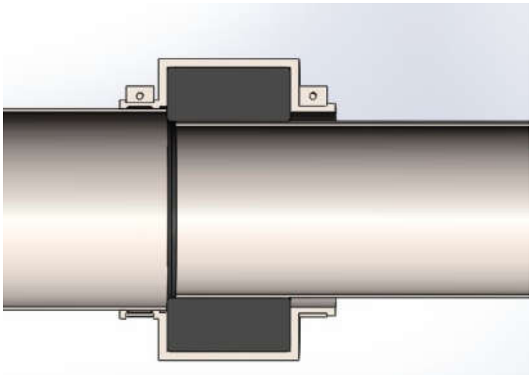
Name	# part	Part ID	Material Choice	Order
Interface bowl	2	I2	stainless steel	Special delivery
Rockwool ring	1	RW2	Prorox PS 960	Supplier
Clamp	2	CL174	Standard steel	Supplier

List of specially designed parts in the subassembly
- Interface bowl
- Rockwool

Function of the interface between valve A42 and the the bleed line system is the same as for valve A43, A44 and A51, with the exception of dimensions.



Picture: Interface valve 42
(Designed in SolidWorks by bachelor group).

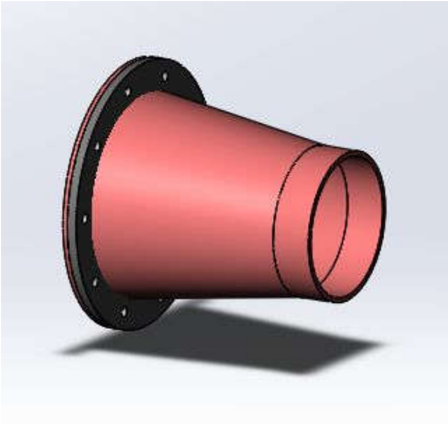


Picture: Section view of interface valve 42
(Designed in SolidWorks by bachelor group).

See component attachment - Interface valve A42 and rockwool for more information

3.3.1.3 Flexible Connection Bleed Lines - Duct

Picture below shows how the flexible connection to duct can look like. It is the same dimensions for A43, A44 and A51. Valve A42 have larger dimensions.



Picture: Flexible connection pipe to duct
(Designed in SolidWorks by bachelor group).

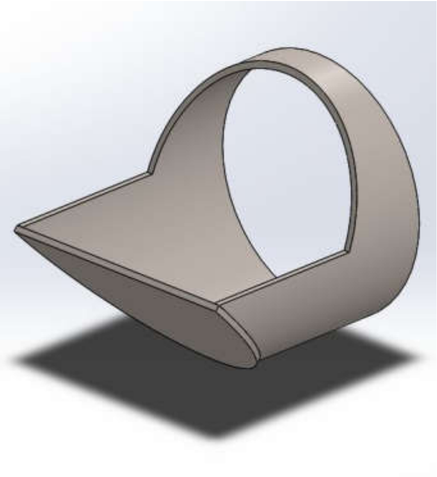
List of parts

Name	# part	Part ID	Material Choice	Order
Metal ring	4 (same size on A43, A44 and A51, different size on A42)	SE2, SE3	stainless steel	Special delivery
Membrane	3	SE1		Special delivery
Bolt and nuts	10x4 of each		Stainless steel	Supplier

See component attachment *flexible connection bleed lines - duct* for more information.

3.3.1.4 “Spoon” Inside Duct

Bleed pipes from valve A42 and A44 is mounted horizontally on the duct. To help the air change direction from horizontally to vertically we put a “spoon” unit that helps the air change direction.



Picture: shows the mechanism to hinder the air to go directly into the wall of the duct. (Designed in SolidWorks by bachelor group).

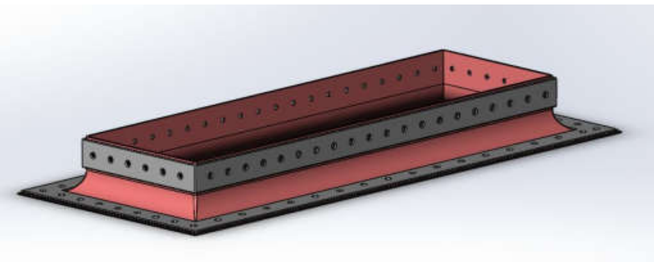
List of parts

Name	# part	Part ID	Material Choice	Order
Metal pipe part	2 (different size on A42 and A44)	RB111	stainless steel	Special delivery
End plate	Sheet metal		Stainless steel	Special delivery
Welding	One welding on each “spoon”.		Stainless steel	

See component attachment *“Spoon” inside duct* for more information.

3.3.1.5 Flexible Connection Duct - Roof

Picture below shows the design of the flexible connection between duct and roof.



Picture: shows the design of the flexible connection (Designed in SolidWorks by bachelor group).

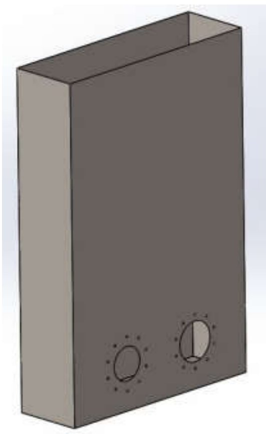
List of parts

Name	# part	Part ID	Material Choice	Order
Membrane	Composition from Eagleburgmann	SE3	Composition from Eagleburgmann	Special delivery
Fastening plate to duct	Sheet metal		Stainless steel	Special delivery
Fastening plate to roof	Sheet metal		Stainless steel	

For more information about EagleBurgmann membrane product see attachment for technological choices *flexible connection between duct and roof*.

3.3.1.6 Duct

All the bleed pipes dump the air in the duct. The duct moves the air up through the roof into the silencer. Se picture beneath for design.



Picture: shows the duct where the bleed pipes dump the air
(Designed in SolidWorks by bachelor group).

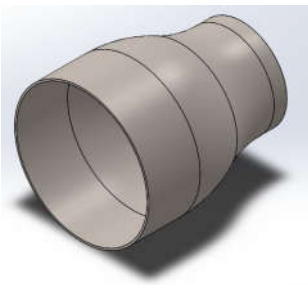
Name	# part	Part ID	Material Choice	Order
Duct complete		DT1		
Sheet metal	Front and back - 1500x1000mm		Stainless steel	Special delivery

Sheet metal	Sides - 300x1500mm		Stainless steel	Special delivery
Sheet metal	Bottom - 300x1000mm		Stainless steel	Special delivery
Welding	All the sheets must be welded together			

See component attachment *Duct* for more information.

3.3.1.7 Nozzle

The nozzle reduces the size of the pipes. The largest diameter is connected to the interface against turbine and the smallest diameter is welded to pipelines. See picture for design.



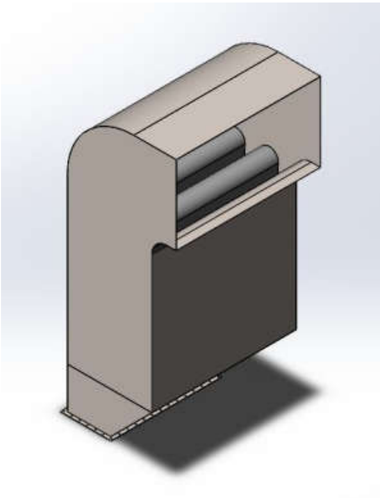
Picture: Shows a picture of the nozzle used to reduce the diameter
(Designed in SolidWorks by bachelor group).

Name	**# part**	**Part ID**	**Material Choice**	**Order**
Nozzle	From 210 to 141,3mm, length 250mm	RB12, RB32 and RB42	Stainless steel	Special delivery
Welding	The nozzle is welded on the pipelines.			

See component attachment *Nozzle* for more information.

3.3.1.8 Sound Silencer

The sound silencer is ordered from external companies that is specialized on reducing noise from mechanical machinery like this. The picture shows a possible design for a silencer like this.



Picture: shows a simple design of a sound silencer based on research
(Designed in SolidWorks by bachelor group).

See component attachment *Sound silencer* for more information.

3.3.2 Standard Buyable Components

3.3.2.1 Pipes

All the pipes can be bought from supplier. Some of the bends need to be custom cutted out of standard bends. Every end from the bleed system that is pointing at the turbine (besides A42) will have a nozzle welded on before the interface is connected. Information about the nozzle is described in section point 3.3.1.7. An overview with pictures of the consisting parts of each pipeline are listed below.

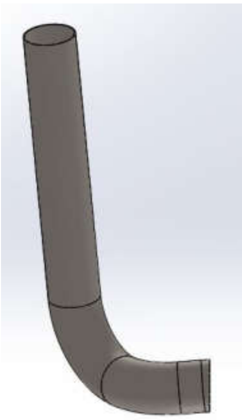
Pipeline from Valve A42(Part.Id-RB21)

Picture: shows bleed line from valve A42
(Designed in SolidWorks by bachelor group).

What	Outer diameter	Length
Straight pipe	168,3mm	1080mm
Bend 90 deg.	168,3mm	2 x diameter bend radius
Strait pipe	168,3mm	50mm

Total weight: 17kg.

Pipeline from Valve A43(Part.Id-RB42)



Picture: shows bleed line from valve A43
(Designed in SolidWorks by bachelor group).

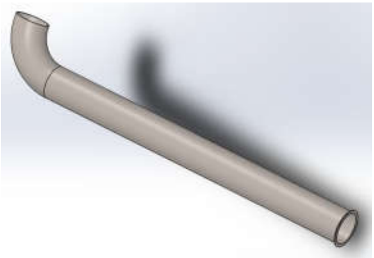
What	Outer diameter	Length
Straight pipe	141,3mm	775mm
Bend 90 deg.	141,3mm	2 x diameter bend radius
Bend 45 deg.	141,3mm	2 x diameter bend radius
Strait pipe	141,3mm	65mm
Bend 45 deg.	141,3mm	Custom cutted, 2 x diameter bend radius
Nozzle	From 210 to 141,3	250mm

Total weight including nozzle: 16,2kg.

Pipeline from Valve A44

A44 consists of two parts because of the weight.

Part one (1.Part.Id-RB13)

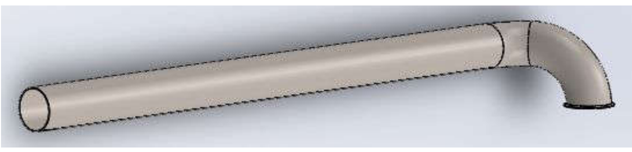


Picture: shows bleed line from valve A44 part one
(Designed in SolidWorks by bachelor group).

What	Outer diameter	Length
Bend 90 deg.	141,3mm	2 x diameter bend radius
Strait pipe	141,3mm	1415mm
Flange		Welded on for pairing part one and part two.
Nozzle	From 210 to 141,3	250mm

Total weight including nozzle: 19,9 kg

Part Two (2.Part.Id-RB14)



Picture: shows bleed line from valve A44 part two
(Designed in SolidWorks by bachelor group).

What	Outer diameter	Length
Straight pipe	141,3mm	1972mm
Bend 45 deg.	141,3mm	2 x diameter bend radius

Bend 90 deg.	141,3mm	2 x diameter bend radius
Flange		Welded on for pairing part one and part two.

Total weight: 23,5kg.

Pipeline from Valve A51 (Part.Id-RB33)

Picture: shows bleed line from valve A51
(Designed in SolidWorks by bachelor group).

What	Outer diameter	Length
Straight pipe	141,3mm	1972mm
Bend 45 deg.	141,3mm	Custom cutted - 2 x diameter bend radius
Bend 45 deg.	141,3mm	Custom cutted - 2 x diameter bend radius
Bend 90 deg.	141,3mm	2 x diameter bend radius
Nozzle	From 210 to 141,3	250mm

Total weight including nozzle: 17,4kg

3.3.2.2 Rectangular Steel Beam (Part.Id-RA1)

The frame for the bleed system is made of rectangular steel beams. Picture below shows how the frame looks like.

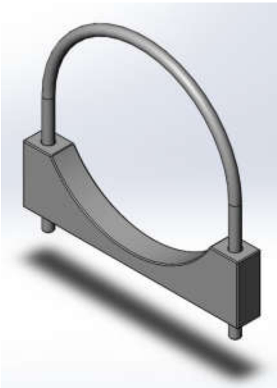
Picture: Shows the design of the frame
(Designed in SolidWorks by bachelor group).

Function	Secure piping
Material	Plain carbon steel
Weight	8,16kg/m
Dimensions	70mmx70mm, 4mm thickness
Supplier	Smith stål
Additional information	See Smith stål for more information (Smith stål, 2010)

See component attachment *Frame* for more information.

3.3.2.3 U Bolt Clamps with Saddle (Part.Id-C1)

The pipes are fastened with u-bolt with a saddle. Here the sizes are based on pipe sizes and whether the fastening shall be loose or fixed. The picture below shows the U-bolt and saddle.



Picture: shows the u-bolt placed in the saddle
(designed in SolidWorks by bachelor group).

Function	Secure piping
Material	Plain carbon steel
Weight	N/A
Inner diameter	Varies from 150mm to 170mm
Supplier	Exhaust components
Additional information	See the reference for more information (Exhaust components Online Store, 2017)

3.3.2.4 V band for Pipe (CL1)

The connection of A44 part one and part two. The picture shows how a band like this can look like.

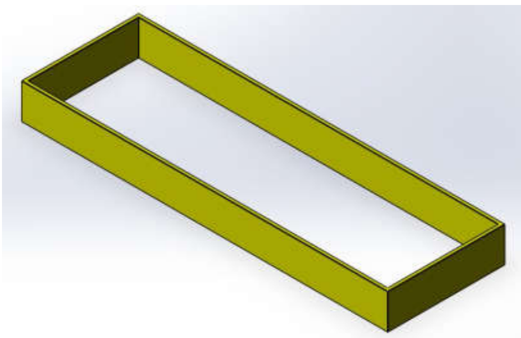
Picture: shows the design of the v-band holding part
one and part two of bleed line A44 together.
(designed in SolidWorks by bachelor group).

3.3.2.5 Screws and Nuts

There will be some different sizes of screws and nuts. These is not prioritized to draw in the 3D model since this is standard parts that can be bought from many places.

3.3.2.6 Insulation Between Duct and Roof

The clearance between duct and roof is stuffed with insulation. Picture below shows the the design.

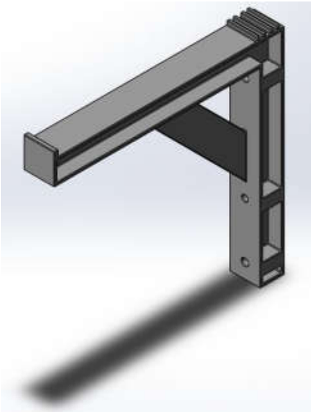


Picture: shows the design of the insulation between duct and roof
(designed in SolidWorks by bachelor group).

See component attachment *Insulation between duct and roof* for more information.

3.3.3 Buyable Parts that Need to be Processed

3.3.3.1 Brackets for Duct (Part-Id-BR1)

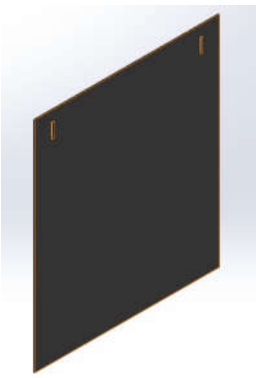


Picture: shows the design of the brackets holding the duct
(designed in SolidWorks by bachelor group).

Size	How to process	Quantity
Length: 375mm Height: 355mm	Buying a bracket, cutting and welding	4 pieces

For more information about the bracket see Harrison metals (Harrison metal inc., 2017).

3.3.3.2 Heat Shield(Part.Id-HS1)



Picture: shows the design of the heat shield
Between the duct and the enclosure
(designed in SolidWorks by bachelor group).

Sheet size	**How to process**	**Quantity**
Length: 1020mm Height: 1220mm	Cut sheet metal, cutting hole for fastening.	2 pieces

See component attachment *Heat shield* for more information.

3.4. Installation

The installation process for this concept is divided in two. The duct with sound canceller and the rest of the bleed system. The brackets for the duct will first be mounted, then the heat shield will set in place with distance disks and screws. Then the duct can be lifted in place with a lifting mechanism and lowered onto the brackets. The flexible joint, duct to roof, the insulation material can be sat in place and be fastened and the sound silencer can be mounted on top. The four flexible connection joints joining the bleed lines with the duct will be mounted before the assembly of the frame starts.

For mounting the bleed system the frame needs to be in place.The frame consists of 5 main parts that will be mounted together. The different distancing parts for the bleed pipes together with the saddle for U-bolt will be welded to the frame parts before mounting. Then the pipes will be set in place with the U-bolts and fastened with nuts on U-bolts. Bleed line A44 consists of two parts where the vertical part will be mounted first and then the horizontal part. The interface will then be mounted in place to connect to turbine.

3.5. Disassembly/Assembly during Service

The main service is scheduled every three years, and in this context the turbine will be removed, to be replaced by another turbine. The turbine package will be at the location it is operating at, and the bleed system must take as little time as possible to remove. The frame and bleed lines will have to be disassembled, while the duct and sound muffler can remain in their positions during service. When the turbine and all of it’s other components are installed at the site, the bleed line system has to be assembled.

After a disassembly simulation it is estimated to take 11 min to disassemble the system. that is without removing the interface extensions, but 12:15 min if they are to be removed, which both are good values compared to the current system, taking 29:30 min, or 31:45 min, depending on if the interface extensions is removed or not.

See service manual for concept 30 for more information on disassembly and assembly.

3.6 Budget

The budget shown below is a rough overview and gives only an idea of how much this bleed system will cost.

Parts			
Parts	**Number of parts/units**	**Price per part/price per meter ($)**	**Price ($)**
Interface Ø210mm (A43, A44 and A51)	3	830	2490
45 degrees bends Ø141,3mm	5	36.5	182.5
45 degrees bends Ø200mm	3	68	204
20mm straight pipe Ø200mm	3	41.5	124.5
90 degrees bends Ø141,3mm	4	56.3	225.2
Flexible connection to duct	4	700	2800
"Spoon" inside duct	2	60	120
Straight pipe Ø141,3mm	5.2	227.5	1183
Nozzle Ø210mm down to Ø141,3mm	3	52	156
Interface Ø153mm (A42)	1	830	830
90 degrees bend Ø168,3mm	1	56.3	56.3
Straight pipe Ø168,3mm	1.2	227.5	273
Duct (including sheet metal + welding)	1	560	560
Heat shield 1220mm*1020mm	2	60	120
Flexible connection roof - duct	1	1000	1000
Insulation material between duct-roof	1	12	12
Brackets	4	120	480
Frame for bleed system (including welding)	1	2350	2350
U-clamps and saddle	10	32	320

V band for pipe A44	1	38.5	38.5
Welding of bleed system	1	2400	2400
Sound silencer	1	N/A	
		sum cost parts	15592

This results in a total price of about 15’600$, Keeping in mind that the price does not represent the real price Dresser-Rand gets from their suppliers, as well as that the price for installation and the sound silencer is left out. Currently we satisfy the cost requirement of the thesis (20’000$) (According to requirements S30).

4. Conclusion

This concept is a product with a lot of known technology and is based on simple principles. There has been a lot of focus on easy disassemble and assemble and to make this as timesaving and quick as possible. All the parts that need to be disassembled during service are weighted below 25 kg which allows a single person to lift each part all alone. The four bleed lines and the frame needs to be disassembled when doing service. Duct and the associated parts can just be in place when the turbine is lifted out. After all we are very satisfied with the simplicity of this concept and hope some of the mapped information can be used by D-R in further investigation of a bleed system.

7. References

Exhaust components Online Store (2017). Truck exhaust pipes. [Internet] Available at: http://rikerexhaust.com/product-category/clamps/clamps-double-saddle-flat/ [Accessed: 15 May 2017].

Harrison metal inc (2017). Electrical utilities. [Internet] Available at:
http://harrisonmetals.com/
[Accessed: 15 May 2017].

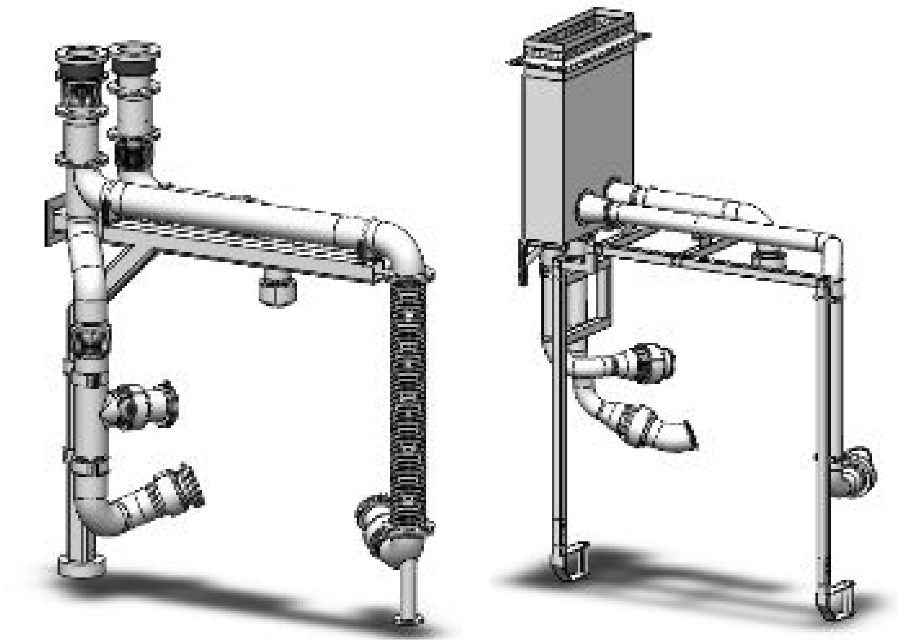
Smith stål (2010). Lagerkatalog. [Internet] Available at: http://www.smithstal.no/SmithStaal/Produkter/lagerkatalog-smithstal.no.pdf [Accessed: 13 May 2017].

DRESSER-RAND

HSN University College of Southeast Norway

Iteration Reports

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
Svenn Bjørnstrøm
Kristian I. Asgeirsson

23.05.2017

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Iteration report

1. Iteration round 1

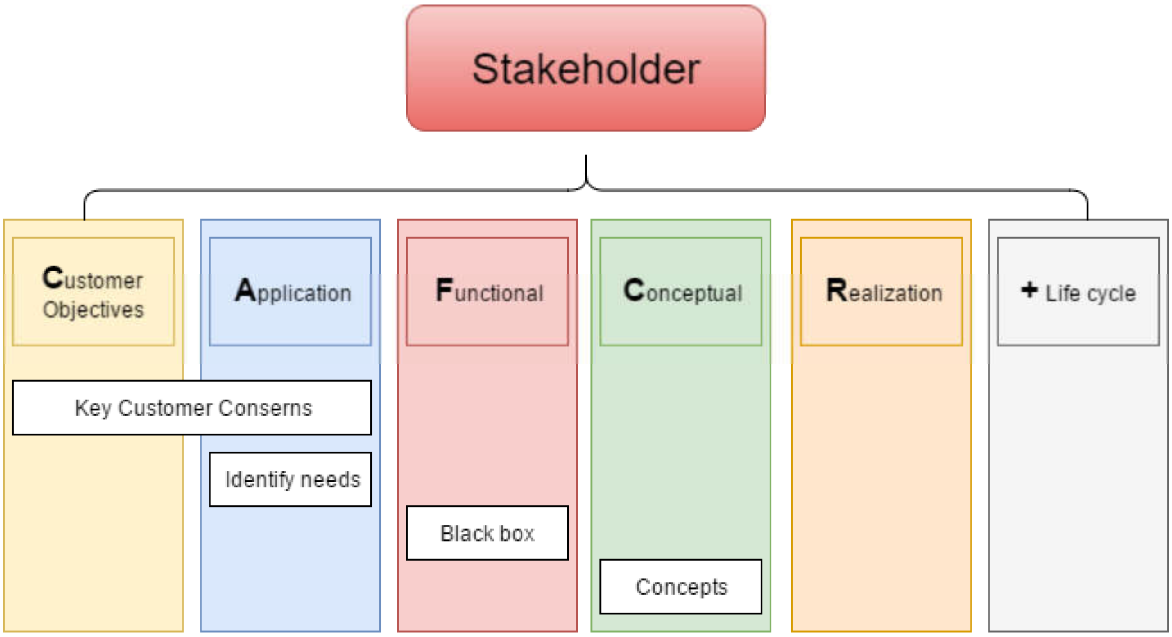


Diagram: shows an overview of iteration 1, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Date: 20.01.2017

Phase: Stakeholder

Iteration views:
- Customer objectives
- Application
- Functional
- Conceptual

Activities:
- Key customer concerns
- Identify needs
- Black box
- Design

Time scheduled: 20 min timeboxing

1.1 Introduction

The group decided four main fields to investigate further in the first iteration. Key customer concern, needs, black box and design. We used a timer for the different rounds, and decided to stop the clock before time was up if the ideas slowed down. The primary stakeholder concern slowed down against the end to be stopped 2 minutes before time stopped. The needs and black box slowed down towards the end, but not enough to be stopped and design was productive of ideas through the 20 min. Cafcr+ model have iterations as a key stone, and they are to be stopped when ideas stop flowing.

1.2 Activities

Activity: Key customer concern - 20 min Time Box

Phase: Stakeholder
View: Customer objectives & Application

The first time boxing was key customer concerns. We wanted key concerns for the project and decided to change the name from Key customer concerns to primary stakeholders concern. This was changed since Key customer concerns doesn't cover the information needed. The concerns are made for tracking down needs, and primary stakeholders needs could generate new requirements. Our primaries are us, company and school. Some requirements and concerns was already found prior to the iteration and new ones was discovered during the iteration. An overview is shown in the primary stakeholders concerns figure below.

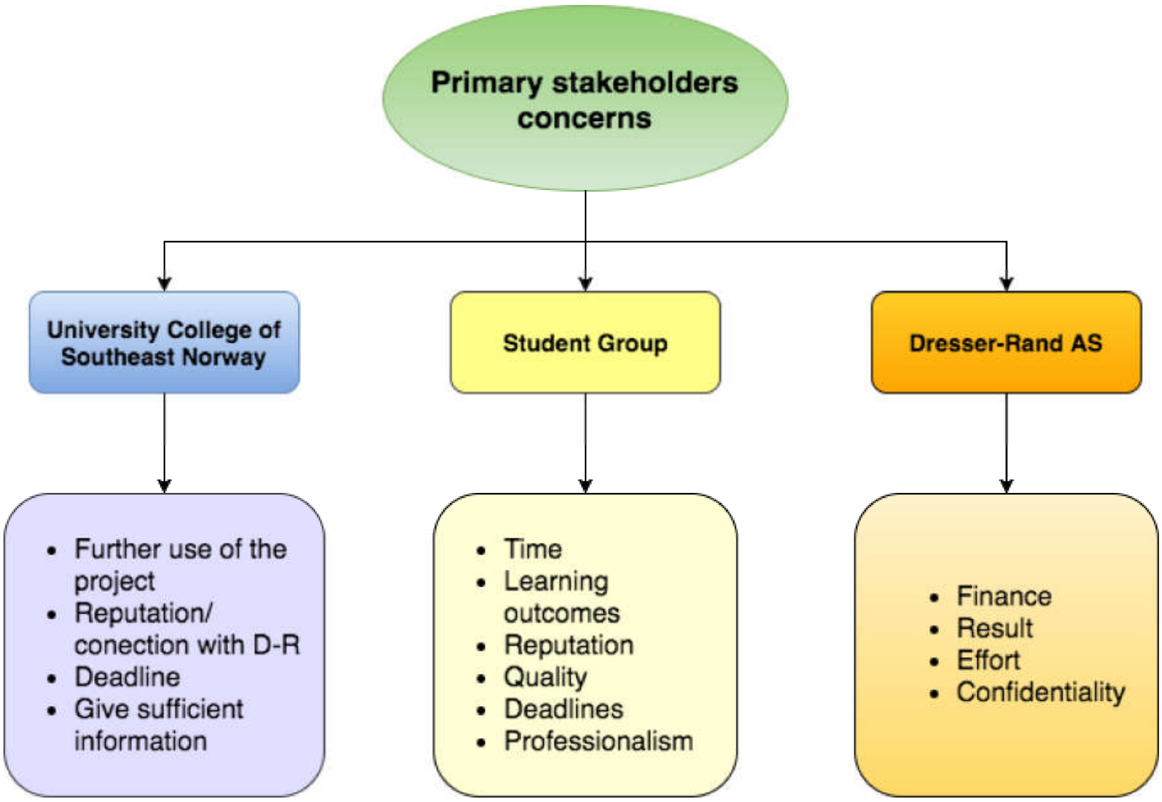


Figure: Primary stakeholder concerns

Activity: Needs - 20 min Time Box

Phase: Stakeholder
View: Application

Timeboxing of 20 minutes was used for tracking needs. The concerns is translated into needs that will influence the product specification (Muller, 2013). We concentrated on company's needs, which will generate the tread to old and discovery of new requirements. We found it difficult in the beginning separating the needs from concerns, but it all sorted out. In needs we tracked who wanted the product(customer objective), to how we are going to make it (application) and final what we are going to do to meet the application (functional). The figure below shows the connection for needs.

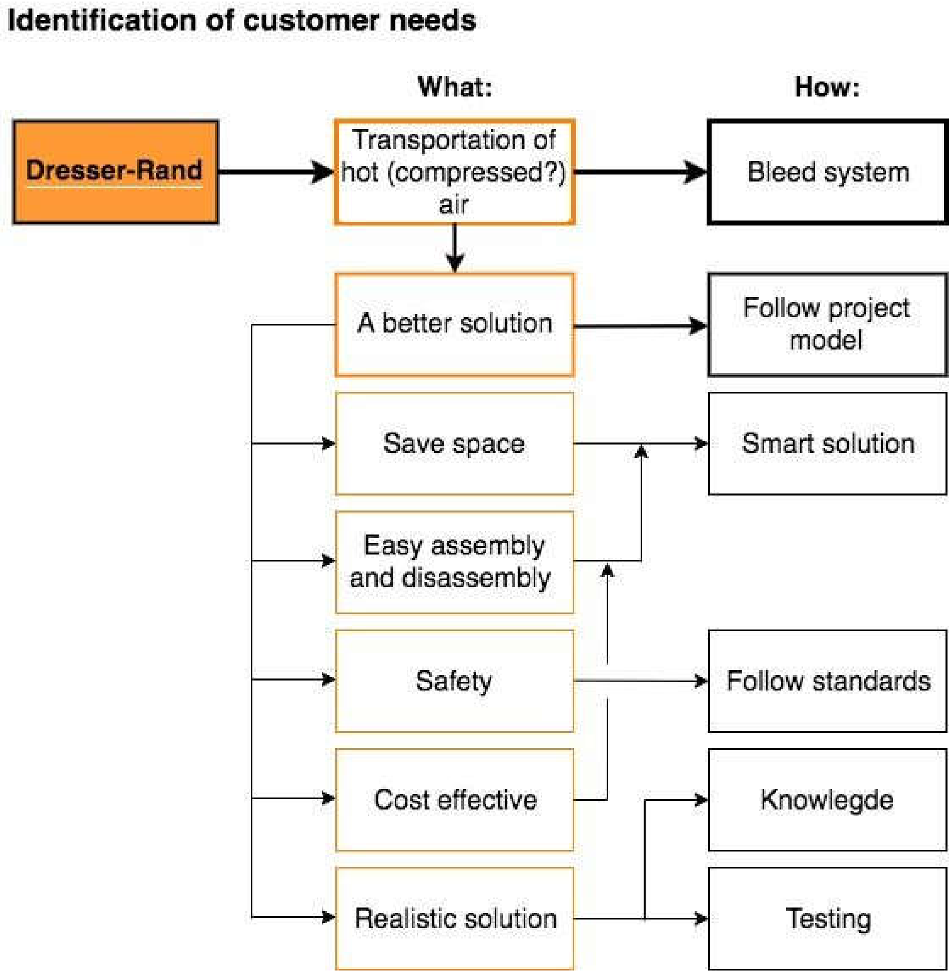


Figure: Identification of customer needs.

Activity: Black Box - 20 min Time Box

Phase: Stakeholder
View: Functional

Timeboxing of 20 minutes was used to design system as a black box. This shows the what of the system, and all of the specifications of the system that is inside the box (Muller, 2013). The lack box shows the system by what goes in, and what comes out without taking in any view about the system itself. It also shows the constraints system have to cope with, and what kind of interfaces we have to take into account. This is giving the studentgroup a better visual understanding of the problem and the environment the system is installed in. The figure below shows the result.

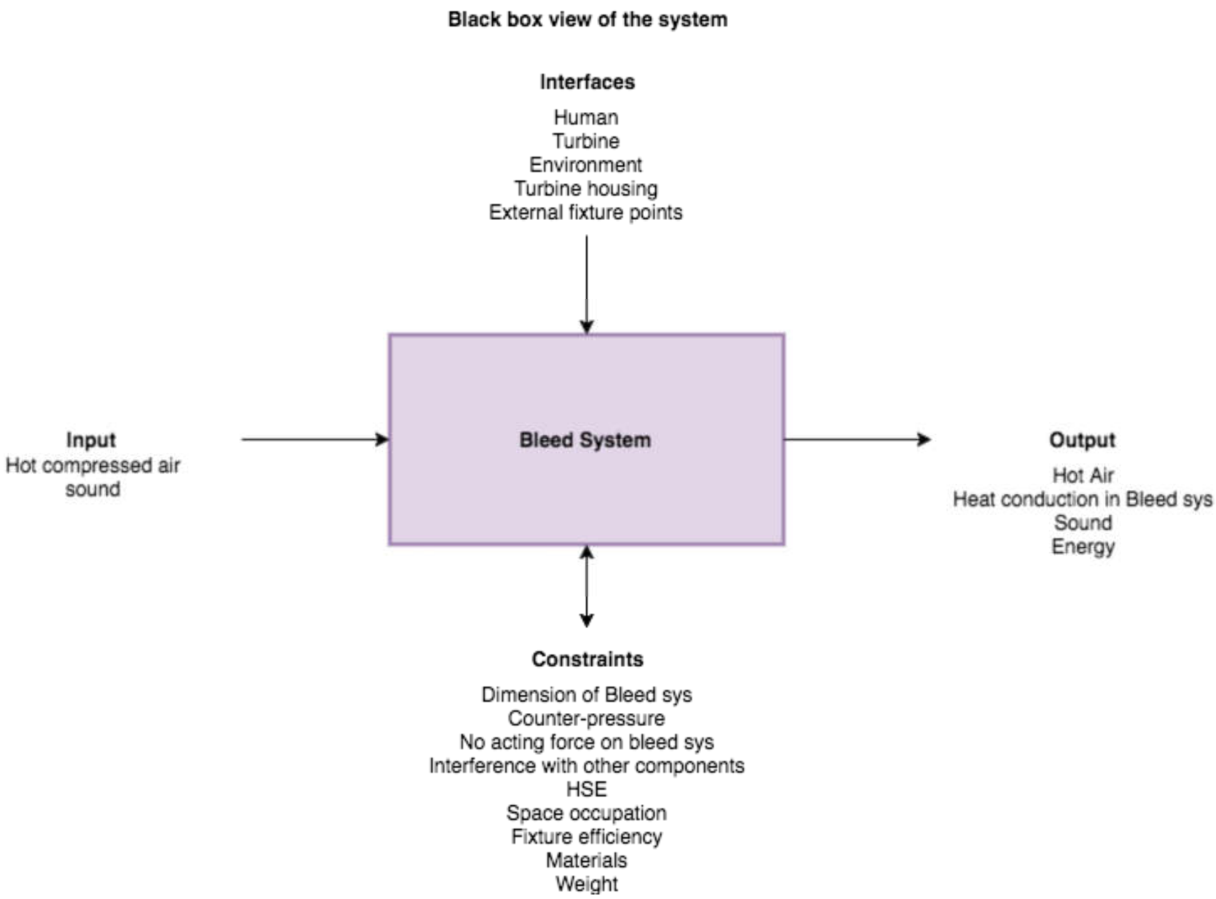


Figure: Black Box

Activity: Concept design - 20 min Time Box

Phase: Stakeholder
View: Conceptual

Timeboxing of 20 minutes was used for design. In the design some of the group members came up with ideas to how the design should be. Three different design was produced, with major differences, and there was discussion around each example to understand the meaning of the idea.

One of the design that we discussed was leading the bleed air back to the turbine inlet. This can give challenges by increasing the temperature of the air at the inlet of the turbine. Since the efficiency of the turbine decreases when the temperature of the air is increasing, we don't want to rise the temperature of the air at the inlet. We have to find out more about how the impact of the hot bleed air affects the main inlet air. And if the efficiency of the turbine decreases, can we accept it when the turbine needs to bleed air by part load and during starting up.

Design number two was a enclosure around the bleed valves leading to a funnel up and through the roof of the enclosing. This solution will demand som flexibility in the connection to roof and/or the pipe itself. The solution will spare the turbine a lot of weight since it will be i light material, and doesn’t take up a lot of room to give the maintenance crew difficulties reaching the other part of the turbine. There will be some restrictions when the air is led out. The top of the funnel will need a sound muffler to prevent the loud noise from entering the environment. One of the restrictions is the high pressure from one of the valves, and the three other which have low pressure. If there is counterpressure the air will blow back into the turbine. The solution must have separation of the low pressure valves and the high pressure one.

The last design resembled solution number two, only now we wanted to lead the air through the walls of the housing. Maybe this is an easier option, but we need more information about details in the housing and the limitation on guiding the air up to the ceiling outside the housing.

1.3 Conclusion

A basic understanding of the environment and system was made, the systems main interfaces and new ideas to the concept was generated. There is possibly some new requirements that need elaboration. Now the knowledge about components in the system are clearer, and some of the obstacles we will meet. In general the iteration result was good, and productive regarding the outcome we wanted. In the first iteration nothing revolutionary was discovered since the group have a lot of time to prepare for the project, and there are more expectations for next iteration round. We also found out with more work done prior to the iterations, less outcome of the productivity in the iteration.

1.4 Reference

Muller, G.J. (2013) *CAFCR: A Multi-view Method for Embedded Systems Architecting; Balancing Genericity and Specificity.* Available at: http://www.gaudisite.nl/ThesisBook.pdf [Accessed: 20 January 2017]

Iteration report

2. Iteration round 2:

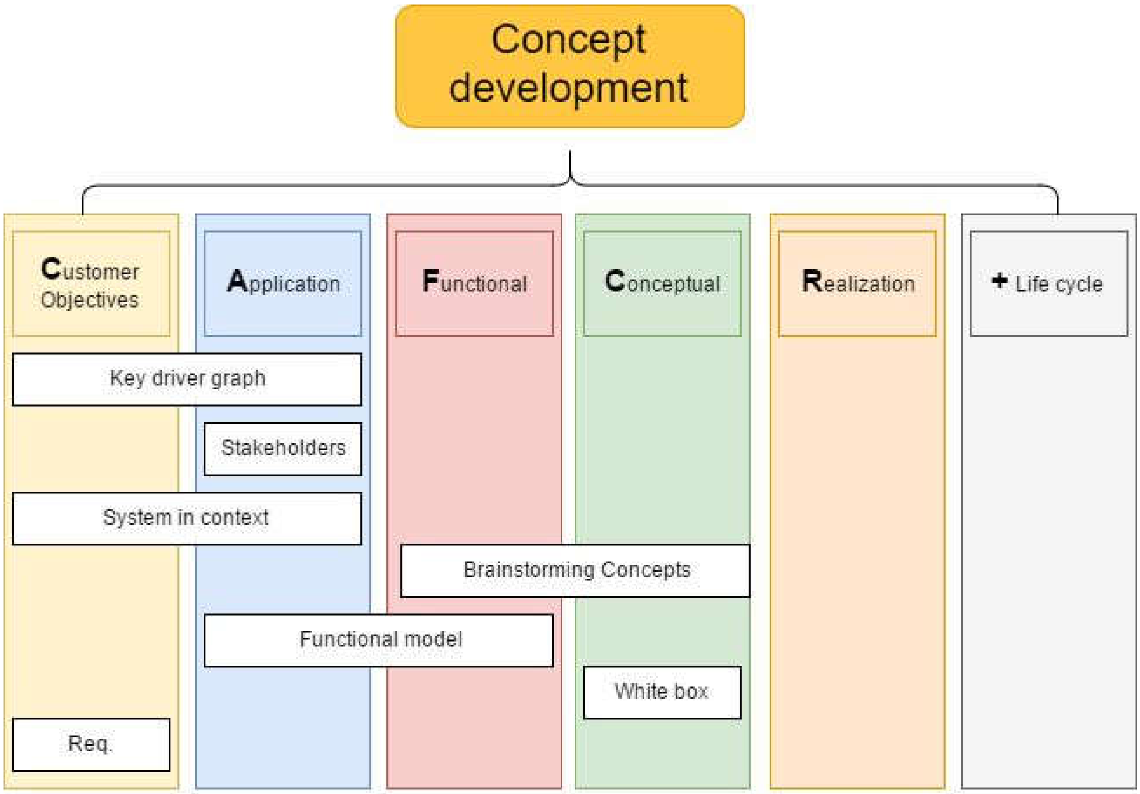


Diagram: shows an overview of iteration 2, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Date: 07.02.17

Phase: Conceptual development

Iteration views:

- Customer objectives
- Application
- Functional
- Conceptual

Activities:

- Key drivers

- Stakeholders
- System in context
- Brainstorming concepts
- Functional model
- Whitebox
- Requirements

Time scheduled:
The time boxes was in some activities extended for the purpose of having sufficient time. The ideas was generated in a bigger paste than expected, so the choice was taken in the group to make more time. Some of the activities was doubled, and which ones is described in each activity.

2.1 Introduction

This iteration is the introduction to the concept phase. The goal is therefore to make several concepts to work on further into the phase. Simultaneously we have to validate existing requirements and generate new ones so that the concepts we develop always is what the customer wants and needs. As soon as a requirement is made that is in conflict with a concept, the concept must be eliminated. The activities done during this iteration reflects this iteration goal.

2.2 Activities

Activity: Key driver graph - 20 min Time Box x2

Phase: Concept development
View: Customer objectives & Application

Key driver graph relates the customer needs with the requirements in the product specification.This graph helps to understand the customer better, and helps to asses the importance of requirements (Muller, 2016a).

The way we went about doing this task was by focusing on allocating unknown requirements. So we didn't include derived application drivers that we thought produced requirements we already knew.

The result was good. We allocated several new requirements from the key drivers of safety, maintenance time, cost, operation, and compatibility. The specific requirements can be seen from figure shown below.

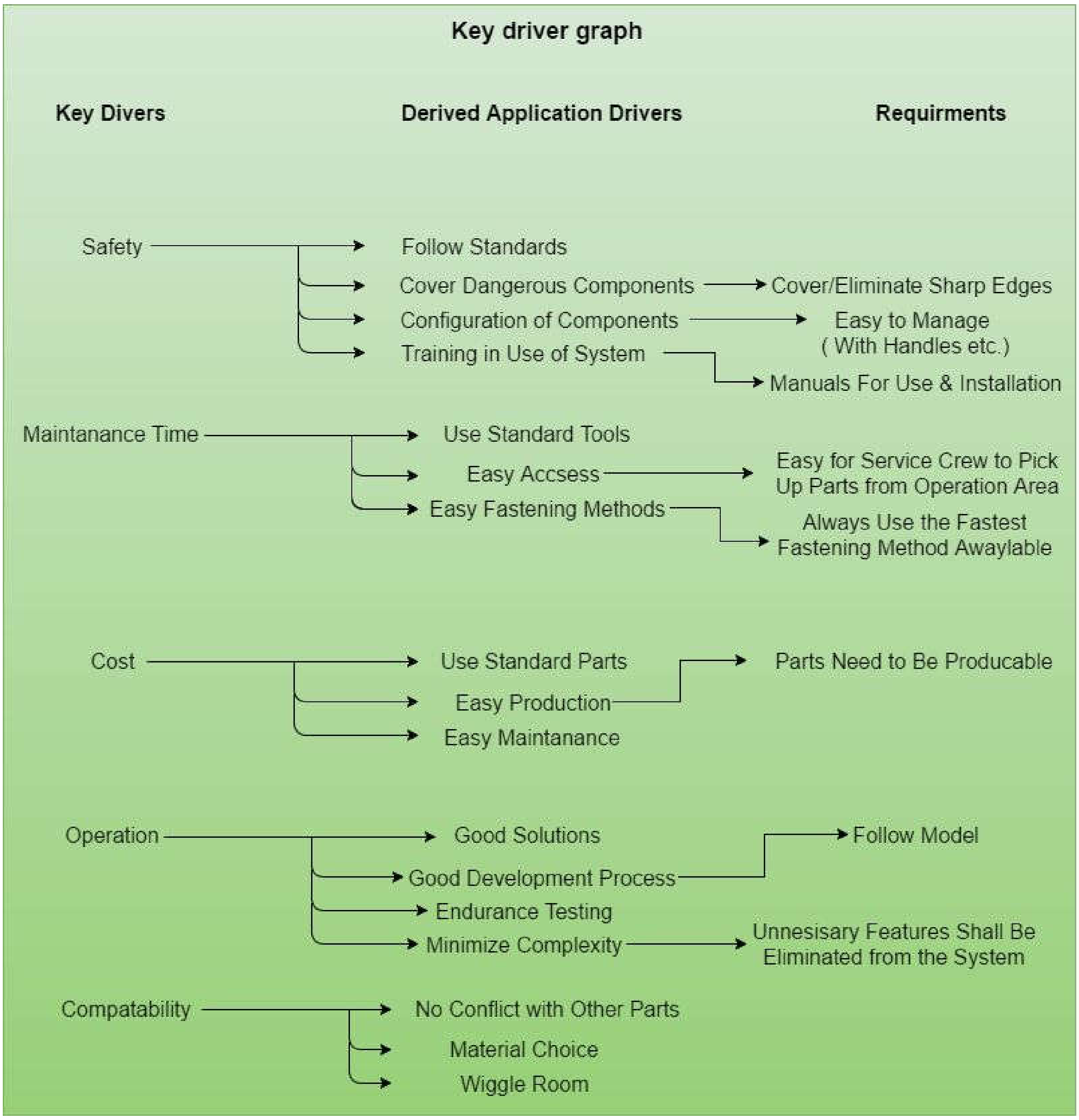


Figure: Shows the resulting Key Driver Graph.

Activity: Stakeholders - 20 min Time Box

Phase: Concept development
View: Application

Main stakeholders, secondary stakeholders, and other stakeholders was reviewed. We evaluated all possible stakeholders by evaluating everyone in contact with the system throughout it's lifetime, and found several new stakeholders. Secondary is the stakeholders with an indirect interest in our product, while primaries have a direct interest. Thereafter we made an overview of them and their concerns about the project to help us generate new requirements. This activity was helpful, even a lot of stakeholders was already recognized earlier in the project, the iteration helped find new stakeholders. Not any new primaries, but five more secondary stakeholders. Figure shows the outcome.

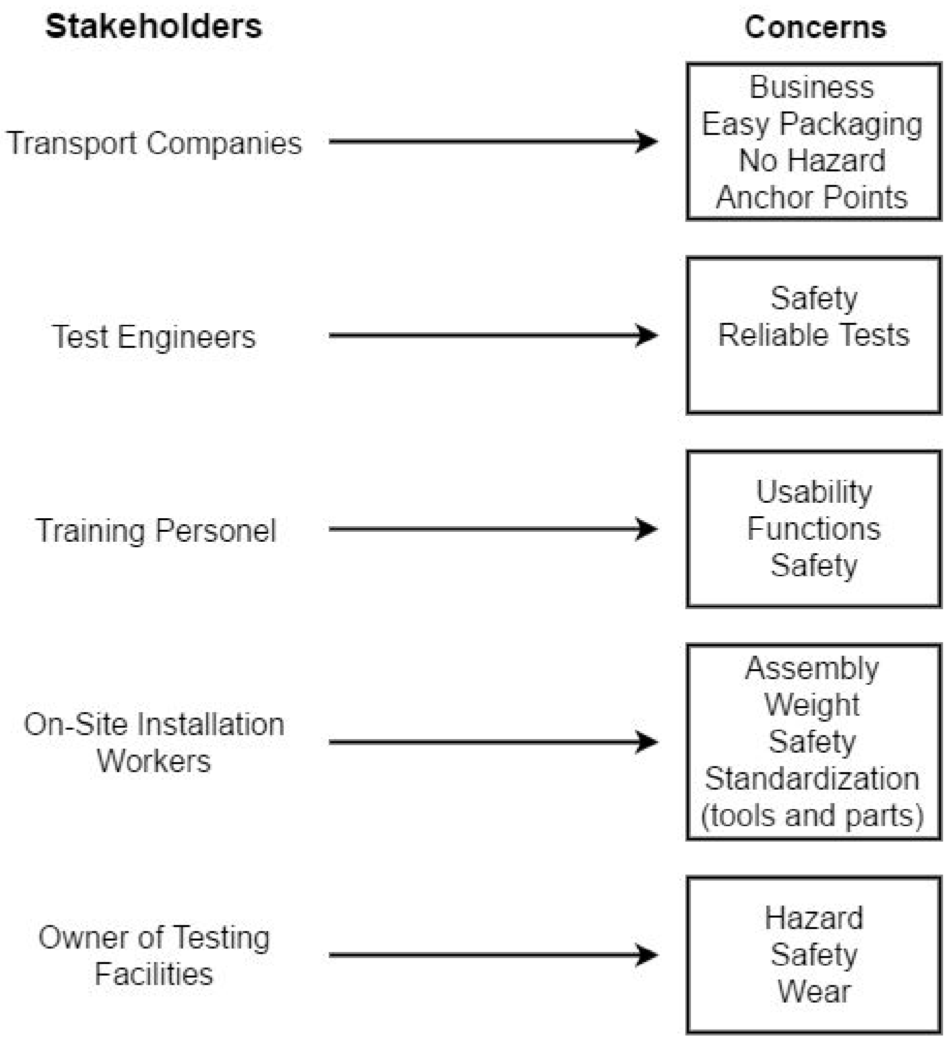


Figure: The figure shows the results from reviewing stakeholders and their concerns.

Activity: System in Context - 2x20 min Time Box

Phase: Concept development
View: Customer Objectives and Application

This iteration activity lets us get the opportunity to see how our system will interacts with surroundings. We have a diagram with the bleed system in the center connected with entities that interacts with the system (see fig.3). The boundary of the system is visible, and the interactions will lead to requirements to the system. We first used 20 minutes for mapping some entities and worked out some interactions. We were not finished before the time was over so we wanted to go one more round on this one. We first did the rest of the activities in this iteration before we used 20 minutes more on this activity.

We found some main entities that have important connections to the bleed system. The lines between the system and entities shows the input/output between the external factors and system. This time we reached six entities that we saw had connection with the bleed system: environment on site, turbine, operator, maintenance crew, housing and customer. From figure below one can see how the entities are connected and arrows that indicates the origin of interactions.

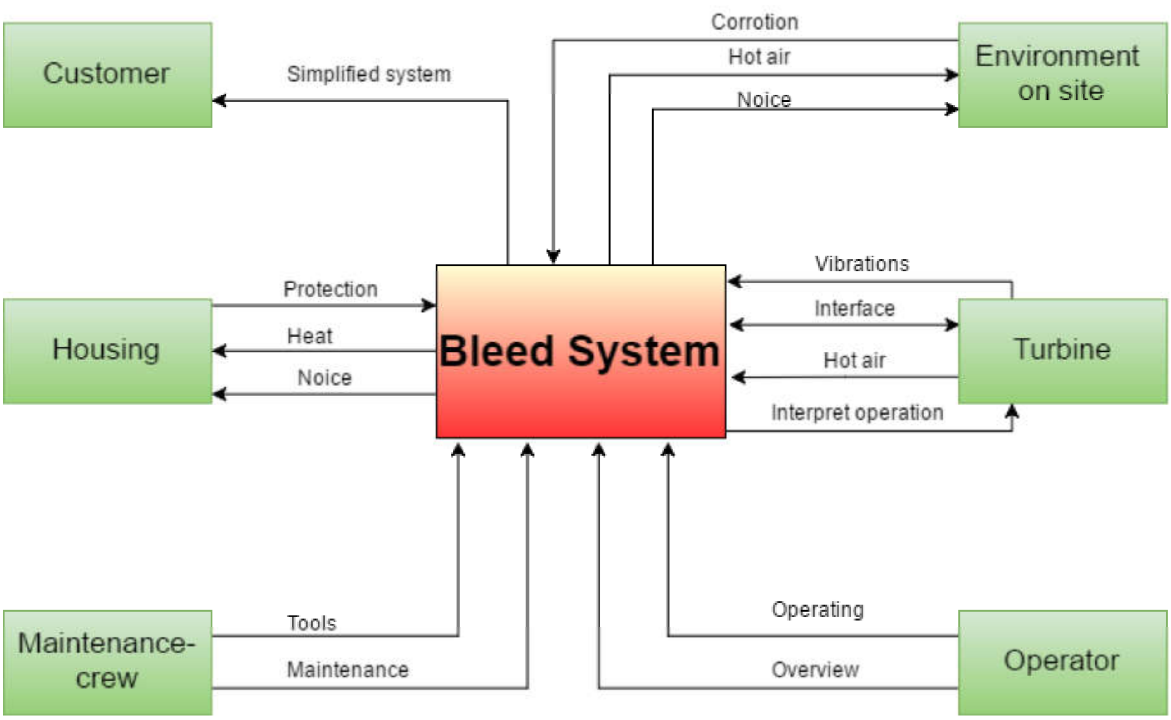


Figure: shows our system in context.

Activity: Brainstorming Concepts 2x30 min Time Box

Phase: Concept development
View: Functional and conceptual

Every ideas about the how to make this system was put to paper. Without any re evaluating the concepts was the possibility to make ideas to build on, and working further with. All of the group members participated in giving solutions, and a lot of questions about the system came up. All concepts was drawn to paper by the student having the idea. There was taken 30 minutes time boxes which group thought was too short, and it was extended by 30 minutes. 15 ideas was created, and result came as creative ideas to lead air, connect the interfaces and protect the environment.

Activity: Functional model 20 min Time Box

Phase: Concept development
View: Functional and conceptual

Functional model gives the understanding of the interface and the solution world. This model will lead to more quantifiable requirement, and gives a better understanding of the systems functions. The idea of the functional model is to describe the functions and processes assist of discovery of information needs. It concentrates on describing the dynamic process. This will help to identify opportunities and determining solutions (Wikipedia, 2017). The dynamic process is told by what we deal with, and what we need to do. It' s told by verbs and tells the story from the systems high energy air, which is the first step in process, to adjust impact of air, the last what we need to do. Figure below is made of boxes following each other, with a line describing what is the next step.

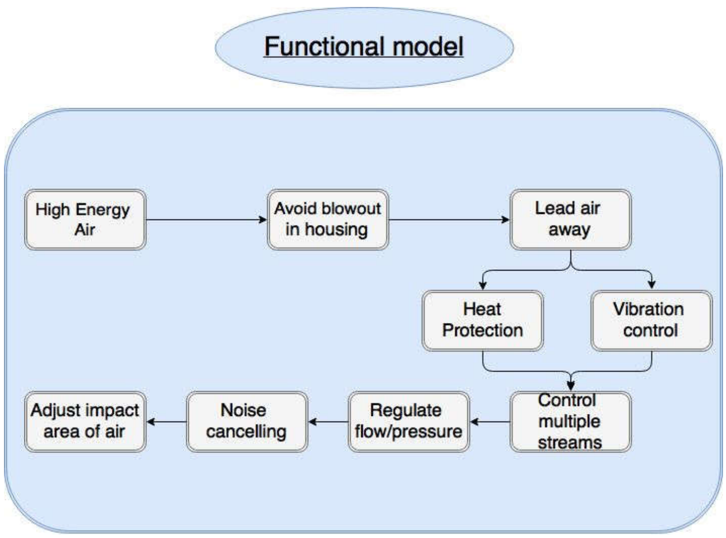


Figure: Functional model

Activity: White Box 20 min Time Box

Phase: Concept development
View: Conceptual

White box diagram is a lot like the black box diagram, but shows the internal of the system. The components help other components to achieve its functionality. Shortly after starting iterating around this activity we saw that this activity was not as meaningful in this stage. It was too early to map the interaction between the internal parts of the bleed system since we had no specific concept with selected parts yet. And basically a bleed system is not very complicated and consisting of infinitely many parts. So we agreed that this activity is more helpful later in the process when we are working with selected concepts and the iteration was stopped after few minutes.

Activity: Requirement 20 min Time Box

Phase: Concept development
View: Customer objectives

We always want to have a good overview over the requirements. To work with requirements is something we see will going to continue throughout the whole time of this project. Here we lists the requirements to consider from iteration 2:

- Cover/eliminate sharp edges.
- Easy to manage parts(with handles etc.).
- Manuals for service.
- Fastest possible way to attach and disassemble parts.
- To consider geometry when producing parts(casting, welding, turning, extrusion etc.).
- Student group will follow project model.
- Excessive parts will be eliminated.

2.3 Conclusion

A lot of requirements from this iteration round was achieved. The group didn’ t think some of the diagrams would help in locating requirements since we already knew a lot about the project, but we was proven partly wrong. The stakeholders and key driver graph gave a lot of missing information, while context diagram and white box didn’ t. White box was in fact eliminated since it didn't suit the project at the time.All of the diagrams will be reviewed soon, to find new requirements to the project. All in all, the general outcome of the iteration round 2 was giving usable results, and our student group know the customer better by the requirements generated

2.4 Reference:

Muller, G.J. (2016a) *Key Drivers How to.* Available at: http://www.gaudisite.nl/KeyDriversHowToPaper.pdf [Accessed: 22 January 2017]

Muller, G.J. (2016b) *Communicating via CAFCR; illustrated by security example.* Available at: http://www.gaudisite.nl/CommunicatingViaCAFCRPaper.pdf [Accessed: 22 January 2017]

Wikipedia (2017). *Function Model.* [Internet] Available at: https://en.wikipedia.org/wiki/Function_model [Accessed: 3 February 2017].

Iteration Report

3. Iteration round: 3

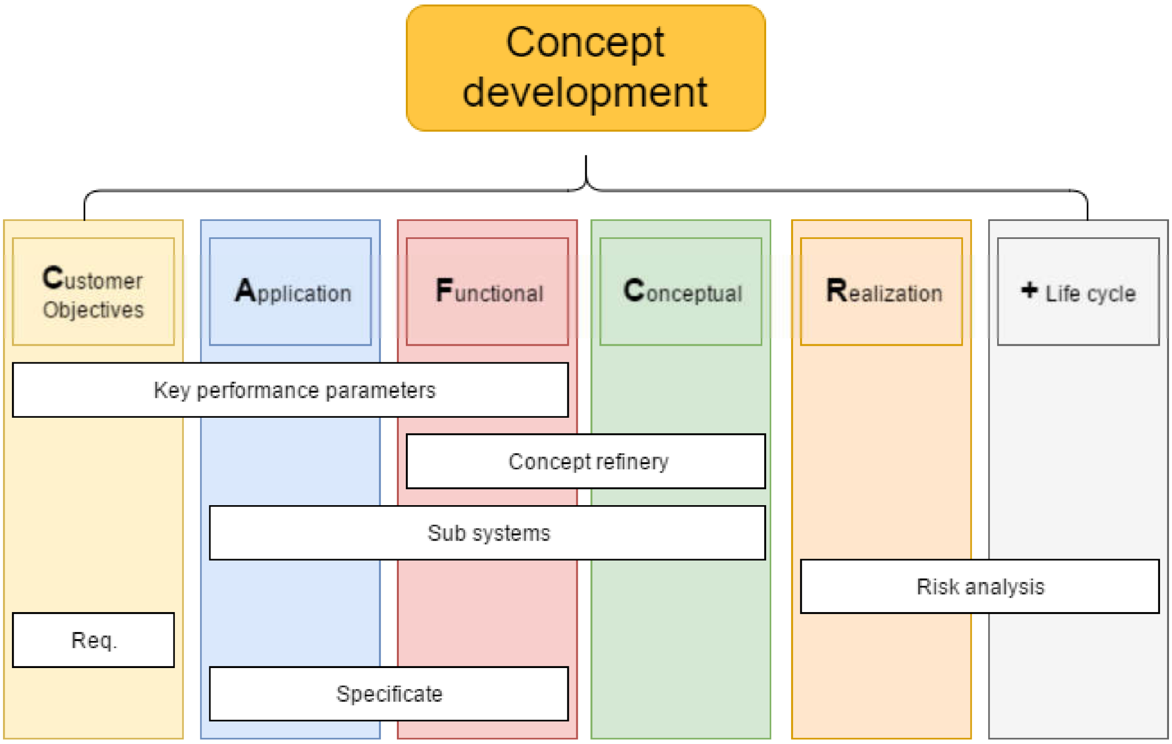


Diagram 1: shows an overview of iteration 3, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Date: 17.02.2017

Phase: Concept development

Iteration views:
- Customer objective
- Application
- Functional
- Conceptual
- Realization
- Lifecycle

Activities:
- Key performance parameters

- Concept refinery
- Sub system
- Risk analysis
- Requirement
- Specificate

Time scheduled: 20 min timeboxing

3.1 Introduction

Working with concepts continues and it need to be selected which concepts we want to continue. More focus on the smaller parts, sub systems, is also important when we start focusing with a more detailed view on remaining concepts. We have also identified a risk analysis where we see which events will be serious for our project. New requirement will always emerge and must be written down in the requirement document. And the last activity is about specification for coupling methods we can use for the piping.

3.2 Activities

Activity: Key Performance Parameters - 20 min Time Box

Phase: Concept development
View: Customer objective, Application & Functional

This section gives a better overview for valuable parametre. It is important to start with the basics and understand the scope of these values. One way to evaluate key performance parameter it is to use SMART criteria. This letters stand for specific, measurable, attainable, relevant and time-bound. Is the parameters specific, can it be measured, is it realistic, attainable, is it relevant for the project and what is the time frame for achieving this goal (Klipfolio, 2017).

In the process of finding key performance parameters we have through meetings with D-R mapped many of these. What we achieve here is to get a larger overview of all parameters in the same picture and simultaneously getting better differentiation of the key performance parameters. The mentioned key performance parameter is measurable and attainable. A better differentiation of the threshold values will help them to be even more specific and more relevant. The time bound will depend of the progress in the project. Some of the key performance parameter will be measured by hand calculations during testing through the development of concepts.The figure below shows our key performance parameters.

Key Performance Parameter

Parameters	Treshold values
Cost	20.000 $
Part weight	25 kg
Reliability	25 years
Maximum airflow	10,8 kg/s
Counter pressure	* A42 ≥ 24kPa, A43 - A44 - A51 ≥ 70kPa
Assembly/disassembly	60 min
Temperature resistance of system	* A42 = 155°C, A43 - A44 - A51 = 265°C
Sound to environment	83 dB

*identifies the four different bleed valves

Figure: Shows the values associated parameters.

Activity: Concept Refinery - 20 min Time Box x2

Phase: Concept development
View: Functional & Conceptual

The work in this time box is based on important concept feedback from the customer. We put down on paper an overview of whether different aspects of the various concepts where opportunities (fig.2 in green boxes) and which were limitations (in red boxes), in addition we have marked some partial solutions as possible if they work as intended (in purple boxes). These will require more research to be able to conclude. Here we tried to locate the best features of the worst concepts and the worst features of the best concepts. By doing this, we make sure all the best features are considered independent of the concepts, and a critical review of the best concepts is conducted. 20 minutes was not sufficient enough, so another 20 minutes timebox was added after the whole iteration round. This overview we can use to see which partial solutions can be used from different concepts to further combine these and develop better solutions. Below the figure shows the result.

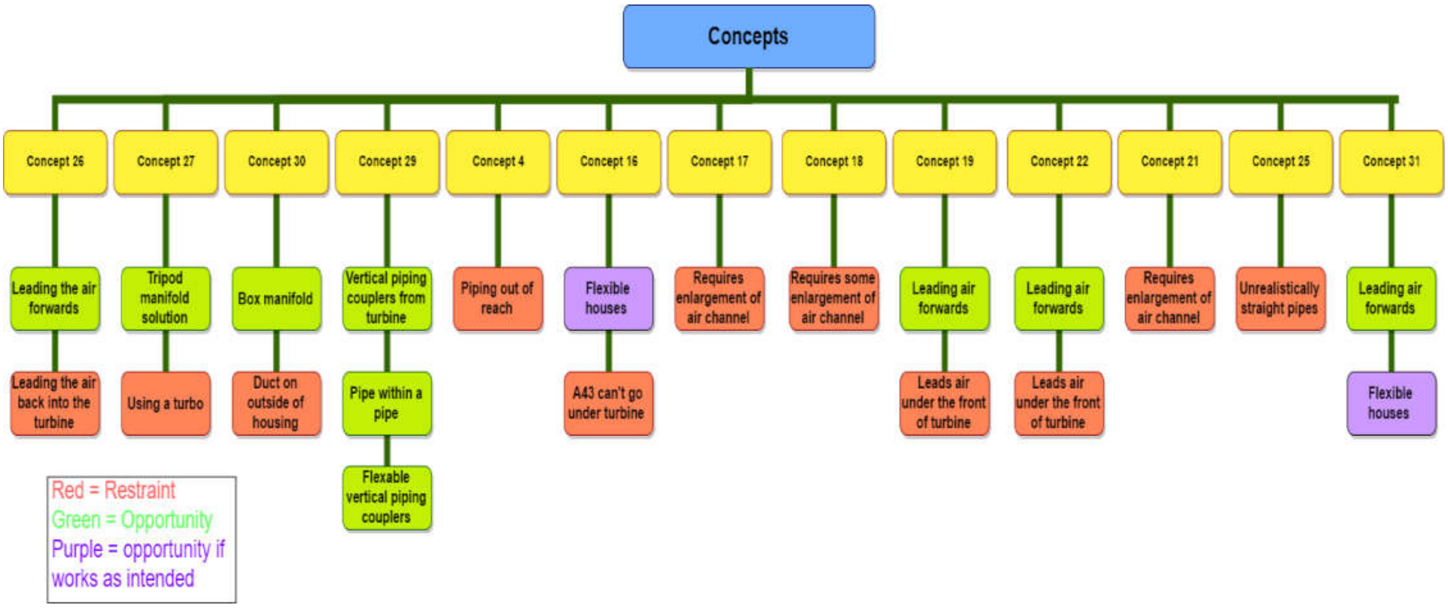


Figure: Shows the concept refinery.

Activity: Sub system - 20 min Time Box

Phase: Concept development
View: Application, Functional and Conceptual

The subsystems is parts of a bigger system playing a role as a component. The sub system can be divided to more detailed levels, like sub-sub-systems and further. To use this diagram in the bleed line project we define what kind of components the project contains. This is hypothetically, and all of the concepts made have been considered in this diagram. In the end there will be chosen one or two concepts, and will lead to parts of the sub-system diagram components to be evaluated. The reason for choosing the whole concept in one diagram is the low complexity, and few parts the bleed system consists of. On the other hand the whole picture; turbine, power turbine, housing etc. is very complicated, but is not our task.

We found our parts, and have divided them into sub-sub system. The reason for making the diagram is to get to know the system better, and to write requirements from these new information. The diagram also provides information about what to focus on in the system. To read this further down the line of the project, it will have to be discussed where the jointings should be, also what kind of joints should be flexible. The subsystem figure 3 haven't been a revolution so far, but in later iteration rounds it will be completed, and the expectations are high to what we make out of sub systems. Figure below shows the subsystems and will be a very helpful tool in the project.

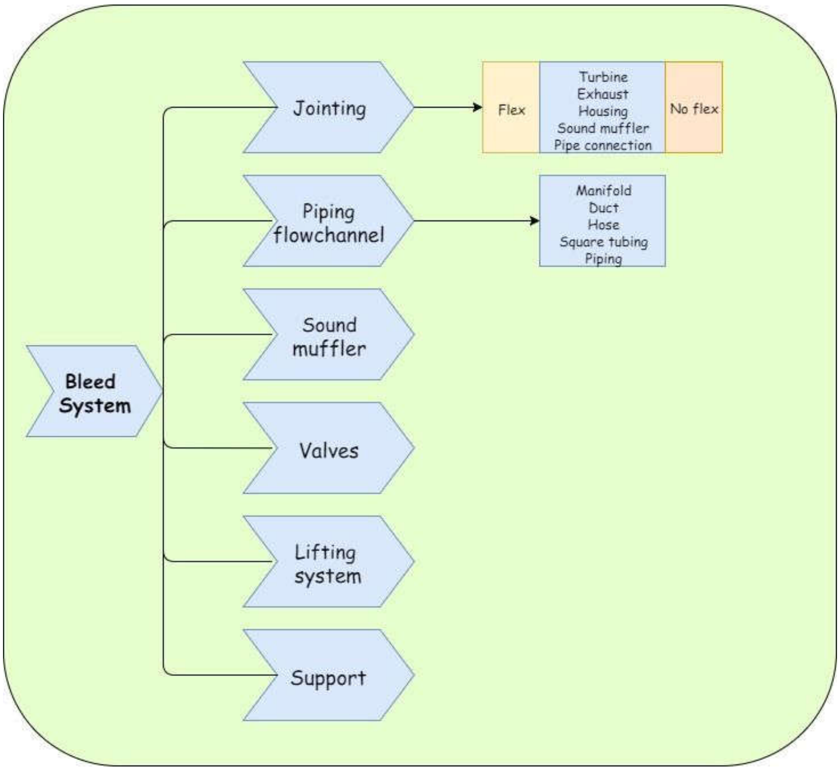


Figure : Shows the bleed system possible sub systems.

Activity: Risk Analysis - 20 min Time Box

Phase: Concept development
View: Realization & Lifecycle

The risk analysis is based on a typical setup. The resulting risk of a shortcoming in the project consist of the value of probability of the occurrence multiplied with the consequence. Risks that are highly probable of occurring but don't have great impact, and risks that have reasonable impact but low probability of occurring won't be a big concern, but the risk with higher probability and bigger impact will be spotted and according to the risk level the right measures will be made.

We have decided that risks arranged to the green tiles of the model are accepted, and no actions will be made regarding these. The risks arranged to the yellow tiles are considered to be the ones that need to be discussed among the group members to decide whether to make an active measure to prevent the occurrence of the risk factor. The risk arranged to the red tiles represent the ones that we will definitely make actions to prevent the occurrence of the risk factor. The next figure shows the result of the risk analysis.

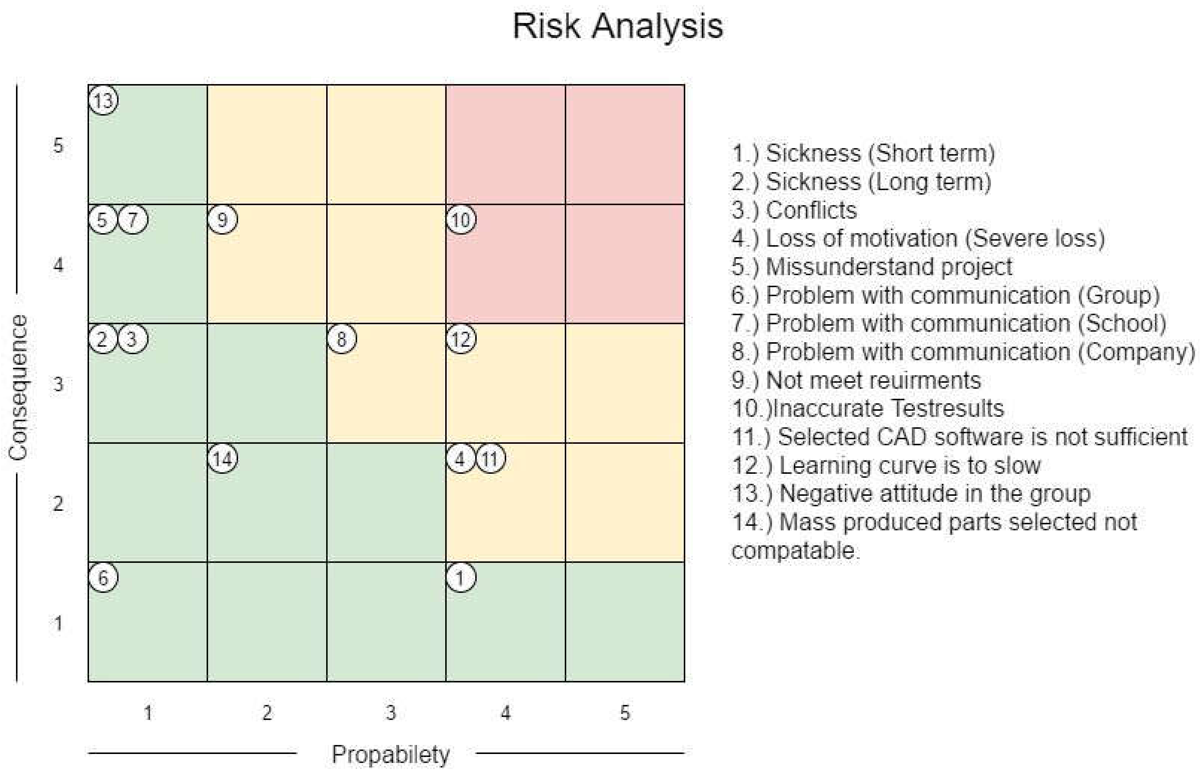


Figure: Risk analysis, the numbered risks is located in its associated color.

From the timeboxing we learned that several risks need to be considered, but also fortunately we discovered that many of the risks we came up with would have little or no impact on the project.

For the risk that needs to be considered the next task will be to decide on how to deal with the it. There are different solutions to this. We can try to avoid the risk happening, we can share the risk (insurance), or just accept it.

Activity: Requirement - 20 min Time Box

Phase: Concept development
View: Customer Objective

With this iteration we found some new requirements that are more on a detailed level. It is about that screw must be fastened so vibrations from turbine do not loosen them, that parts shall be accessed without ladder, that it must be focused on time estimating part by part when assembly/disassembly. The last one must be estimated when we are finish with the refinery of concept. Always looking for new requirements will help us build the right product for our customer, D-R.

Activity: Specificate - 20 min Time Box

Phase: Concept development
View: Application & Functional

This activity is based on specifying some of the different coupling methods we can use on the piping of the bleed system. Then we listed up pros and cons to find which of them that is best suited for the system. This is done to get an understanding of what kind of coupling methods that is possible and preferable for us to use. See figure for detailed information.

Specificate

Coupeling Methods

Welding	
Pros	Cons
No leakage Less parts to dis-/assemble	Competence Calculation Weight Less flexible dis-/assembly Expencive

Screws	
Pros	Cons
Flexible dis-/assembly Cost Mass produced	Rust Leakage Sensitive to vibration More parts to dis-/assemble

Hub Screw	
Pros	Cons
Fast dis-/assembly Easy dis-/assembly Flexible dis-/assembly Mass produced	Sensitive to vibration Leakage Weight Cost

V-Band	
Pros	Cons
Fast dis-/assembly Easy dis-/assembly Cost Mass produced Few parts Simple pipes	Leakage

Pipe in a Pipe	
Pros	Cons
Simple pipes Fast dis-/assembly Easy dis-/assembly Cost No fastening parts	Leakage

Figure: shows specification of coupling methods.

We found five different methods, as seen above. They are divided into three different colors; red, yellow and green, that corresponds to; less preferable, neutral and preferable. The color given to the different methods is based on pros vs cons, but the results here is not final, this is only a introduction to the research around the coupling. As can be seen from the tables the clear winners is the “V-Band” and the “Pipe in a Pipe” solution. They both have a lot of pros and only leakage as a con. Leakage of small amounts is tolerated from the Bleed System, so the two methods are interesting choices later in the project.

3.3 Conclusion

This iteration round 3 gave us a better overview of the key performance parameter in an orderly manner. Concept refinery is an important activity in this iteration and we needed to take two rounds on 20 minutes before finishing this. It is worth spending some time on this activity since this will forms the final products. Subsystems shows our smaller parts in the assembly. This is maybe not all of them since this will be more detailed when working with decided concepts. Risk analysis shows what it takes to tilt the project of track. Since we are a hard working group we do not have that many risk that are capable to do this, but it is important to be aware of risks and we need to work with a plan that shows action if the risk occurs.

3.4 Reference:

Klipfolio (2017). *What is KPI.* [Internet] Available at: https://www.klipfolio.com/resources/articles/what-is-a-key-performance-indicator [Accessed: 19 February 2017].

Iteration Report

4. Iteration round: 4

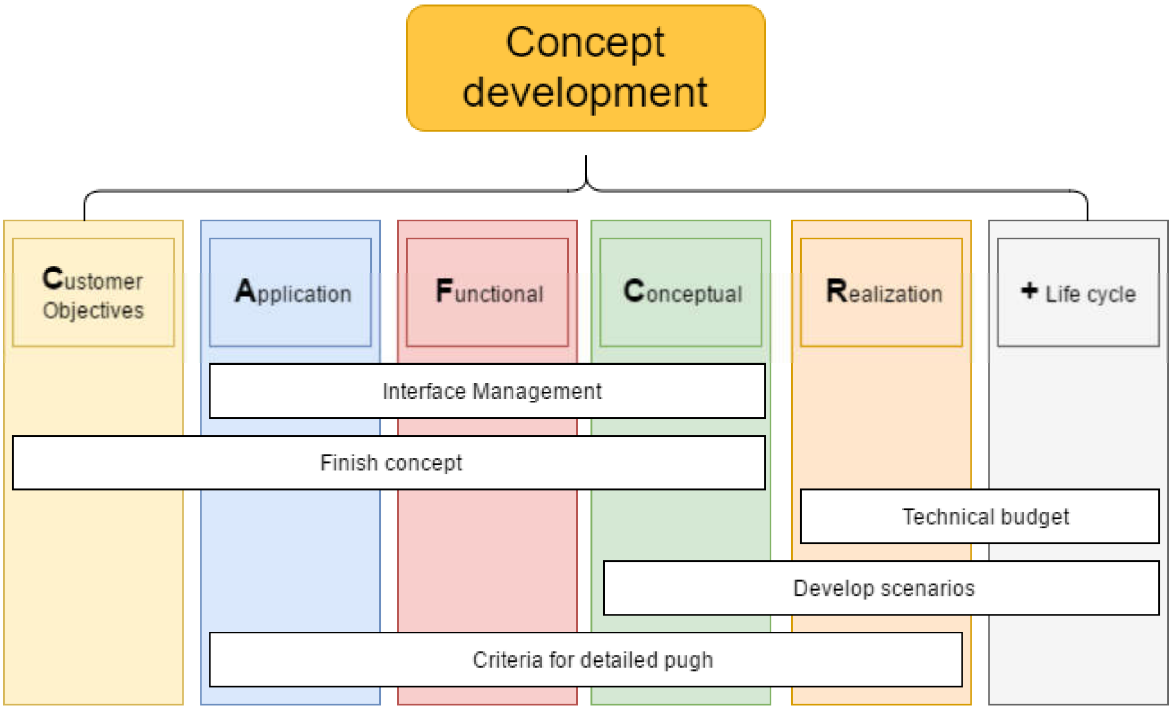


Diagram: shows an overview of iteration 4, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Date: 24.02.2017

Phase: Concept dev

Iteration views:
- Customer objectives
- Application
- Functional
- Conceptual
- Realization
- Life cycle

Activities:
- Interface management
- Finish concepts

- Technical budget
- Develop scenarios
- Detailed pugg criteria

Time scheduled: 30 min Time Boxes

4.1 Introduction

Iteration 4 will be focused on gathering useful information to have a good basis for concept selection. The order of the weeks iteration activities is something more important than the former, since this week's activities retrieves information from each other. We will first conduct a review where all concepts are given more detailed interfaces between the bleed system and adjacent systems, secondly, we will think about details in the remaining parts of the various concepts, which will form the basis for performing technical budget for each of the concepts. scenarios of each of the concepts will then be of help to discover the more abstract problems. Finally we have a good basis to create criteria for the detailed Pugh matrix.

4.2 Activities

Activity: Interface Management - 30 min Time Box

Phase: Concept development
View: Application, Functional & Conceptual

The first mission in I4 is setting the interfaces from the turbine to the bleed line system. The timeboxing was set to 30 minutes, and the group started brainstorming as many types of connection joints within the given time as possible. It was divided into two categories, joints which is connecting two pipes, and joints connecting hose and pipe. The figures will be described closer to give an understanding of what the solution is meant to show, and the first category is connecting pipe to pipe. Details are described above each figure.

Pipe with pipe connections

The idea of the concept is the pipe coming from the turbine (bottom) have a clearance to the rest of the bleed line system. The turbine can then move without any forces affecting the bleed valves. The gasket ensures no air is leaking, and it gives the pipe possibility to move in the axial direction.The bleed line system is locked in place and can not move at all. The gasket will be attached with a hose clamp on both pipes (see figure).

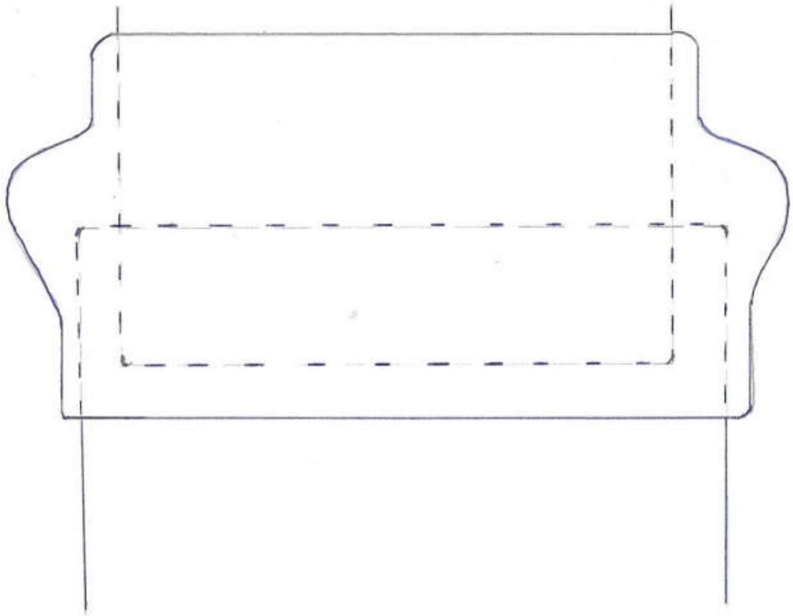


Figure: Pipe inside a gasket

The next figure illustrates two pipes meeting with a clearance, and a hose covering the gap to prevent the air from leaking. The turbine pipe in the bottom have possibility to move in both radial and axial direction without creating too much stress on the bleed valves. The hose will be attached with a hose clamp in both ends.

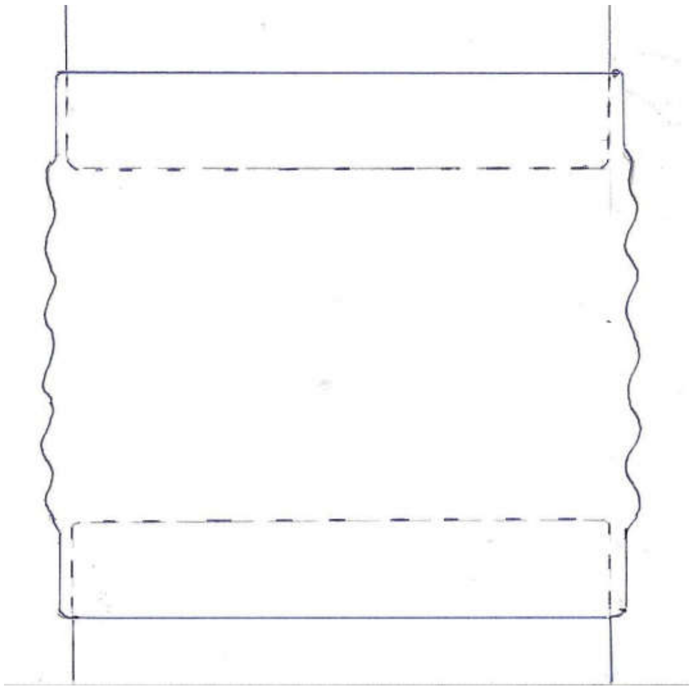


Figure: Pipes connected with a hose.

Figure below illustrates the pipe in the bottom from the turbine, entering the bleed line system pipe. This is to prevent further pressure loss with the elimination of sharp edges and protecting the hose from the large flow of air. This principle is the same as the prior concept, with the difference of pipe inside pipe. The hose will be connected with hose clamps in both ends.

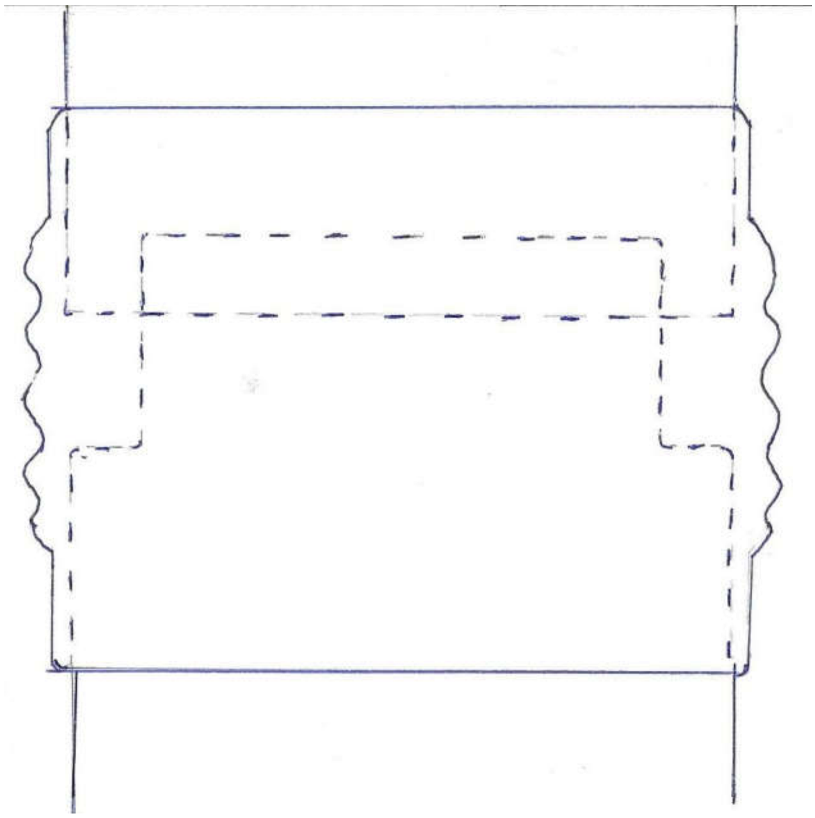


Figure: Bleed line system inside with hose.

The illustration figure below shows the bottom pipe from turbine, and the bleed line pipe from the top with a rubber gasket attached. The rubber gasket is flexible and not tight, so the turbine pipe can move in both axial and radial direction. The movement in radial will not be a bigger distance than the compression of the gasket, but still enough to satisfy the requirements.

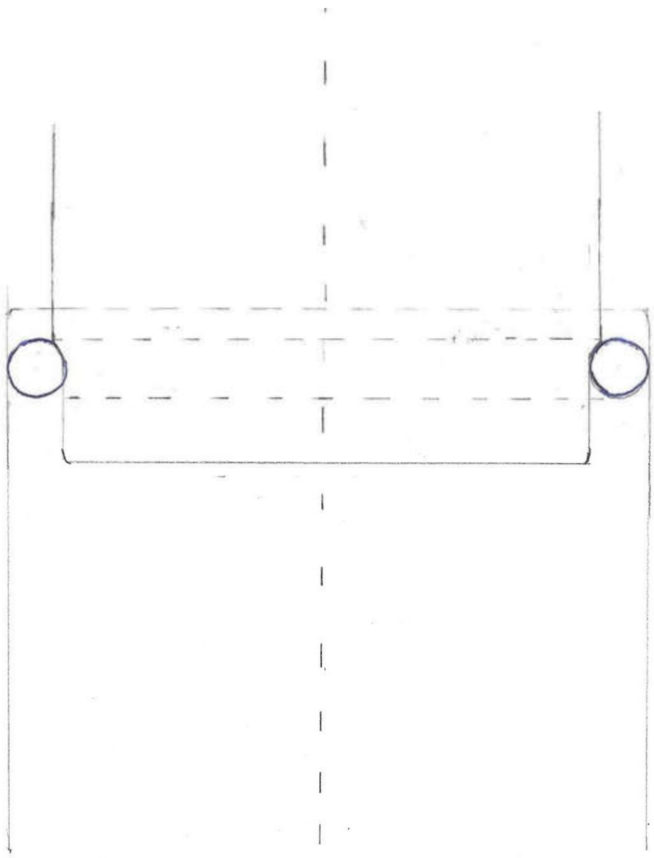


Figure: Pipes with a rubber gasket.

To attach two pipes it can be done with screws tightening the inner pipe. The solution will transfer forces, and is at this time not suited for the connection between turbine and bleed system, but rather for the connection in the rest of the bleed system.

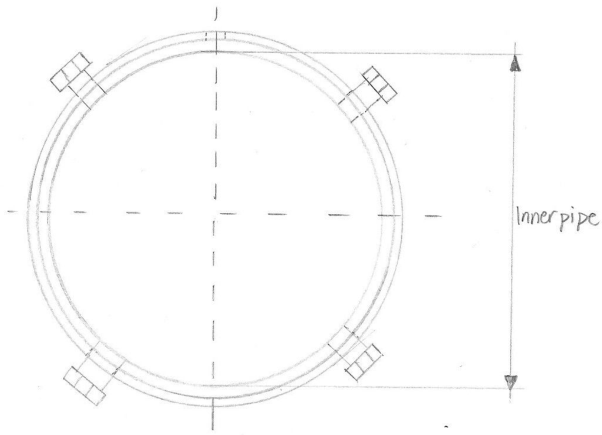


Figure: Bolts tightening the inner pipe.

The concept shown below is used when connecting two pipes together. To get them tight and with no leakage the grooves makes the metal pipe give in when tightened around another pipe. This solution will transfer forces, and have to be used in the bleed system that have no requirement about movement when expanding.

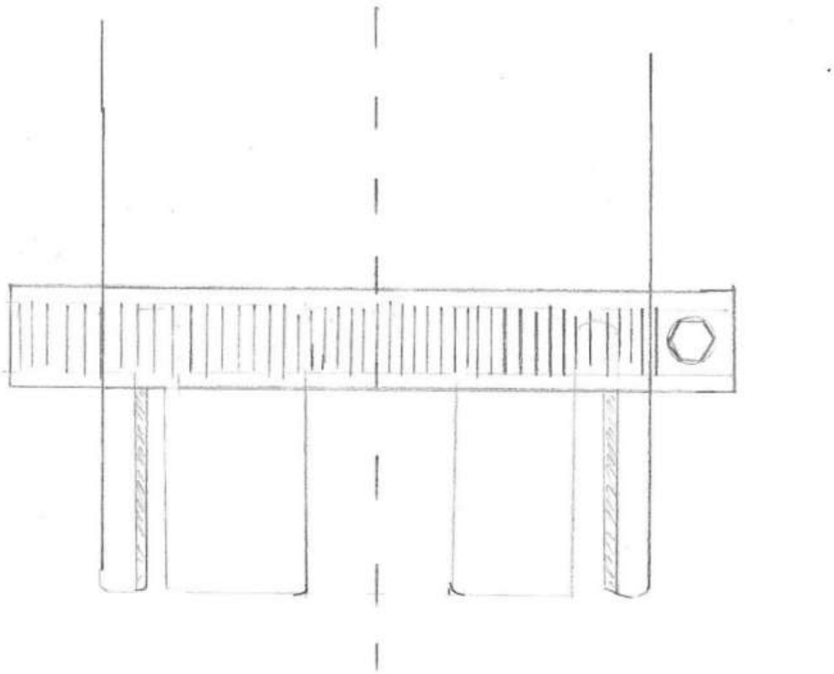


Figure: Pipe with milled grooves.

Pipe with hose connections

The turbine will be connected to the bleed line system with nuts and bolts through a flange. This will give a very stable secure connection, but will take a bit more time to dismantle. The flexibility is satisfying in the concept regarding the stress level imposed to the bleed valves.

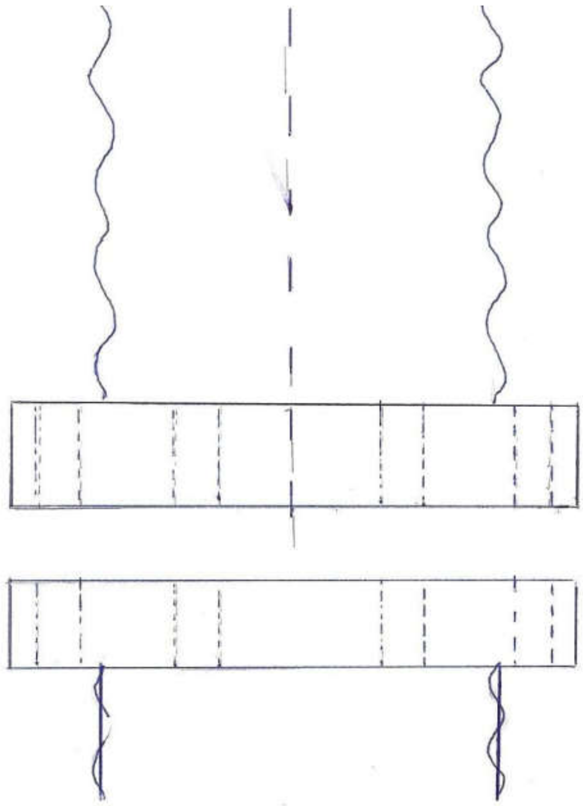


Figure: Nut and bolt

This next concept is a hose from the bleed line system attached to a loose pipe with a clamp. The loose part is designed so it will fit with the pipe from turbine with another clamp designed for pipe to pipe connection. The hose itself have sufficient flexibility to give the turbine the movement in both axial and radial direction as it need.

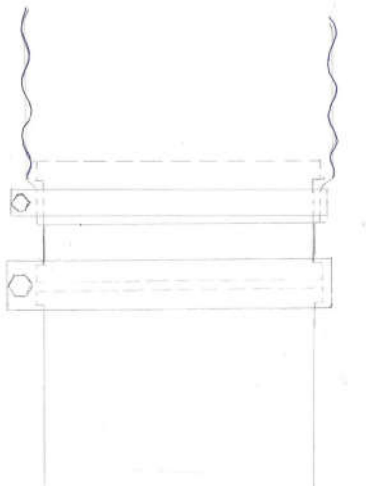


Figure: Hose connected with a loose pipe.

This concept is the least complicated one. The hose from the bleed system is attached to the turbine with a clamp. The flexibility in the hose will let the turbine move without applying forces to the bleed valves.

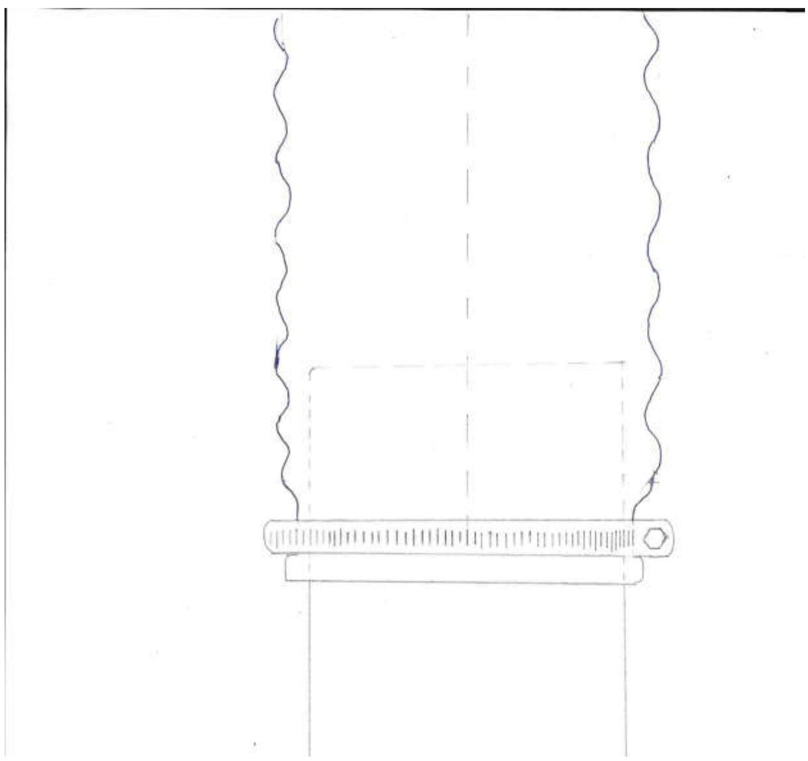


Figure: Hose and clamp.

Activity: Finish Concepts - 30 min Time Box

Phase: Concept development
View: Customer Objectives, Application, Functional & Conceptual

The purpose of this activity is to come up with detailed suggestions to each concept, making them more complete, thereby making it easier to choose the final selection of concepts. We started by looking at one concept, then evaluating it, thereby finding what had to be added, changed or removed from the concept. This process was repeated on all remaining concepts. The results can be seen underneath in the figure. It is not a complete list of what remains to do on each concept, but rather a brief overview that shows the immediate challenges and tasks on the concepts that will be solved in the next phase or that can possibly be one of the reasons that causes a concept to be discarded.

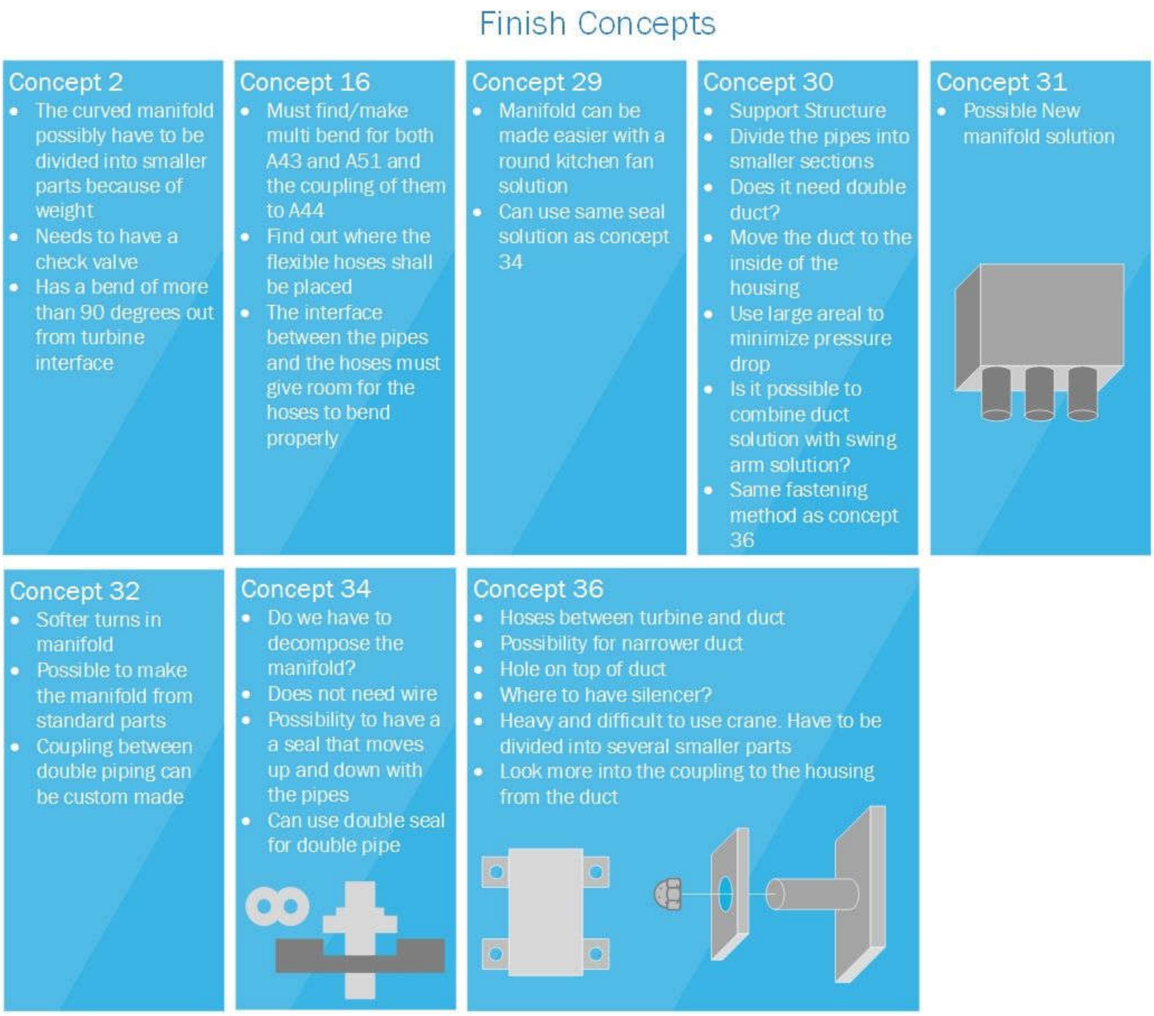


Figure 10: Showing details on the concepts.

Activity: Techincal budget - 30 min Time Box

Phase: Concept development
View: Realization & Lifecycle

A technical budget is a breakdown and budgeting of technical quantities. This is done to get a better understanding of the specific quantities of the different areas of the system and whether it is possible to stay within the specific framework that is desired. A technical budget for a system can e.g. be weight, price, volume assembly time etc.

We decided to focus on the time of maintenance for the system. Since this is one of the most important factors for our system. From before we had a good idea about the time of maintenance for each concept, but by doing this exercise we got to know an estimate of the numbers, and somewhat thoroughly got to consider what consumes the time, and how much time it takes to disassemble the system. Figure below shows the technical budget.

Figure: Showing maintenance time for the concepts.

Activity: Develop Scenarios - 30 min Time Box

Phase: Concept development
View: Conceptual, Realization & Lifecycle

Scenarios come in a bewildering array of forms, and even engineers who broadly agree on what a scenario can be used for may differ on what exactly a scenario is. In some definitions, a scenario is barely different from a description of a static situation; but most scenario engineers have gravitated towards a pragmatic usage where a scenario means some kind of description of a set of activities, most commonly sequential. This has an obvious bearing on the application of scenarios to describe how a system is to behave when interacting with its users.

A useful distinction can be drawn between concrete and abstract scenarios. A concrete scenario involves specific actors, places, and times. An abstract scenario describes what happens in generic (class) terms.

We went for a concrete description of a story. Specifically we chose to imagining the worst case scenario for a specific concept. All that could go wrong was included. The one we chose was concept 32 - F1 Pit Stop Front Vent with Pipes. The reason was that we knew this concept in particular has some features that could generate risks.

An important lesson we learned from the scenario is that when we begin to put together the instruction manual for the system we need to have focus on the order of disassembly for maintenance. Although our scenario is extreme, there is a possibility of all of the accidents. The scenario can be read underneath in the figure.

Per has his first day at work. His work is doing service on a turbine package delivered from Dresser-Rand placed on the Goliat platform in the northern sea. He is arriving on the platform with helicopter, and is delivered the service manual for the turbine. The manual is complicated, and not in the standards Per is used to read manuals in. He is using 2 hours to figure out his questions by calling the developers of the bleed system.
After finally to get working, the turbine is sufficiently cooled down long time ago. Alfred, the assigned helper from the platform is sick, and no other can help Per. Per is opening the service door, and starts to disassemble pipes in the interface turbine/pipe. Per is unlucky and makes a hole in the flexible joint between the turbine valve 44 and the pipe. After he goes around and disconnects 43 and 51, and pulls the splint that keeps the swingarm in place. The pipes hanging down follows the swingarm, and bumps into the turbine, and valve 42' s flexible joint is torn apart because he forgot to attach it. He realizes the order he have done the job in is wrong, and swings the arm back. The he gets his fingers between the turbine and pipes. He have to put on some bandage. He takes dismantles 51, 42 and 43 and swings the arm over and crash the swingarm into the instrument panel, and destroy some of the sensors connected to the instrument rack. He swings the arm back, and swings the instrument panel down. Then the access is there to swing the arm with no obstructions. When Per wants to order parts they are not in standards, and have to made on special order.

Figure: Scenario

Activity: Criteria for detailed pugh - 30 min Time Box

Phase: Concept development
View: Application, Functional, Conceptual, Realization

A Pugh-matrix is a qualitative technique used to rank the multi-dimensional options of an option set. It is frequently used in engineering for making design decisions but can also be used to rank investment options, vendor options, product options or any other set of multidimensional entities.

A basic decision matrix consists of establishing a set of criteria options which are scored and summed to gain a total score which can then be ranked. Importantly, it is not weighted to allow a quick selection process.

A weighted decision matrix operates in the same way as the basic decision matrix but introduces the concept of weighting the criteria in order of importance. The resultant scores better reflect the importance to the decision maker of the criteria involved. The more important the criteria the higher the weighting it should be given. Each of the potential options are scored and also multiplied by the weighting given to each of the criteria in order to produce a result. The advantage of the decision making matrix is that subjective opinions about one alternative versus another can be made more objective.

We want to use a detailed pugh matrix to help us choose the right concepts to develop in our project. And in this timebox we decided on the criteria and the weighting of them for the pugh. Figure below shows what we came up with.

	Weighting	Criteria
	17,50%	Lifespan
	10%	User Friendliness
	2,50%	Recyclability
	10%	Safety*1
	32,50%	Maintenance Time
	15%	Space/accessibilety*2
	7,50%	Cost of production/maintainance*3
	5%	Adaptabilety for both sides*4
Total	100%	

*1.) Safety is weightet so low since all concepts are safe enough.
*2.) Volume has to be considered along with location.
*3.) maintenance cost conserns cost of work.
*4.) All have to have the possibility, but how difficult is it?

Figure: Criteria and weighting for Pugh matrix.

4.3 Conclusion

The view of the concepts was focused on the interfaces and to get one more step closer to the final solutions. All the concepts have been evaluated by splitting them into parts, and scenarios are created, and all to create new requirements, and to discard the concepts that have shortages when it comes to the requirements. As the technical budget showed, some of the concepts will have a longer service time. But the conclusion to eliminate them even time is important can't be done yet. All of the factors in the detailed pugh matrix will count for the one concept it is about. And in the pugh matrix it is weighed how much each area counts. This matrix should give the answer to what concepts counting all the factors, is the most reliable ones.

Iteration Report

5. Iteration round: 5

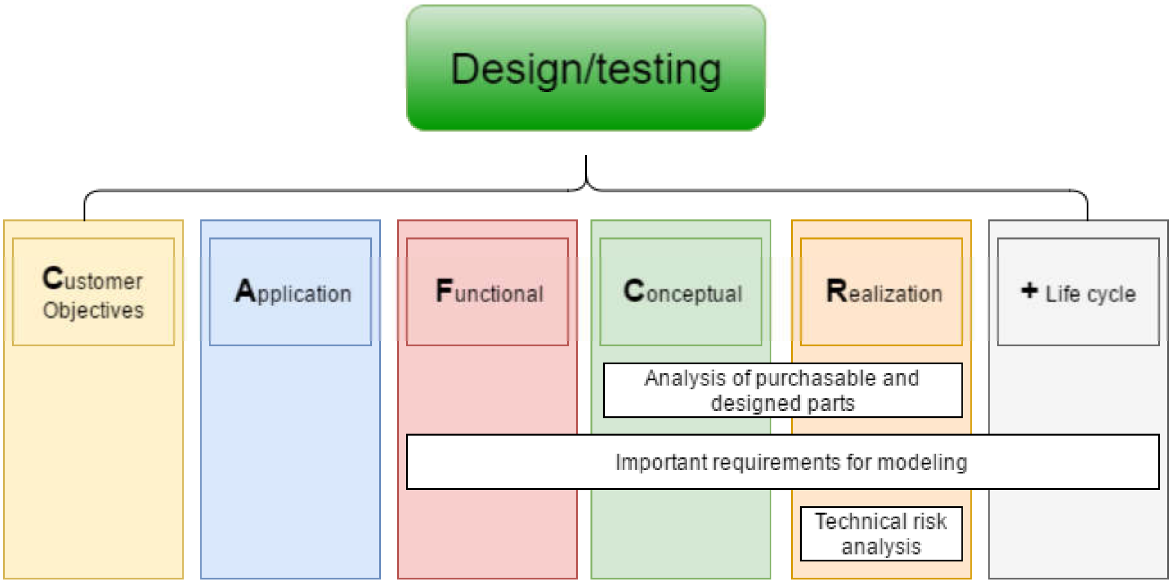


Diagram: shows an overview of iteration 5, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Date: 09.03.2017

Phase: Design/Testing

Iteration views:
- Functional
- Conceptual
- Realization
- Life cycle

Activities:
- Analysis of Purchasable and Designed Parts
- Important Requirements for Modeling
- Technical Risk Analysis

Time scheduled: 30 min Time Boxes

5.1 Introduction

This iteration is meant to give a foundation for us to use when we start designing the models of the concepts in SolidWorks. It will sort out which parts will be purchasable and therefor can be simplified in the model, saving time. Using knowledge from the past iteration rounds we will prioritize the modelling of each concept, so that we don't model the changeable parts of the system, like the bleed lines to the exhaust, when the best solution can be to lead the air through the roof of the housing. All in all the iteration will be a tool to save time, gain knowledge about the concepts that will improve their quality and to avoid making mistakes and doing unnecessary work during modeling of the concepts.

5.2 Activities

Activity: Analysis of Purchasable and Designed Parts - 30 min Time Box

Phase: Design/Testing
View: Conceptual/Realization

The four remaining concepts from the previous elimination rounds have been analysed for which parts is possible to buy, and which of them needs to be designed. The piping system in general is concluded to be standards, from internet piping contractors. While others have to be designed, and some need further investigation to find the right product. The work to be addressed is finding who can deliver parts, who can manufacture them, which standards should we look into and is there possibility to use design from Dresser-Rand from specific components. The figure below shows which standard or designed part needs to take care of under each concept. This will also give a pinpoint to what to be aware of when modelling, and what assumptions have to be made for drawing some parts. Some challenges is in general, and need to be sorted out before the designing take place.

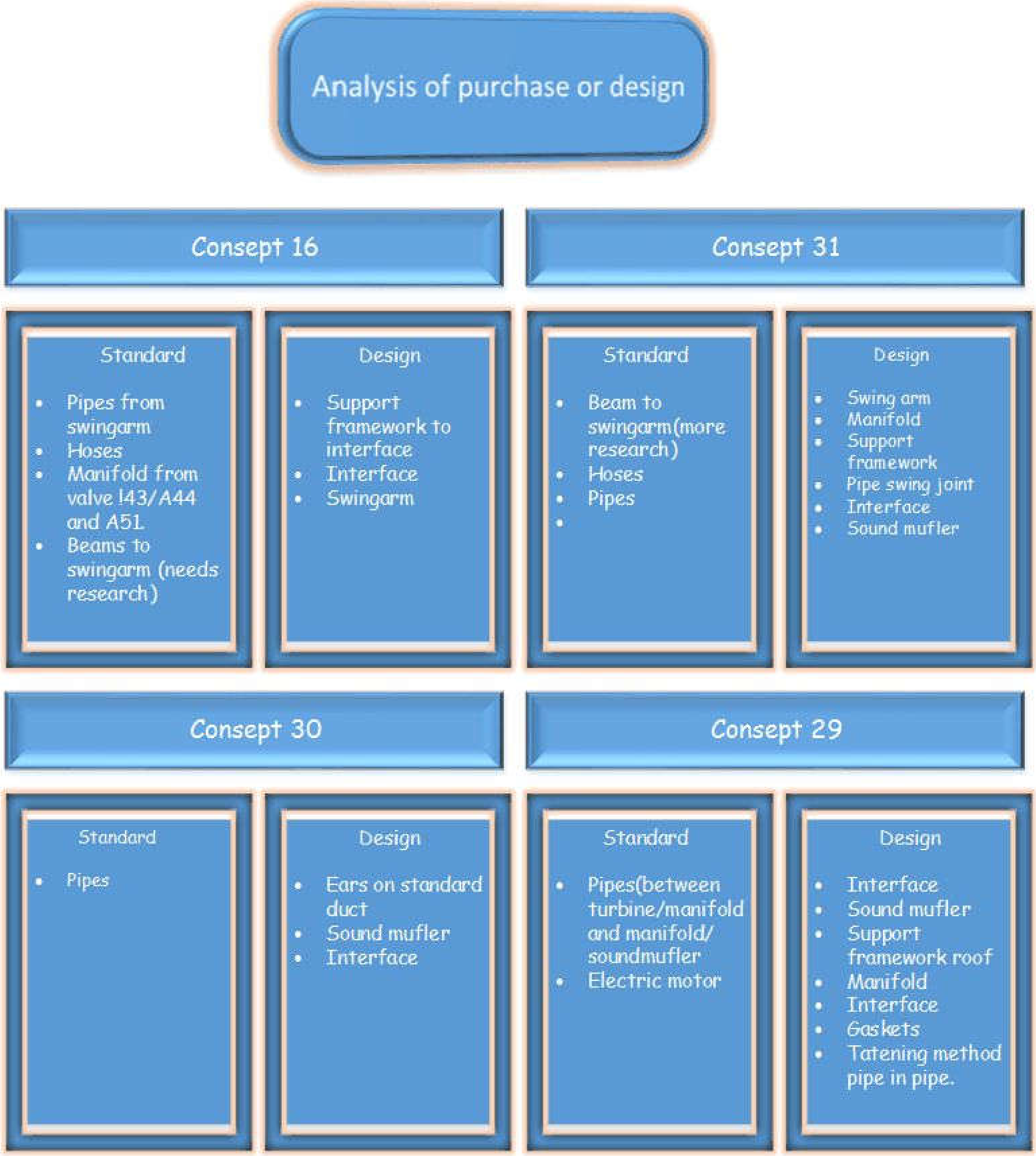


Figure: Shows the analysis of purchasable and designed parts

Activity: Important Requirements for Modeling - 30 min Time Box

Phase: Design/Testing
View: Functional/Conceptual/Realization/Lifecycle

When discussing important requirements when we now will start modeling bleed systems we saw that some of the requirements was very obvious. This because we constantly have implemented a major focus on the requirements since starting this project. Therefore we chose to steer away from the requirements we thought was obviously and rather focused on the requirements that are easy to overlook, but still very important in terms of design, construction and testing of our bleed systems. We only consider of user requirements, but when starting modeling we need to read the associated systems and design requirements so we keeps us self updated on the details during modelling. Next figure shows all user requirements we need to remember when designing.

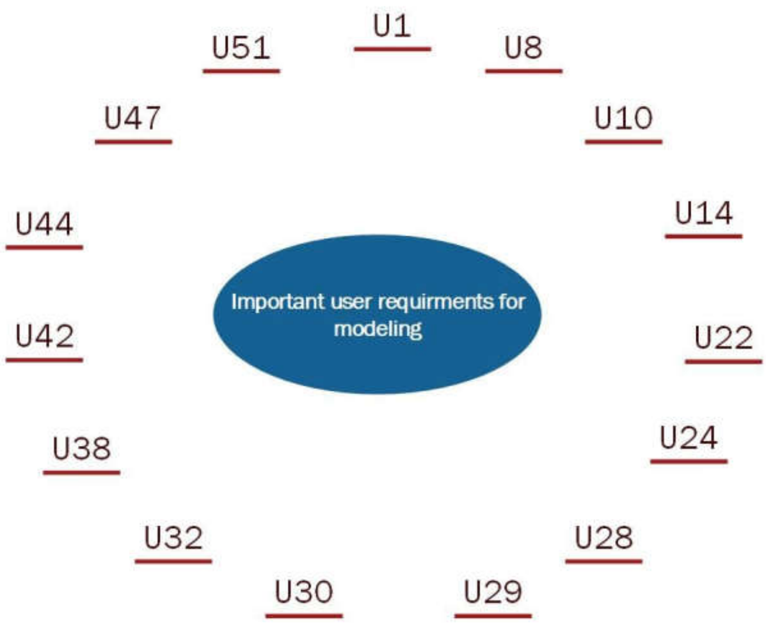


Figure: listed important user requirements that can be found in test specification document.

Activity: Technical Risk Analysis - 30 min Time Box

Phase: Design/Testing
View: Realization

After made a good progress with the project we wanted to take a closer look at the uncertainties we could imagine will exist in these last concepts. We have now four concepts we want to bring further in the project and we need all details about them. This iteration activity gave us deeper insight into the details we must emphasize. What was common and repeated in all the concepts was the interface connection points from turbine to bleed system. So we need to get focused on these when modelling our concepts. The figure below shows all the technical risks that came out during iteration.

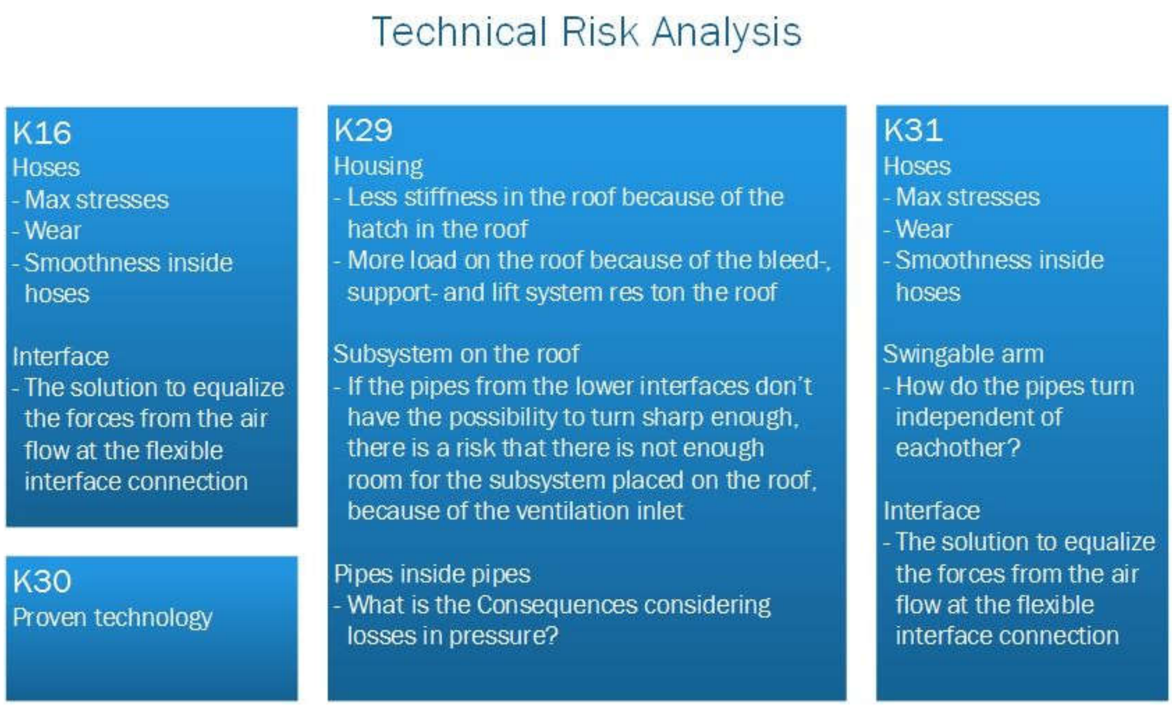


Figure: Shows the technical risks.

5.3 Conclusion

Before we now are starting modelling we wanted to get a better overview on details we need when designing in SolidWorks. This iteration helped us to find this information and we are now more prepared to action. It requires a little research on reading through requirements that are relevant, not only user requirements but also systems requirements but it will be helpful then since we can avoid major blunders on the road.

Iteration Report

6. Iteration round: 6

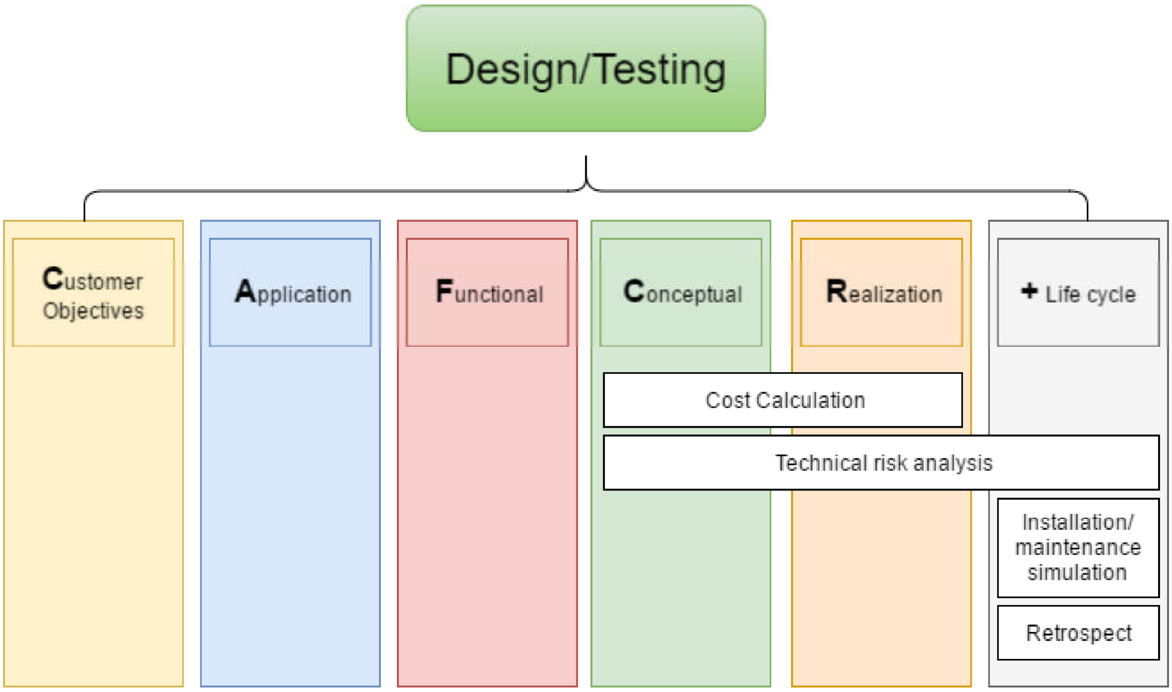


Diagram: shows an overview of iteration 6, and which views the activities are correlated to. the diagram is taken out of the iteration plan included in the project plan.

Phase:
Design/Testing

Iteration views:

- Conceptual
- Realization
- Life cycle

Date: 04.05.2017

Time scheduled: 20 min Time Boxes

Activities:

- Cost calculation
- Technical risk analysis

- Installation/maintenance simulation
- oppfrisking av prosess på begge konsepter

6.1 Introduction

At the moment we are working for the last week with designing and testing, and preparing to change the focus towards documenting all of the work in the project. The most of the technical specifications are falling into place, and we are close to implement the right components and configurations to get the wanted functionality of the two remaining design concepts. As usual we think it is of great importance to always be on top of technical risks at all times during the project, thus we also conduct a technical risk study in this iteration. In conjunction with the assembling of the final design it is natural for us to focus on the the best possible way of installation and assembly/disassembly during service. It is only when we have established how we want to stack the system together that we can be sure that the configuration of the parts is right. although we have a rough idea about the price of the two systems as this has been an important factor when choosing the best possible parts. We can now get an more accurate answer on the price. lastly we prepare the next phase of the project by looking back on some of the most important technical decisions and changes associated with the designing of the two systems.

6.2 Activities

Activity: Cost calculation - 20 min Time Box

Phase: Design/Testing
View: Realization

In this iteration activity we decided on a uniform way for the whole group to conduct a more detailed analysis of production cost. earlier, we have made estimates of high and low cost for various aspects of the system concepts we've worked with before, but since the production cost was unimportant in relation to cost of maintenance for the system this iteration activity could wait until after we have received a smaller selection of concepts to work with. Now that we have a selection of the strongest candidates of concepts we can go on to optimizing production cost for each of the concepts. The first step to doing this is to get an overview of what they in their present condition will cost. prices represented in the analysis is based on the costs of parts from suppliers, and costs of machining of workshops.

What we decided on was the following points:

- We will find the exact price for all parts if possible, if not possible we will use the general price for a product of that kind.

- Regarding Manufacturing cost of the parts we will try to get quotes from suppliers, if not possible we will estimate the price based on average wage, and hours needed for the parts.
- We exclude transportation cost to begin with, but include them if we have time.
- The strategy on how to contact suppliers was established.This was done to get answers from suppliers. from experience we know that some suppliers tend to show no interest when contacted by students. We decided to approach them in an honest way by presenting ourselves as students working for the industry in kongsberg, but trying to appeal to them with the opportunity they may have by indirectly working with D-R. without making any false hopes.
- Bolts and nuts are included in the calculation.

Activity: Technical risk analysis - 20 min Time Box

Phase: Design/testing
View: Conceptual, realization and life cycle

In the project per this date there is still the possibility of technical risk. In the iteration round the group wants to get a general overview of them, to use the result when proceeding with the concepts. The technical risks shouldn't be so big they will stop the project, but can rather set it back by some time. The technical risk is considered for both remaining concepts, and some of the risk can apply for both. The approach is to evaluate piece by piece the components in the concepts, and recognize the unknowns. The unknowns will be evaluated of severity, and find if there is any replacing methods for solving the problems.

Technical risks:

Rockwool

- The supplier of rockwool that is intended to use as a flexible seal between the turbine, have not been able to give information yet about the products capability of coping with the stresses it will be exposed to. This is a critical component, and the requirement supporting this part of the system is rated A. A necessary requirement. The possibility until we get information, or if the rockwool doesn't work, is to replace it with rubber bellows. Rubber bellows have been used earlier in bleed line systems from Dresser-Rand, but have some weaknesses. It doesn't handle heat very well, and is therefore unsuitable in theory in the project. Even this it have been used, without failing in earlier versions of the bleed line system.

T-bend

- T-bend in general is standard parts. The bend we want to use in the concept have a 5 degree angle into the center of the pipe. This is a part still to be explored. The solution is to get a manufacturer of pipes to look at the 3D model and give their approval, or the pipe have to be modified. It is still possible to weld a standardized bend to a standardized t-bend. The last solution would create to much work in the 3D model, and have to be recommended to contracting entity in the supporting information of the project.

Fabric seal

- In the concept there is selected a fabric seal from one supplier. This fabric is not in the same dimensions as we have designed in the model. To get the proper information the supplier have to be contacted to evaluate if they can make this seal in our specifications. There is another solution, to implement an expansion joint between the pipes and the duct, to prevent the formation of tension in the system due to heat.

Gasket to interface

- To seal the connection points between the pipe and the interface capsule in the part fixed to the pipe, there is designed for a gasket. The gasket have the purpose of keeping the hot air from leaking out of the bleed line system. The soloution can be to use a liquid seal applied, which can resist the heat. A copper pasta used in the auto car industry is possible. Ther is possible to use a steel gasket, a woven steel thread gasket sealing when subjected to force when the capsules is screwed together. The requirements set for this part is that there can be small leakages. The decision is to leave this part without gasket, and accept the small leakage created.

Conclusion

All in all, the project is within the limits set in the project plan, and the recognized risks is insignificant for the outcome.

Activity: Retrospect - 20 min Time Box

Phase: Design/testing
View: Lifecycle

The retrospect is look back on what decisions have been made in the concepts from day 1. The iteration is done to have a complete view of the project, and be aware over the important and significant changes done. All of these decision shall be in the documentation periode at the end of the project. Both concepts have been exposed to smaller changes done by every group member, and have been improved by the whole group.

Changes in concept 30

- The pipe from valve 44 was expected to be bent by Niras, a company specialized in induction bending. The reception it received from project owner was not good, and was recommended to be changed.

- The diameter of the pipes was changed due to the low pressure drop, and to save weight on the pipes.
- Fabric seal in the roof implementation
- Heat Shield between wall and duct
- Size of duct
- Length of duct
- Attach arrangement to the wall
- Fabric instead of expansion joint in the roof
- Sound Muffler build on the roof instead inside the duct
- Duct on the inside of the enclosure instead of outside.

Changes in concept 16

- Stripwound hose instead of corrugated hose.
- Boom configuration
    - Height
    - Shape
    - Number of booms
- Interface capsule close mechanism, v band instead of screws.
- Interface capsule connected to bleed line system instead of valves.
- Location of expansion joint
- Narrowing the pipe on the bleed system from valve 42
- Changed center point of pipe through roof
- Roof implementation, swivel joints instead of disk
- Bend from valve 44 changed
- Number of hoses in the bleed system, from all hoses to one hose.
- Decided attachment points to the bleed system
- Added expansion joints

Conclusion

A lot of changes have been made through the project, when we have been doing more research about products and dimensions. It shows the way from a incomplete bleed line system, to a fully functionable.

Activity: Installation/Maintenance simulation - 20 min Time Box

Phase: Design/testing
View: Lifecycle
In This activity we established a system for how we wanted to go forward with analysing how the systems would be installed and disassembled/assembled during service. It is only when we have established how we want to stack the system together that we can be sure that the configuration of the parts is right.

We decided on the following points:

- The Installation simulation will be performed from start to finnish. This will include the order of installation for the parts, how they are fastened, and which tools will be needed. It will be this simulation which will create the basis for the Installation manual.
- The maintenance simulation will include the order of disassembly and what procedures need to be performed, which tools will be needed. It will be this simulation which will create the basis for the maintenance manual.
- The few specially made pats in the systems will have production 2D-drawings.
- manuals for both installation and maintenance shall be as visual and simple as possible. Only necessary notes shall be included. Ikea manuals shall be used as inspiration.

6.3 Conclusion

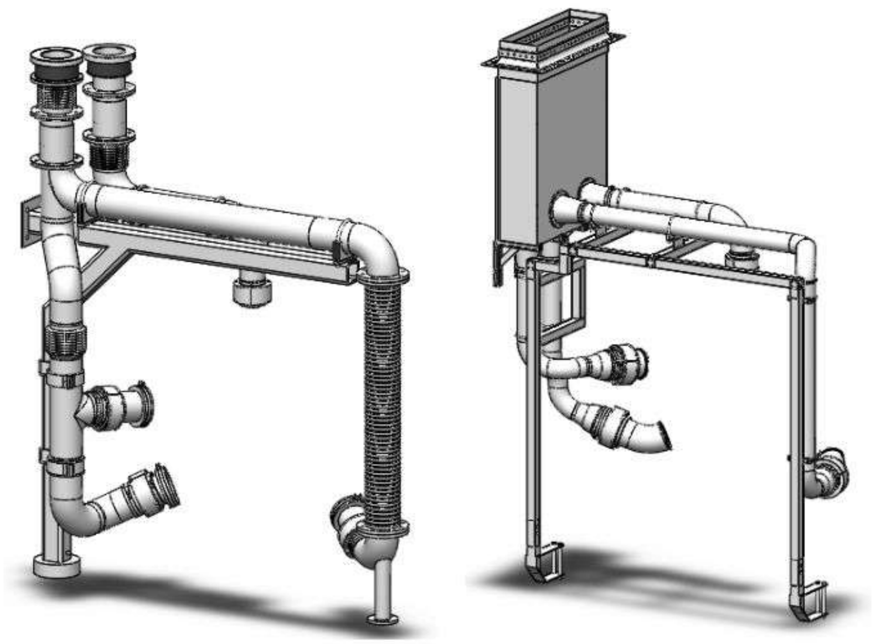
This iteration round has involved cost evaluation, technical risk, simulations and review of the changes the concepts have been through since startup. Knowing how we proceed with estimates and analyzes helps to make work smoother, and it is easier to get an overview of what remains of work. The iteration round has given a better understanding of the system as we go into it, and find out if we meet the requirements for service time. Here we are also in the documentation period that is incredibly important for the project, and provides a valuable refresher of forgotten innovations.

DRESSER-RAND

HSN University College of Southeast Norway

Service Manual C30

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
Svenn Bjørnstrøm
Kristian I. Asgeirsson

22.05.2017

Document History

Date	Version	Changes	Approved by
14.05.17	0.0	Created	Daniel
15.05.17	0.1	Parts, tools, disassembly	Daniel
22.05.17	0.2	Correcting and structuring	Daniel, Kristian
22.05.17	1.0	Approved for submission	Daniel

Table of Contents

1. Introduction

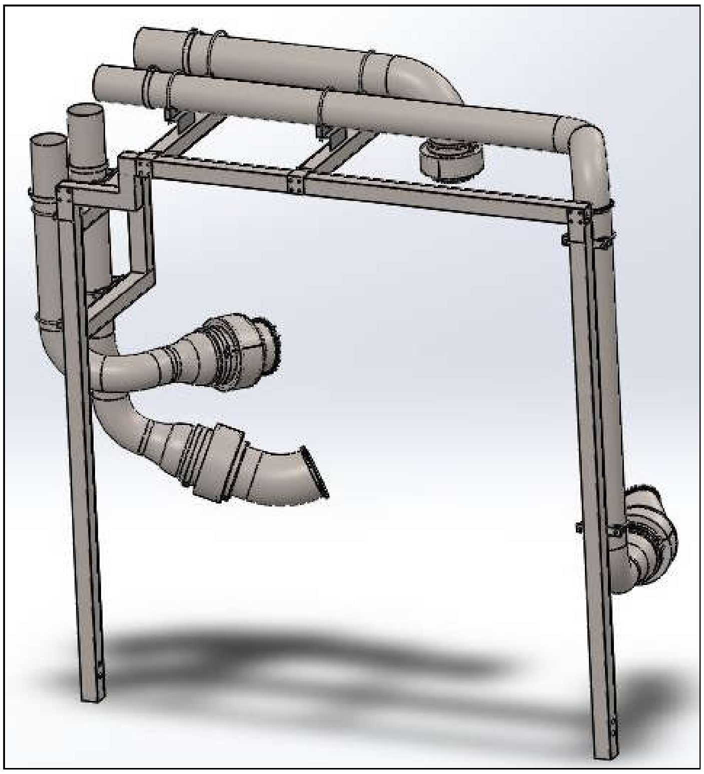
This manual will show how to disassemble and assemble the system during services, which tools are required and which parts are involved.

2. Tools

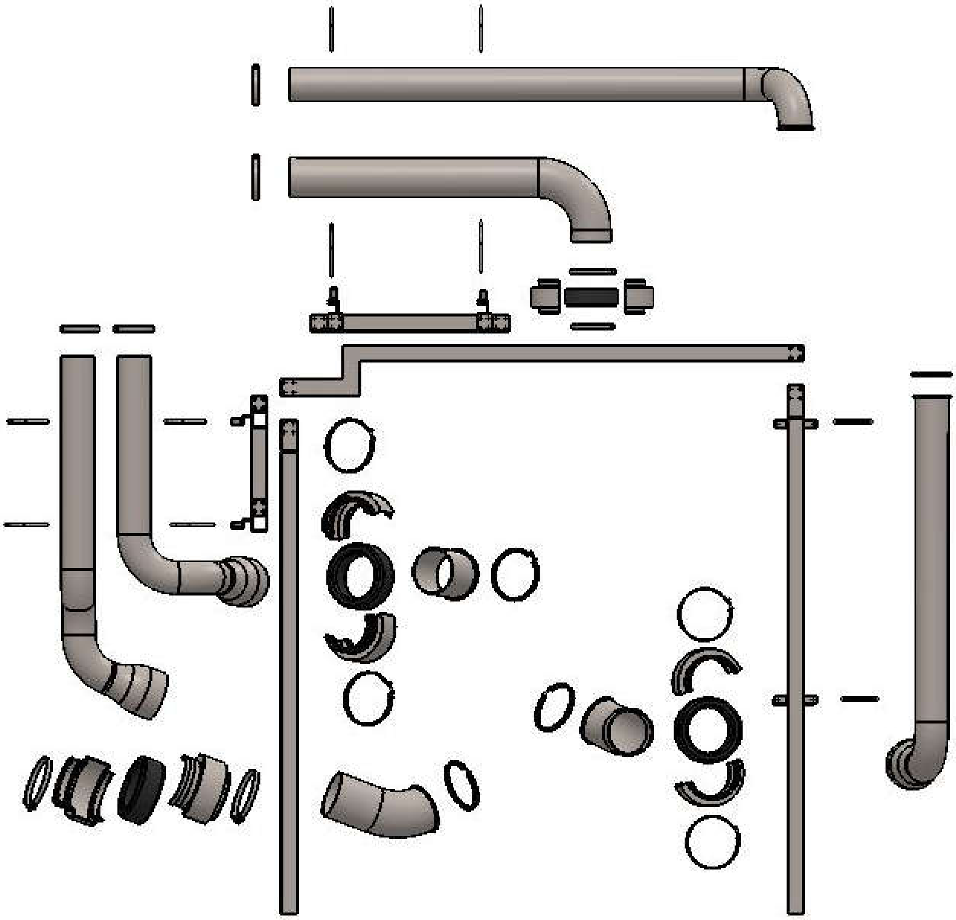
- Drill → V bands and frame
- Socet set → U bolts

3. Parts

In this section the system is shown in assembled state, both with the rest of the system and just the parts that needs to be removed during maintenance.



The picture shows the parts of the bleed system that needs to be removed.



The picture shows an exploded view of the parts that needs to be removed.

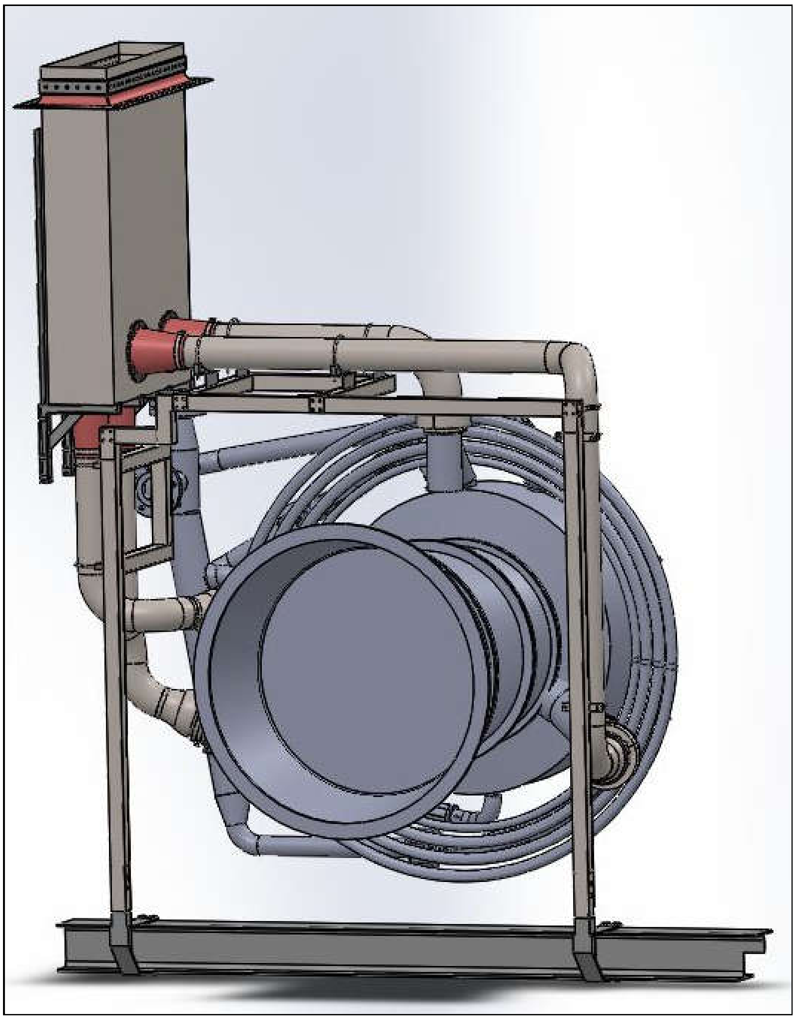
A detailed list with components and specification can be found in the technology document for C30.

4. Disassembly

In this section the disassembly of the bleed system is explained in detail through the pictures shown below.

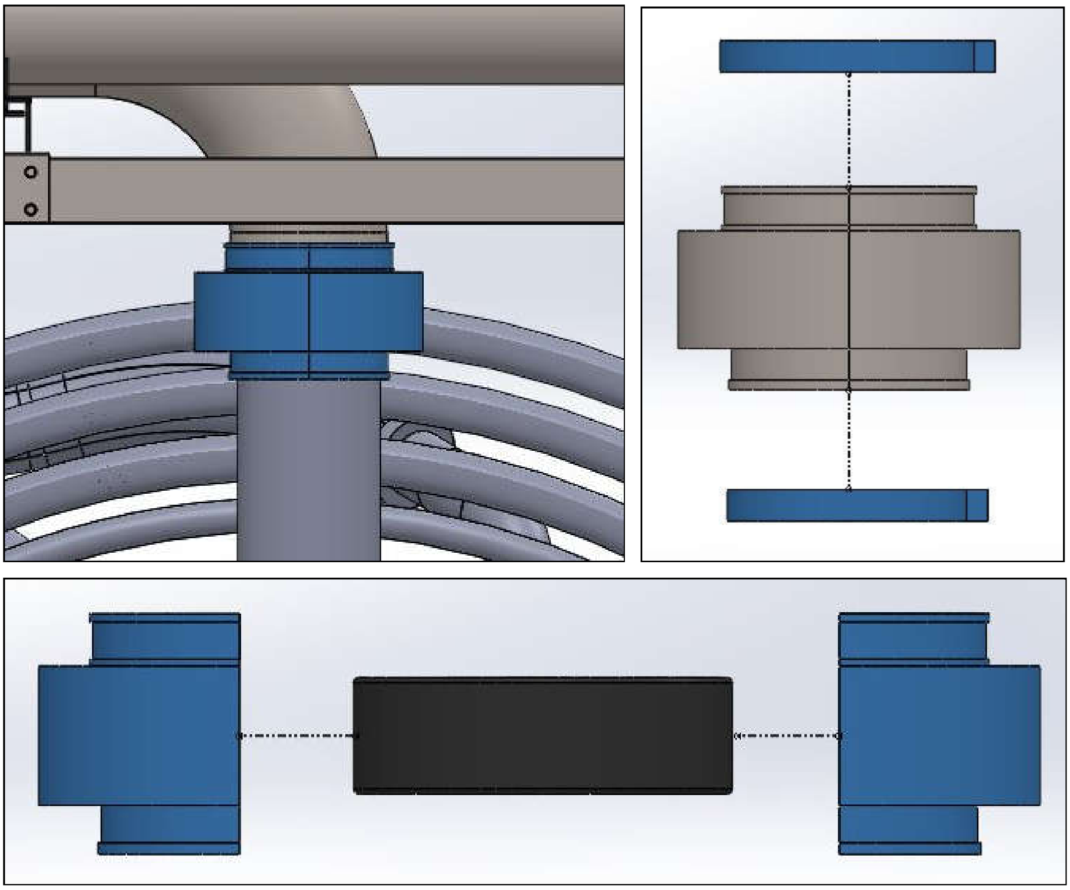
Estimated disassembly time is 11 minutes, without removing the interface extensions, and 12,25 minutes if they are to be removed.

Start: The bleed system is assembled and needs to be removed

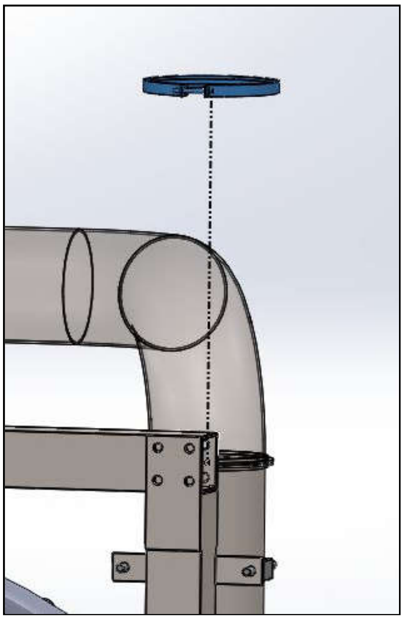


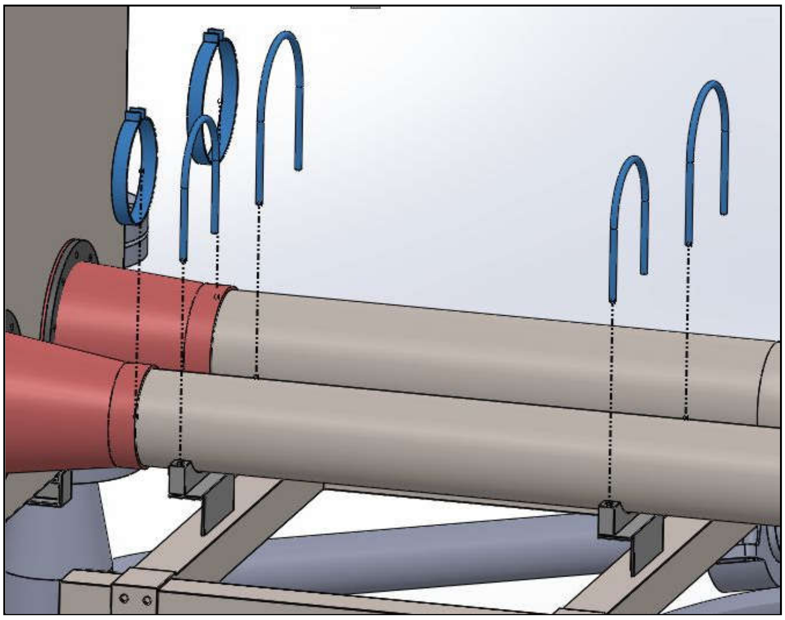
Step 1: Remove interface joint A42

Estimated time: 35s

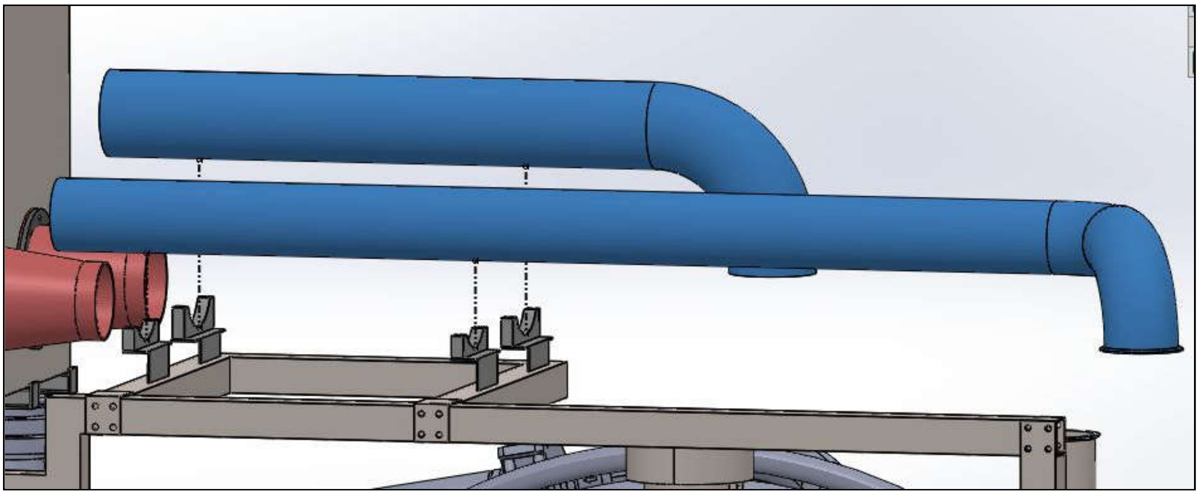


Step 2: Remove fastenings on pipe A42 and A44
Estimated time: 95s

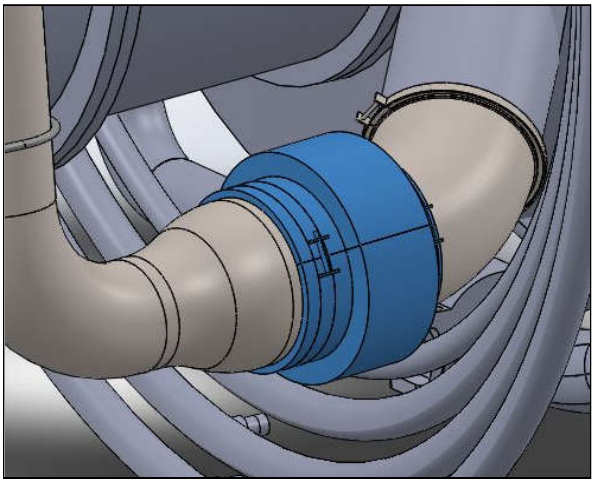


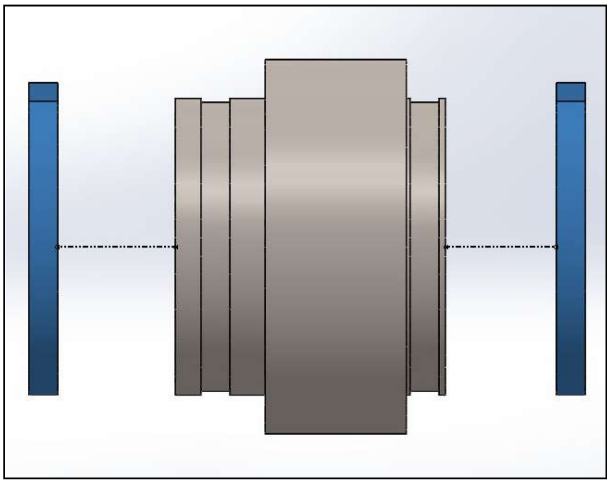


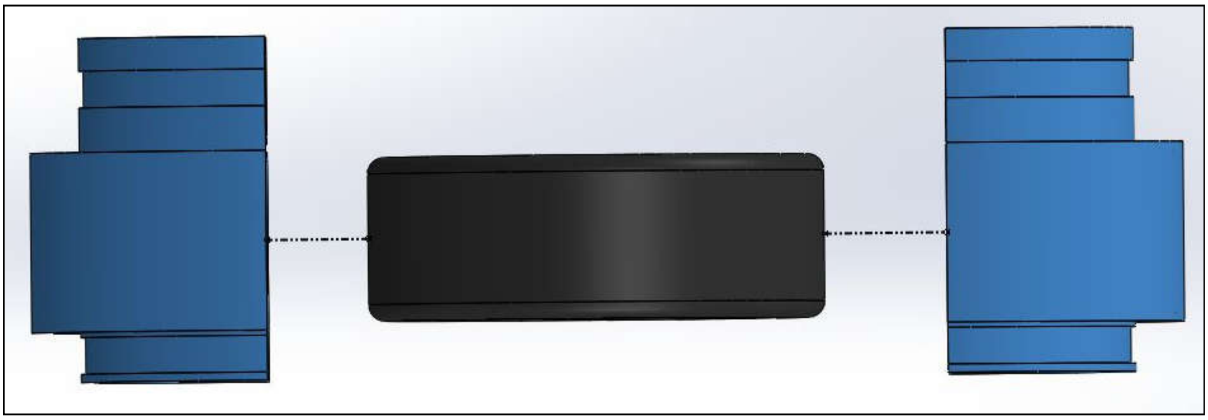
Step 3: Remove pipe A42 and upper A44
Estimated time: 70s



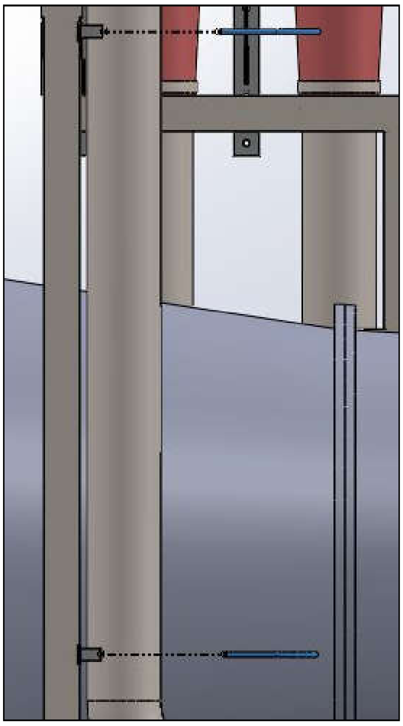
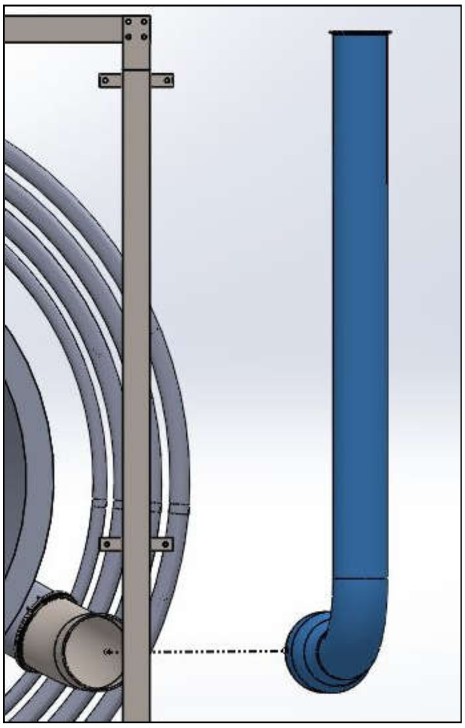
Step 4: Remove interface joint A44
Estimated time: 35s



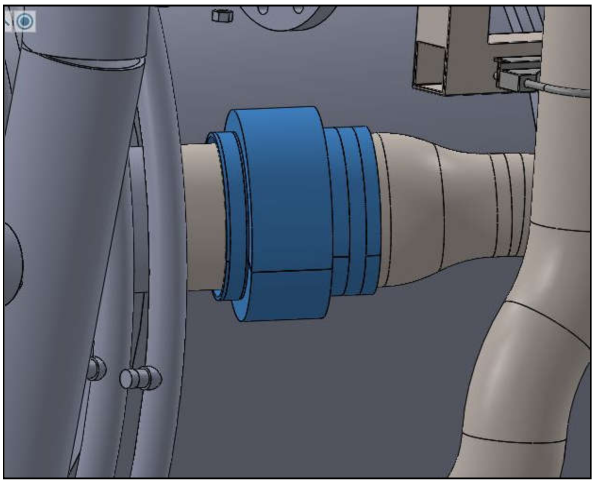


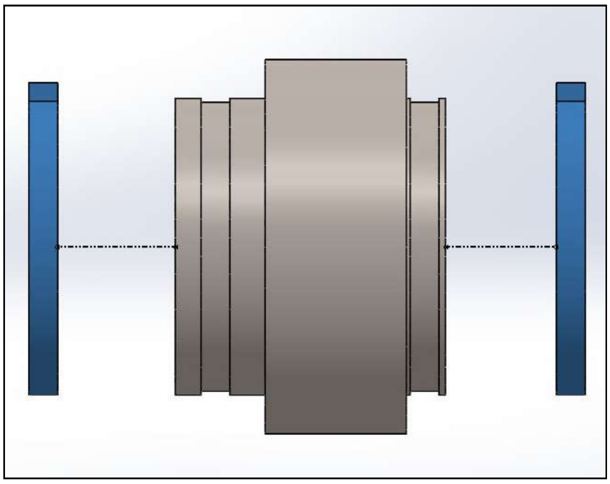


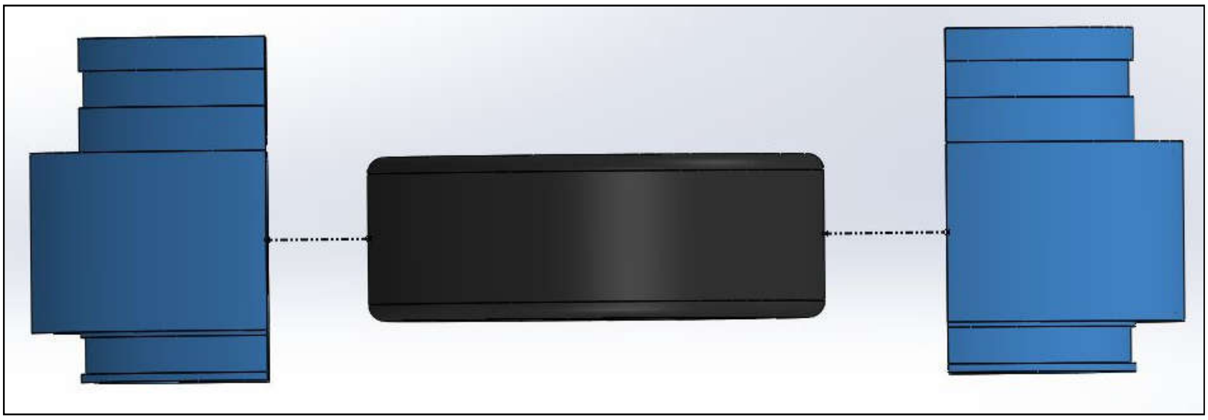
Step 5: Remove fasteners and lower A44 pipe
Estimated time: 50s

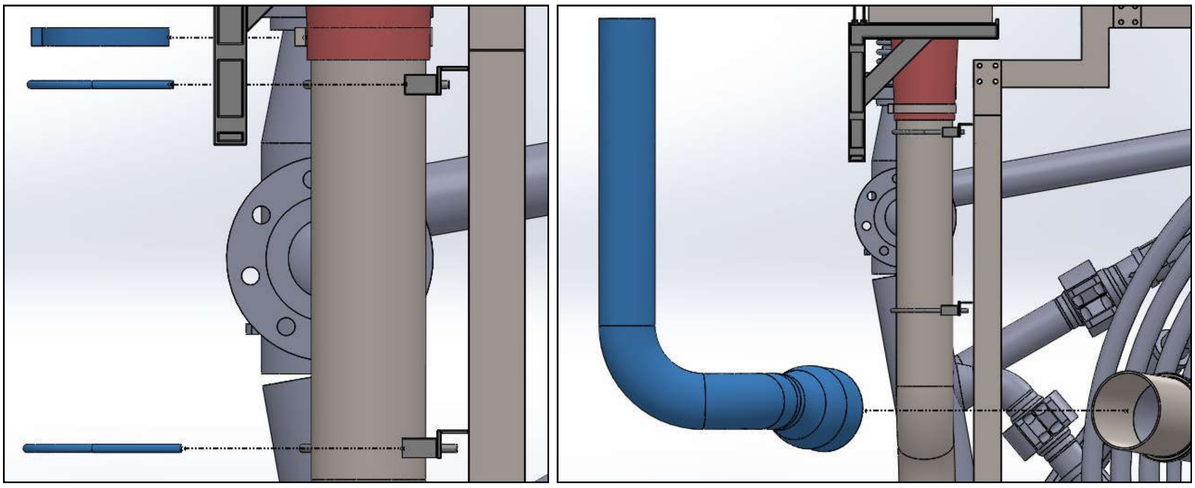
Step 6: Remove interface joint A43
Estimated time: 35s



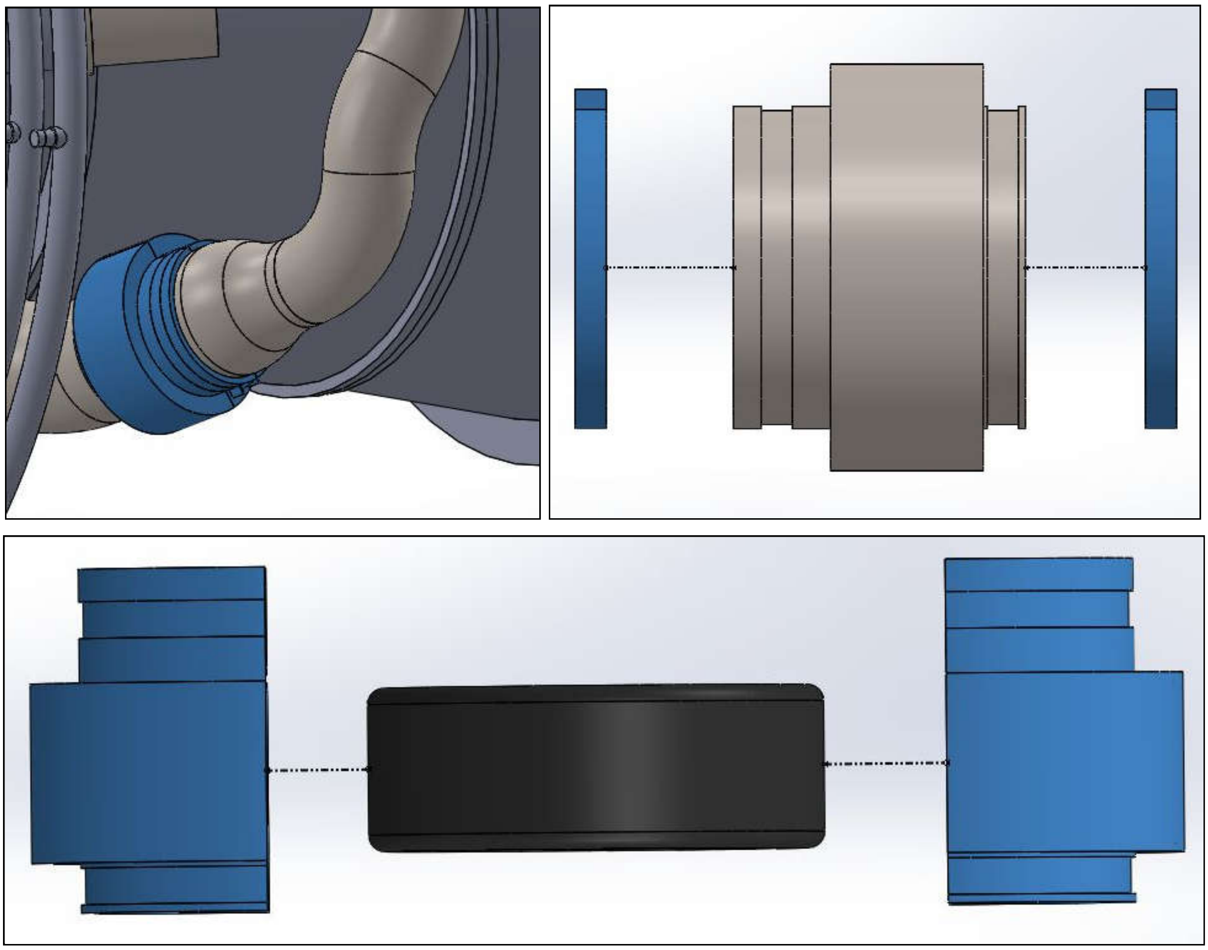




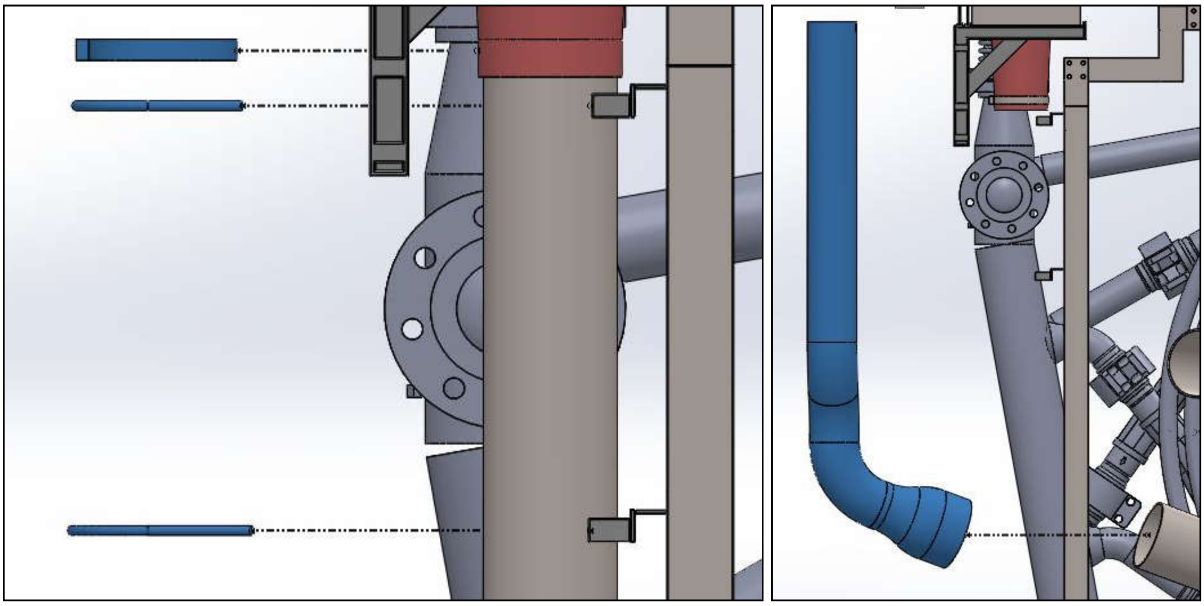
Step 7: Remove fasteners and pipe A43
Estimated time: 70s



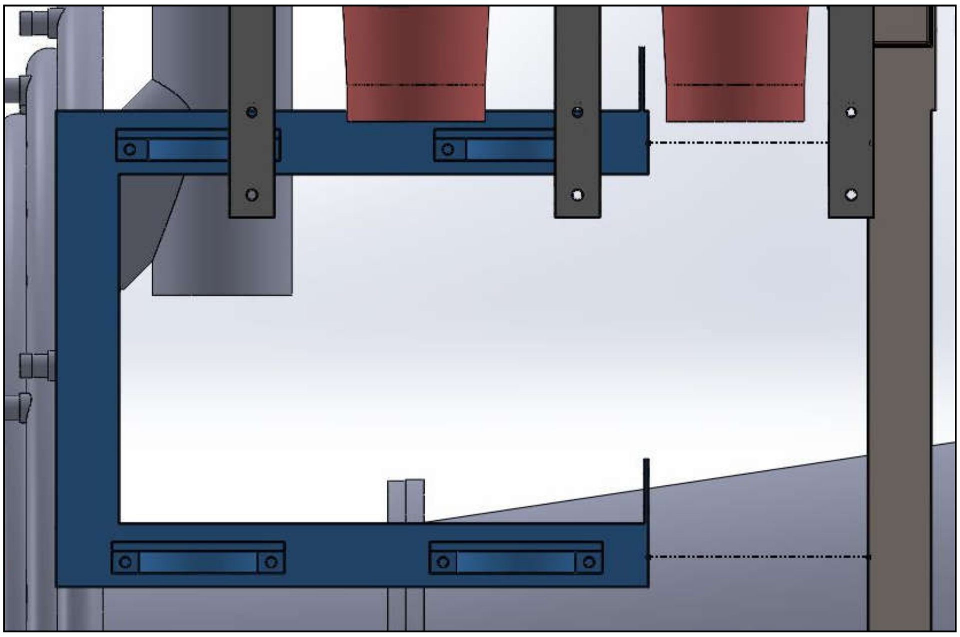
Step 8: Remove interface joint A51
Estimated time: 35s

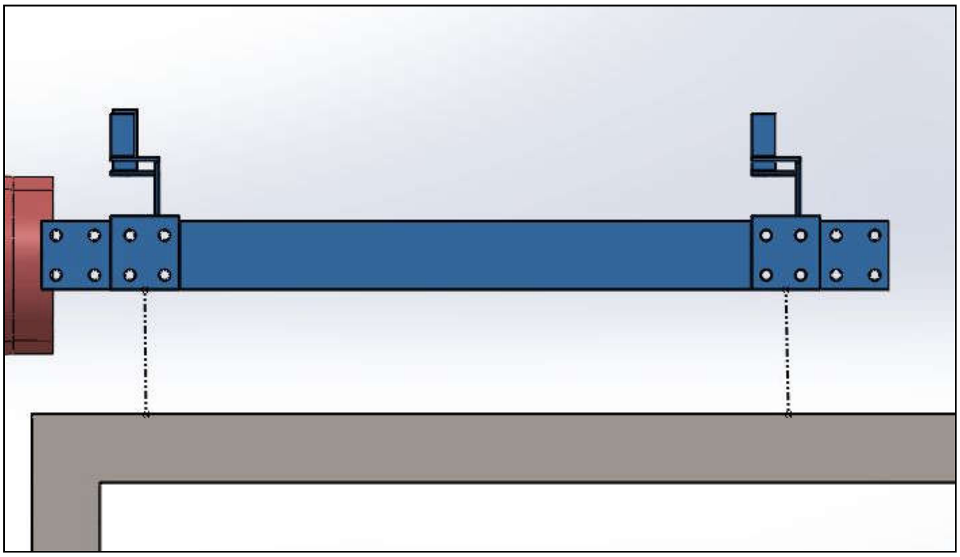


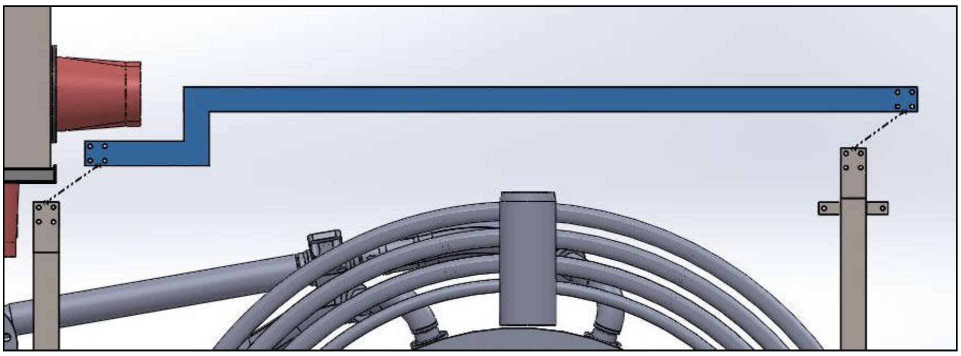
Step 9: Remove fasteners and pipe A51
Estimated time: 70s

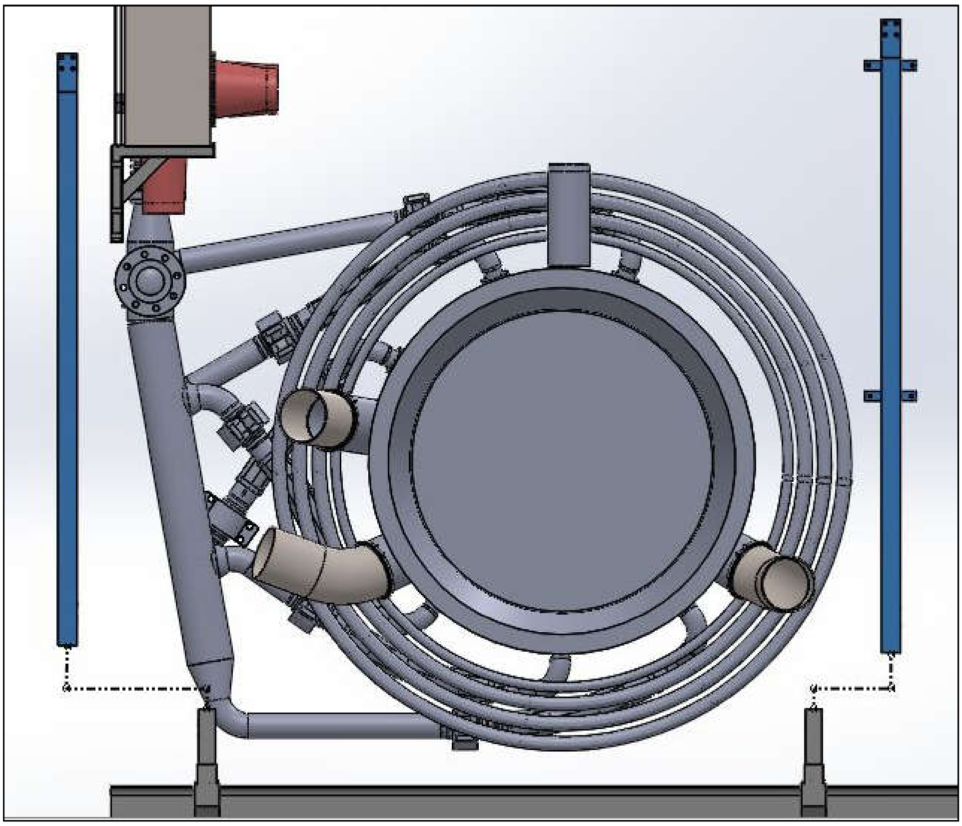


Step 10: Remove frame
Estimated time: 170s

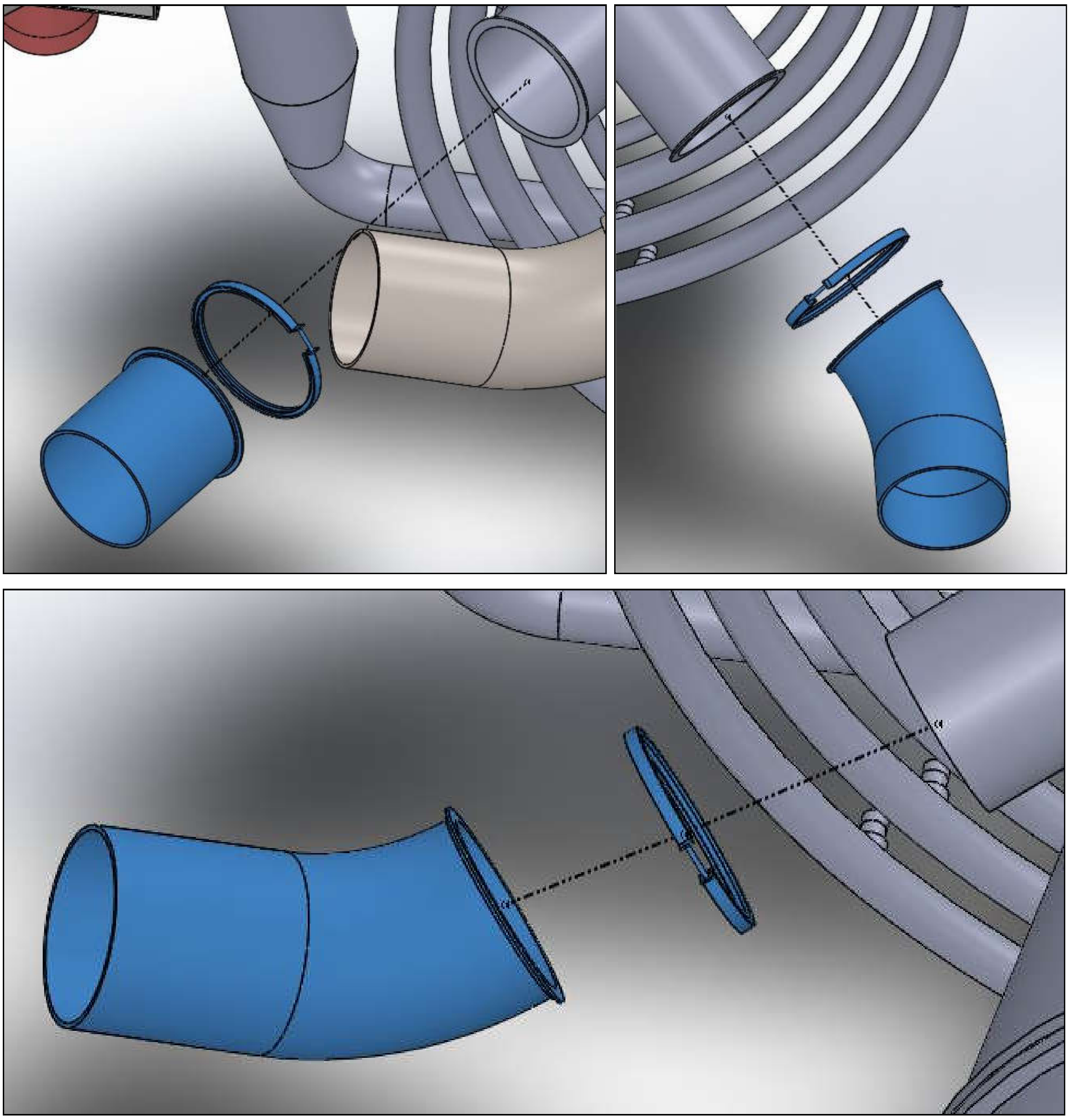




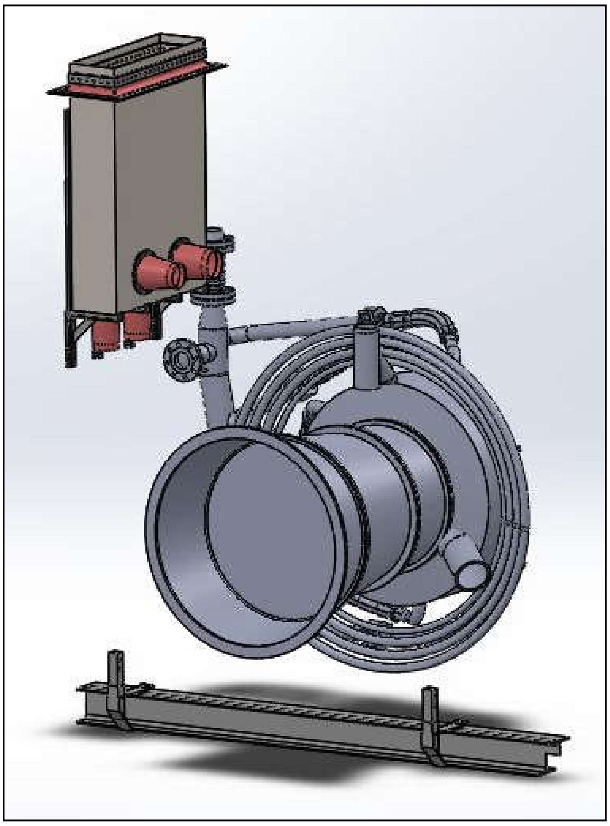




Step 11: Remove interface extension A43, A44 and A51
Estimated time: 70s



End: Bleed system is out of the way and turbine can be removed

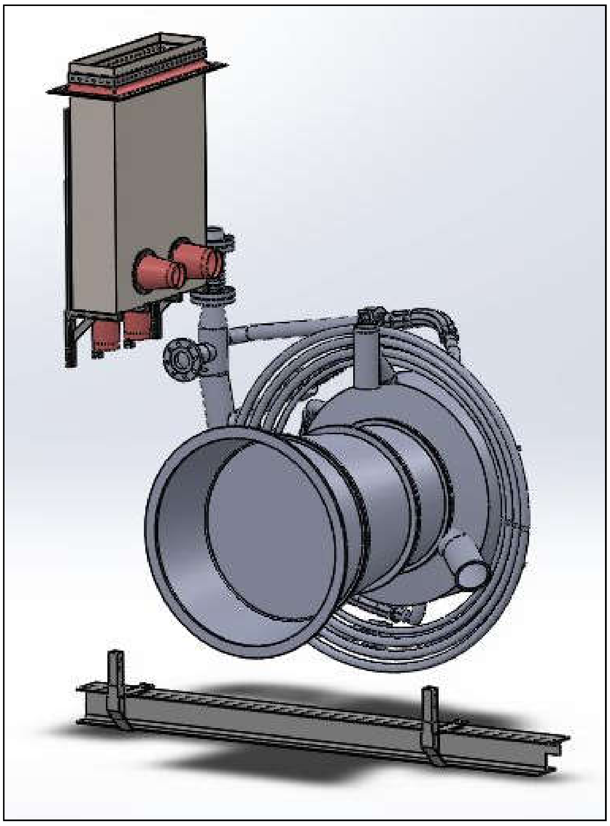


5. Assembly

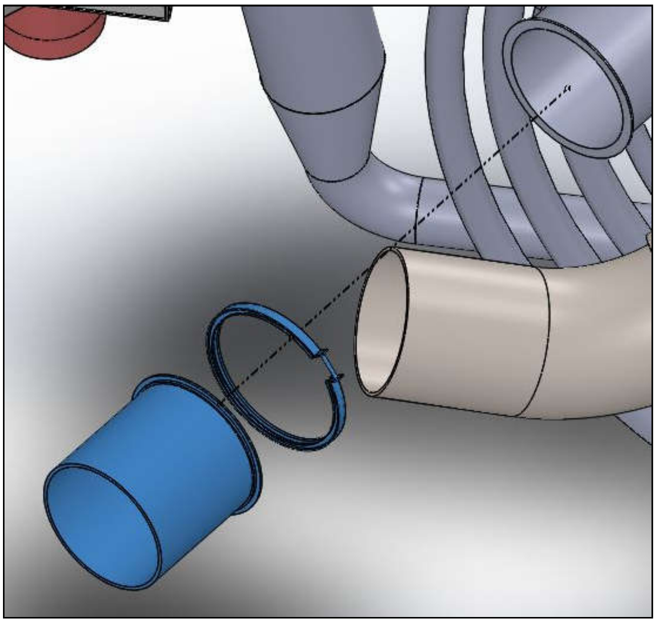
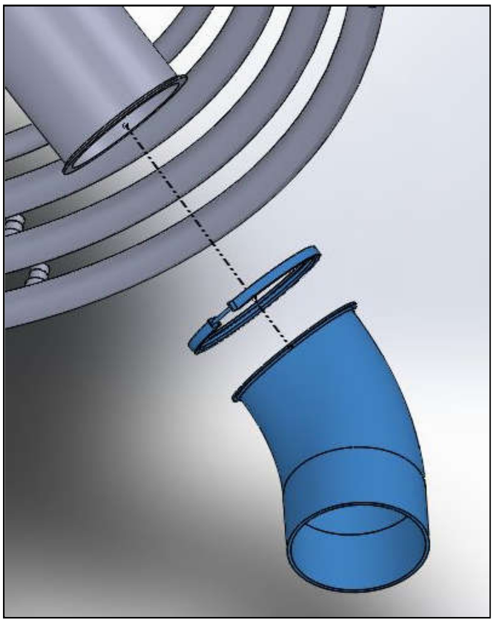
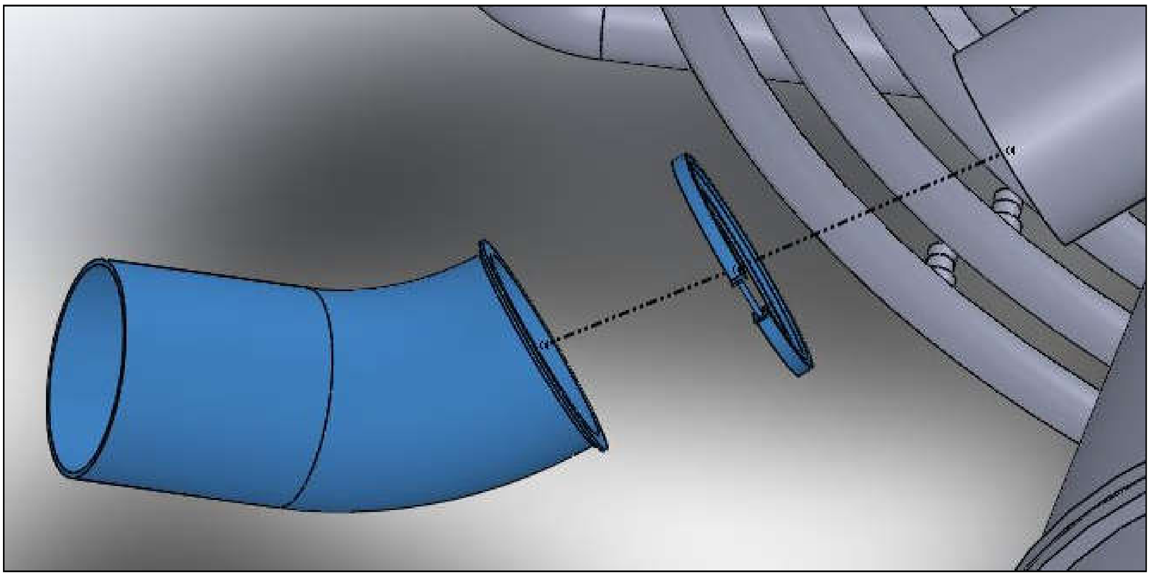
In this section the assembly of the bleed system is explained in detail through the pictures shown below.

Estimated assembly time is 11 minutes, if the interface extensions is already on, and 12,25 minutes if they have to be installed.

Start: Turbine is installed and is ready for the bleed system

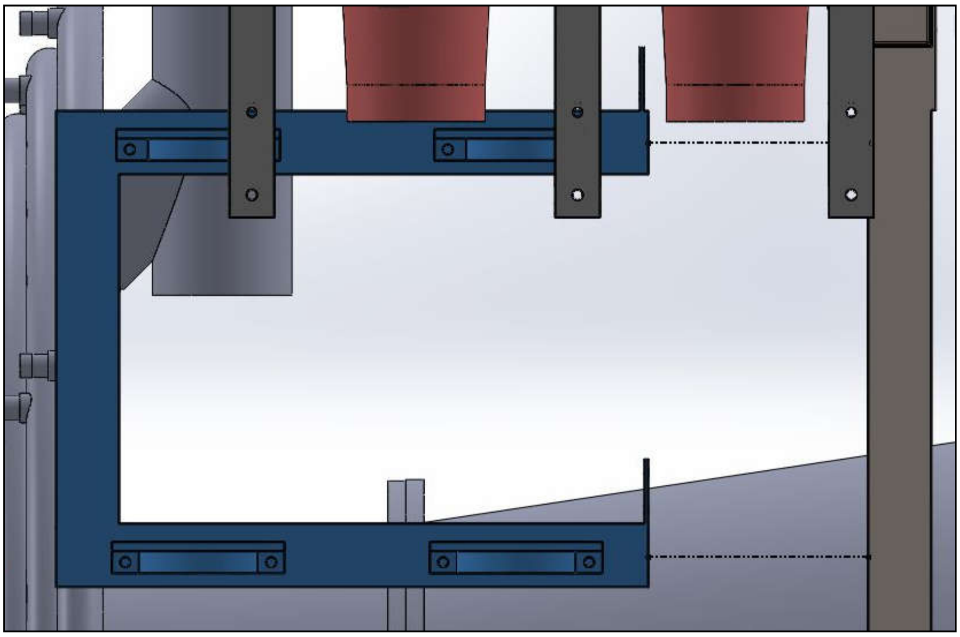


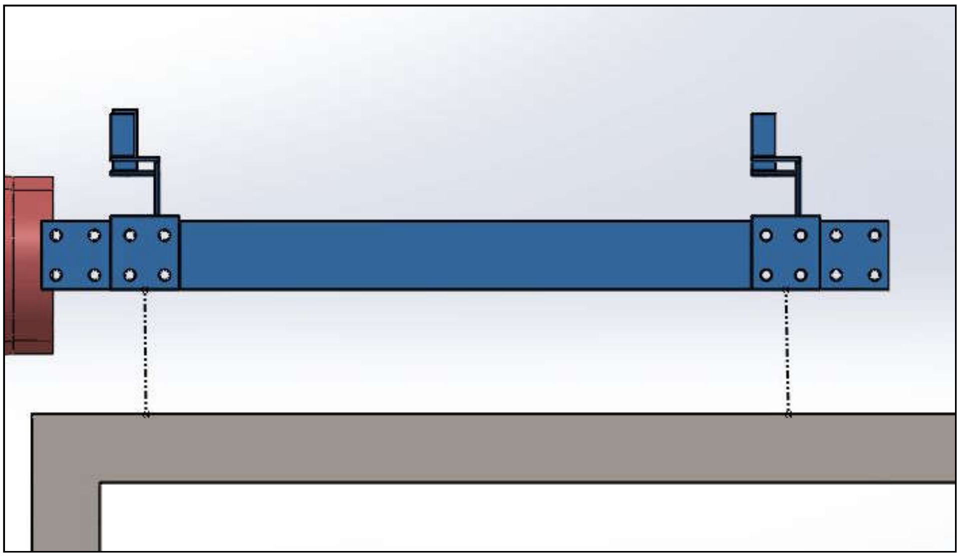
Step 1: Install interface extension A43, A44 and A51
Estimated time: 70s

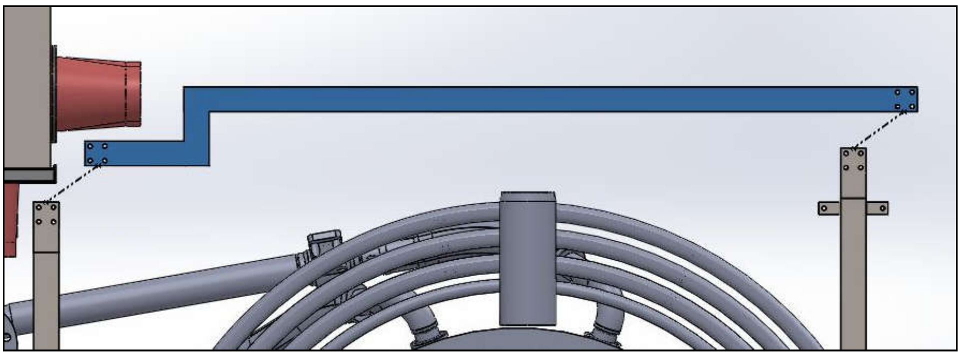




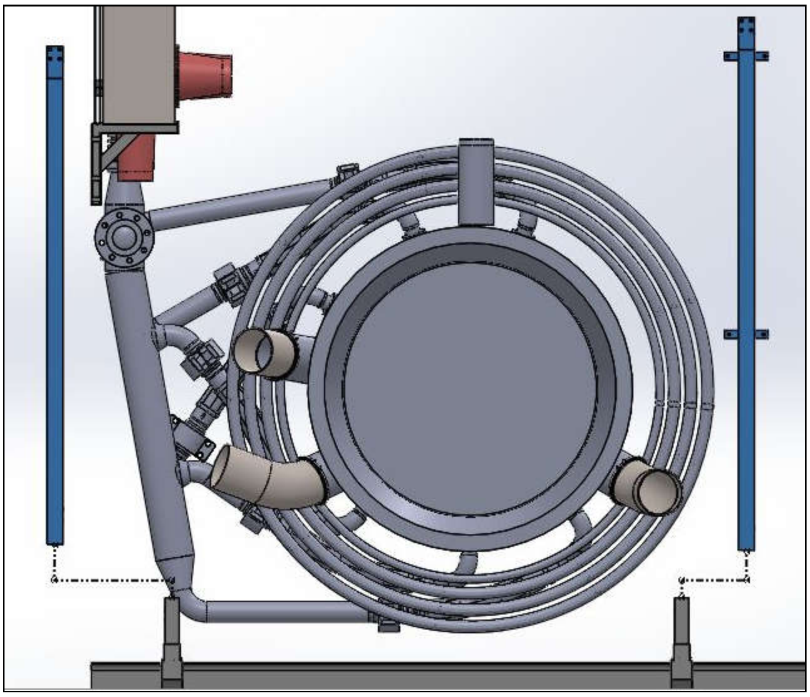
Step 2: Install frame

Estimated time: 170s

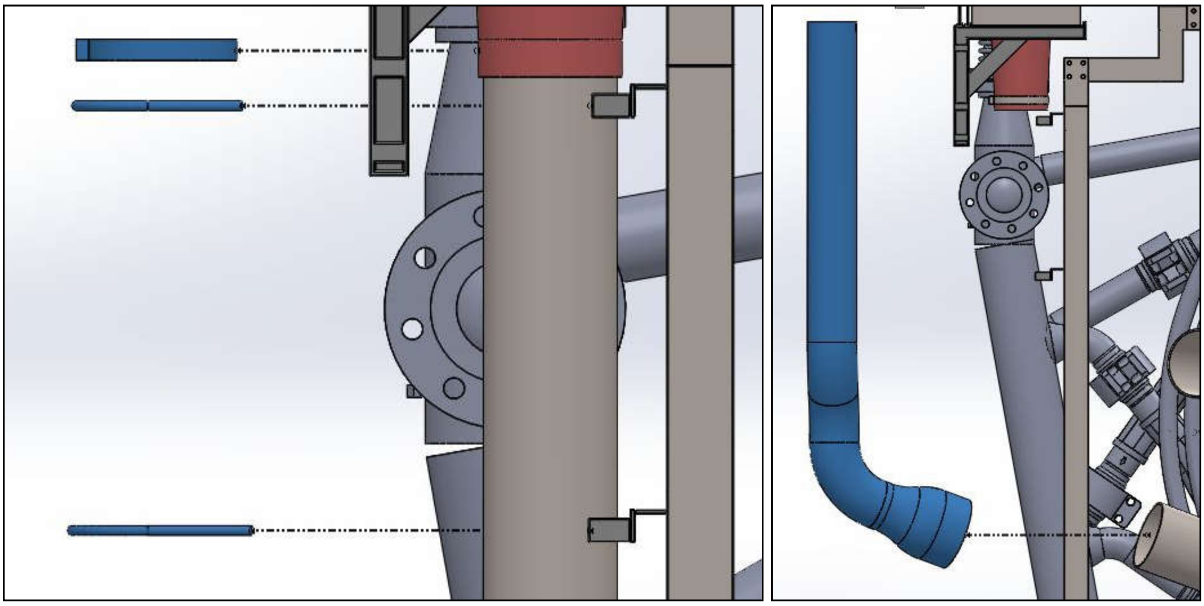






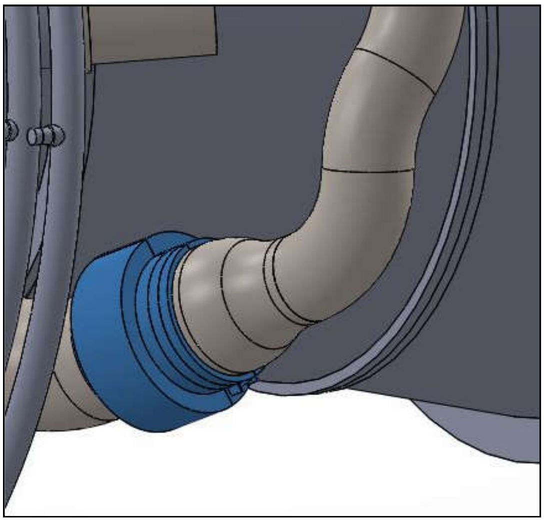


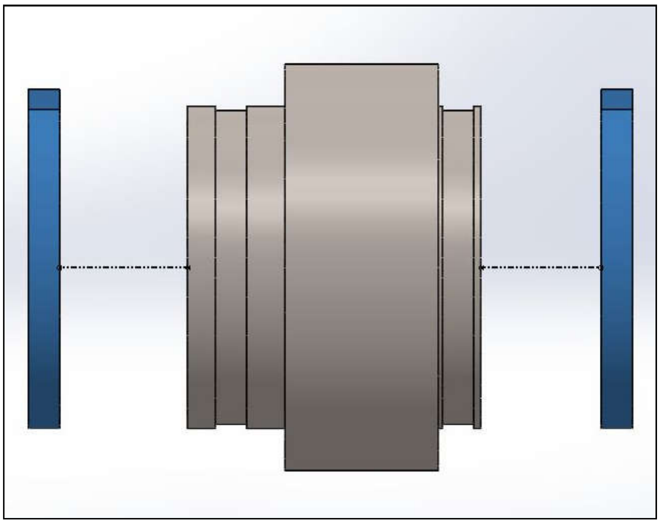
Step 3: Install fasteners and pipe A51
Estimated time: 70s

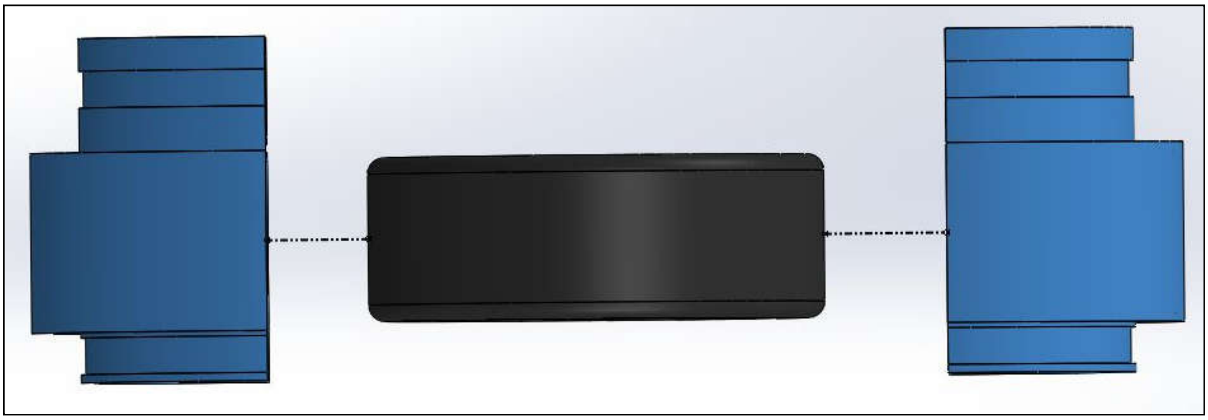


Step 4: Install interface joint A51

Estimated time: 35s

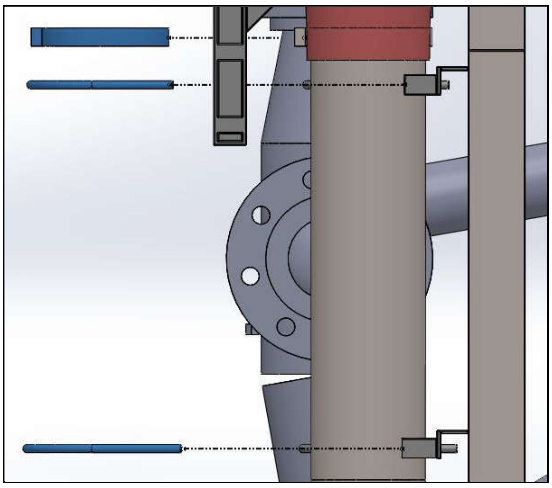


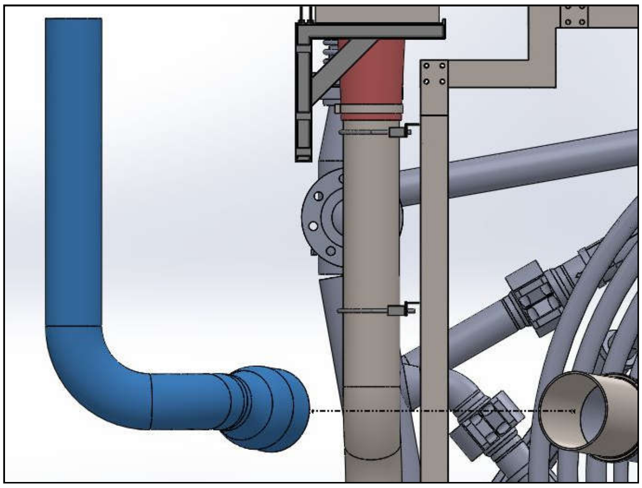




Step 5: Install fasteners and pipe A43

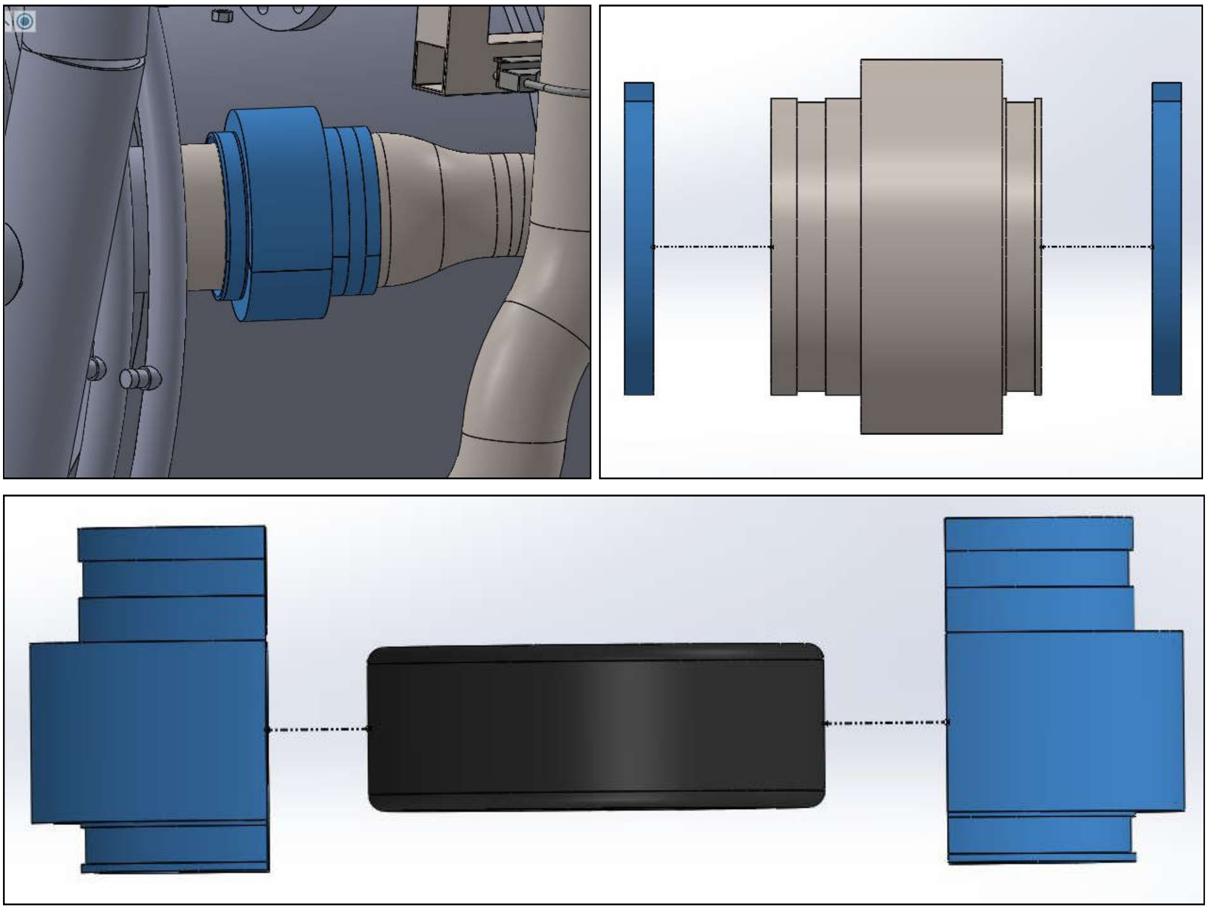
Estimated time: 70s



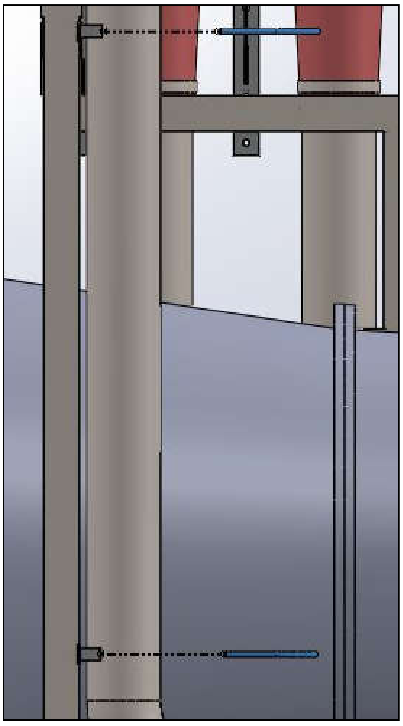


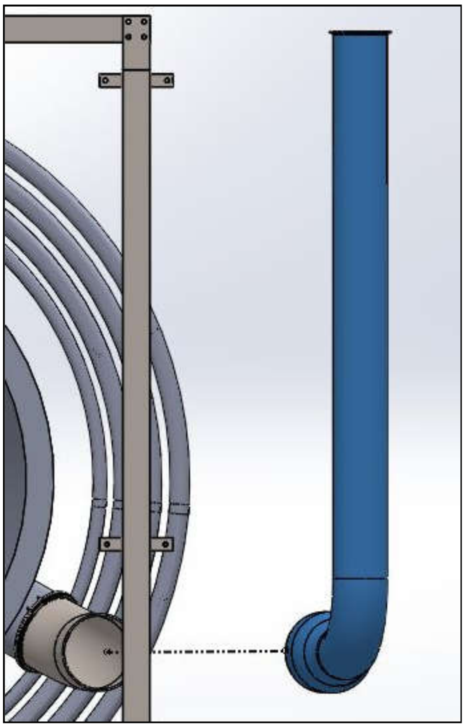
Step 6: Install interface joint A43

Estimated time: 35s

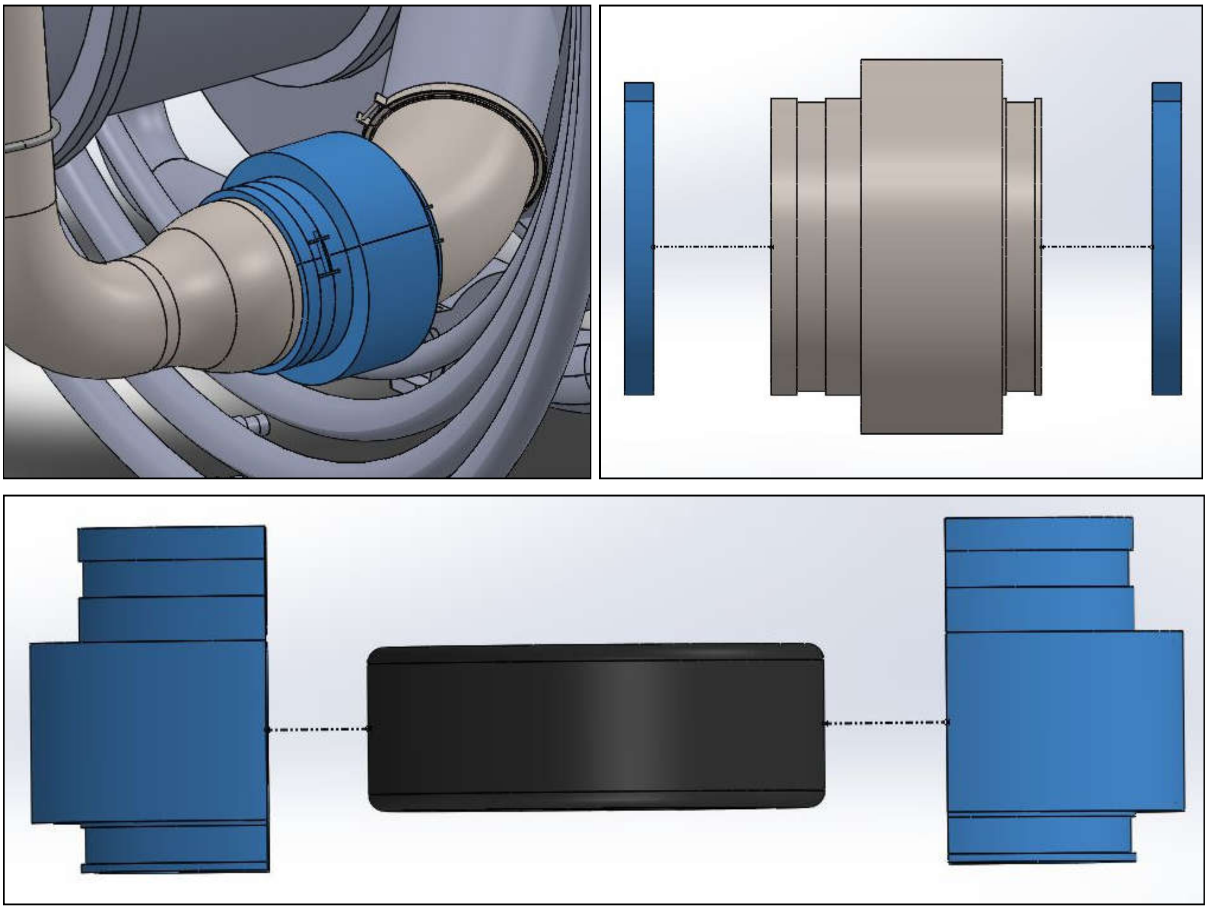


Step 7: Install fasteners and lower A44 pipe
Estimated time: 50s

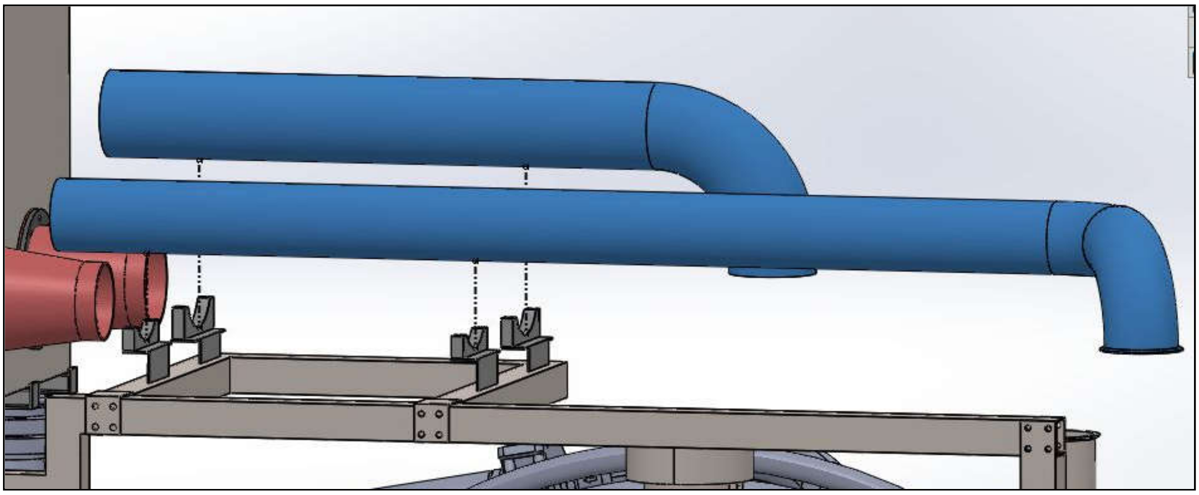




Step 8: Install interface joint A44
Estimated time: 35s

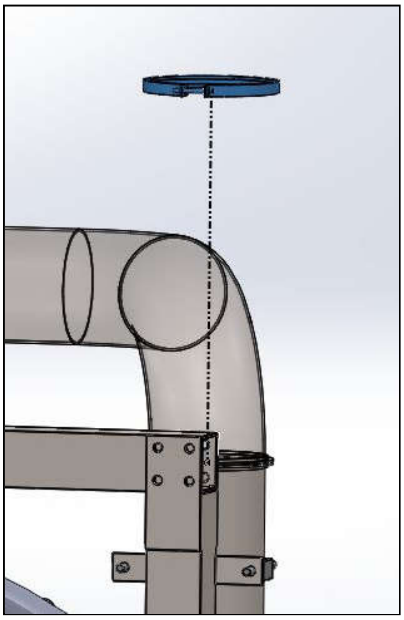


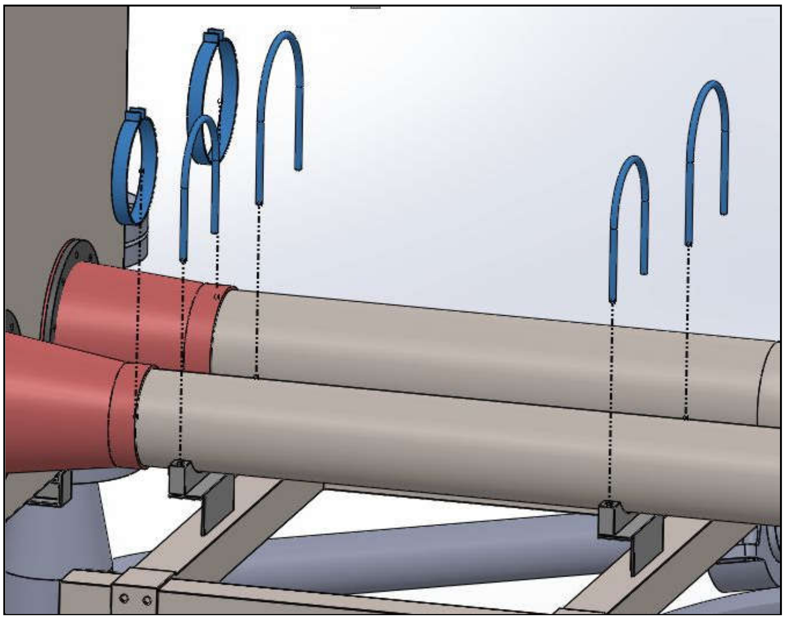
Step 9: Install pipe A42 and upper A44
Estimated time: 70s



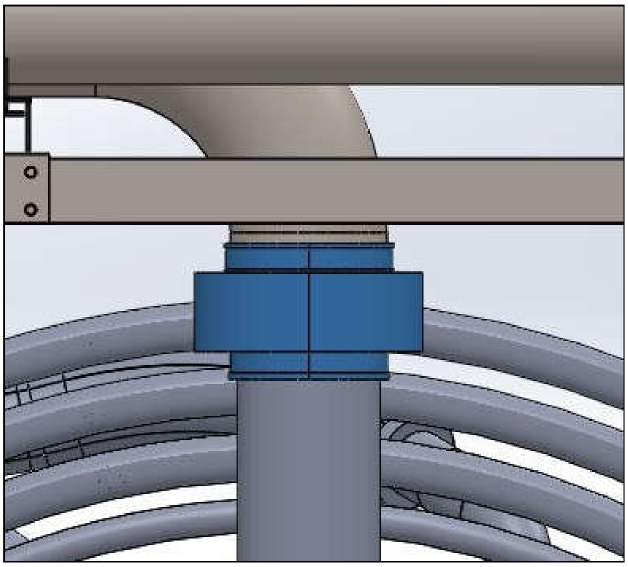
Step 10: Install fastenings on pipe A42 and A44

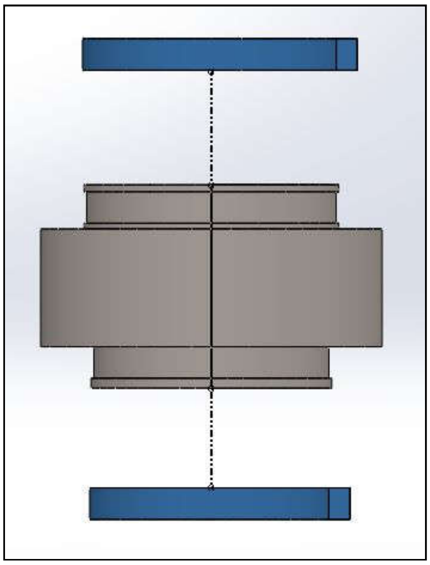
Estimated time: 95s

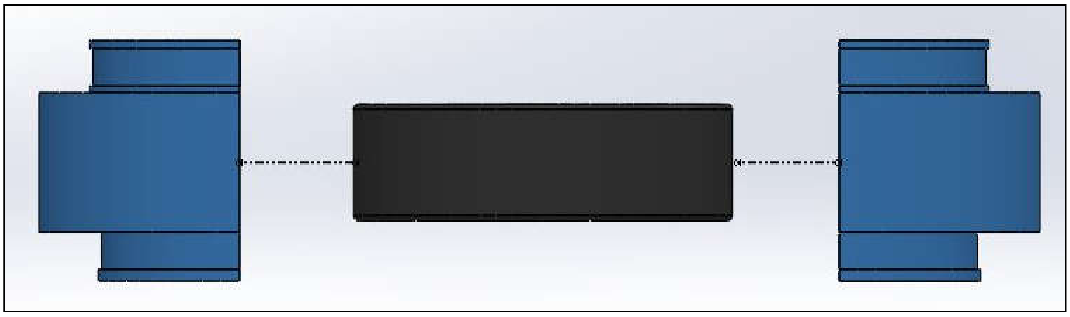




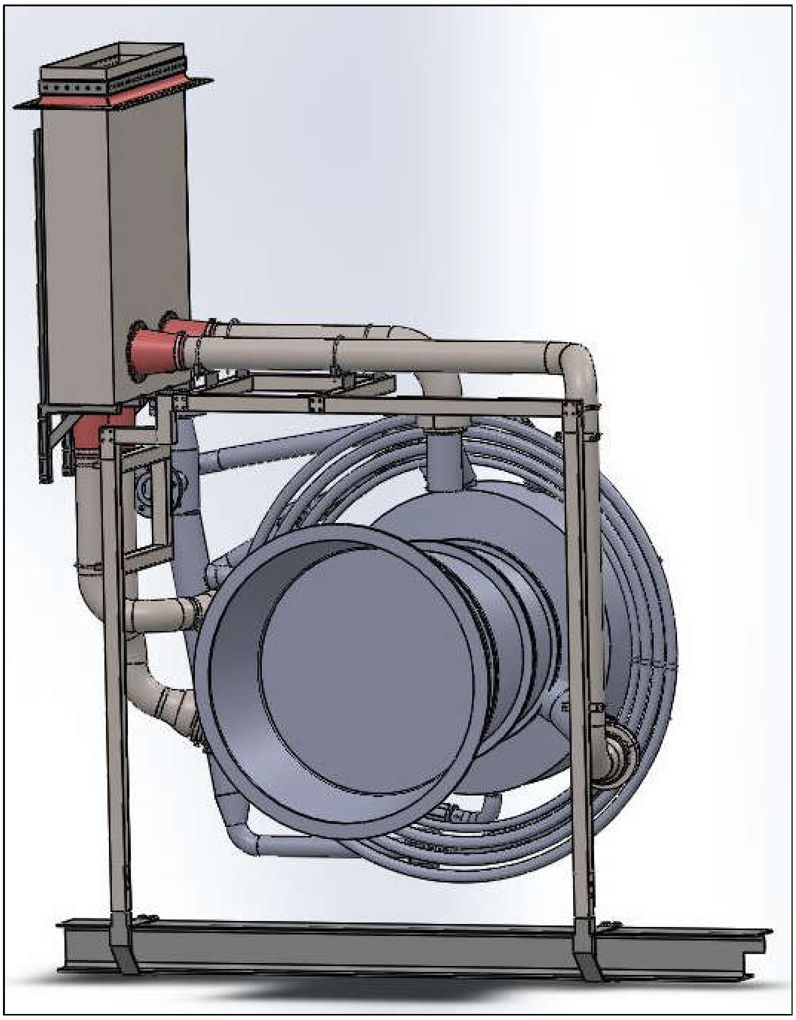
Step 11: Install interface joint A42
Estimated time: 35s







End: The bleed system is assembled and ready for use



6. Simplifications

- The time estimate on the assembly/disassembly is based on the time it takes to:
  - Loosen screws
  - Loosen part
  - Remove part and carry it to outside location

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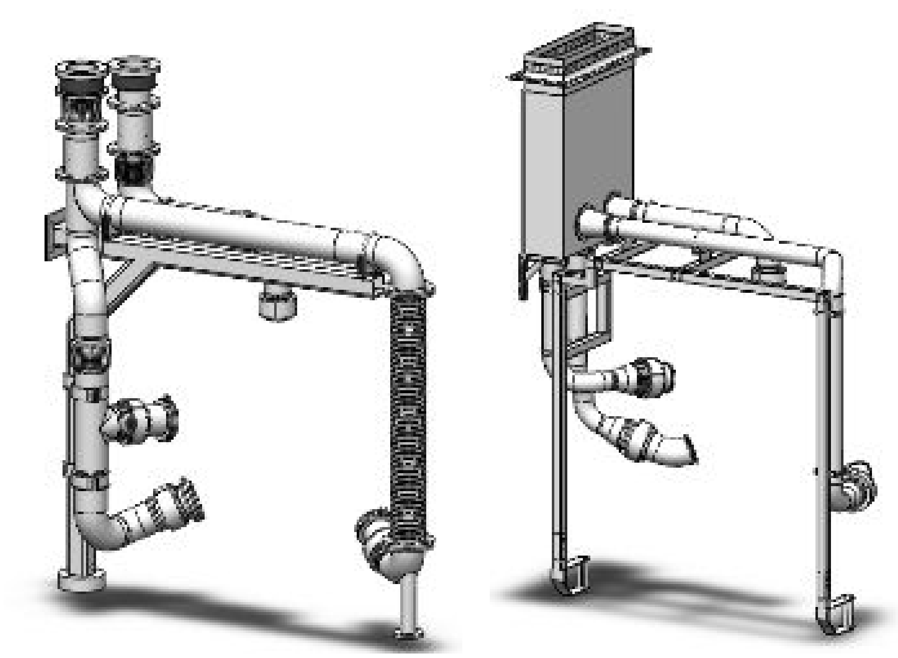
Attachments to Technology Documents

Gas Turbine Bleed System



Gruppe 19

Daniel Herness
Øystein Botnen
Svenn Bjørnstrøm
Kristian I. Asgeirsson

22.05.2017

Table of Contents

1. Attachments to C16

1.1 Instruction for Assembly and Disassembly During Service.

Disassemble during service

During the three year service interval of the turbine the bleed line system needs to be dismantled.

Step 1: The first step is to remove the capsule interface connecting the turbine and bleed system from valve A43, A44 and A51. This capsule is loosened by hose clamps on each end and slided onto the extension pipe of the valve. The extension pipe to the valve is then detached by taking away the v-band, and removing the capsule and pipe extension as one unit.

Step 2: When the three units is removed the foot of first bend to valve A44 is loosened, 2 bolts attaching the foot to the enclosure. The bend is then loose from the enclosure, and still attached to the strip wound hose.

Step 3: The boom B1 is ready for moving, and the secure splint at the foot of boom B1 is removed.

Step 4: The service personnel can then lead the hose by pushing it towards the front of the turbine, and bring it to the opposite wall, making the boom parallel to the long side. The boom is secured by attaching the splint at it’s foot.

Step 5: Secure the splint with pin.

Step 6: The boom with bleed system from valve A42 is independent of the other, and the capsule for valve A42 is loosened from the bleed system, slided back onto the bleed pipe, and attached there before removal.

Step 7: The gap between the bleed system and the turbine will be a couple of millimeter ensuring the valve A42 boom can swing without bumping into the valve. The outer part of the boom during operation is linear with the inner boom, and during service the bleed system from valve 42 is swinged so the to bleed systems is lying side by side. The bleed system in total is estimated to take 10:45 minutes to disassemble.

Total estimated time:

Without interface extension pipes: 4:45 min.
With interface extension pipes: 6 min.

Assembly during service

The two booms is lying parallel to the longside of the enclosure.

Step 1: The boom to valve A44 is swung into position parallel to the valve A42.

Step 2: The capsule of the interface is loosened with loosening the two clamps. The capsule is slided onto the valve and attached over the elevation in the pipe.

Step 3: Loosen the strip wound hose from the wall.

Step 4: Take out the splint from the boom foot.

Step 5: After ensuring every part is secured from movement the boom to valve A43, A44 and A51 is swung into position. Before securing the boom in locked position the extension pipe to the valves is assembled with the capsules of the interface.

Step 6: The bend to valve A44 is attached to the floor with two bolts.

Step 7: The capsules is slided into position over the elevation in the pipe. Then the capsules is closed, and the centering tool is used to adjust the position of the boom.

Step 8: The boom is then locked into position.

Total estimated time:

Without interface extension pipes: 4:45 min.
With interface extension pipes: 6 min.

1.2 Technological Choices

1.2.1 Pipes vs tubes

Problem statement

After deciding between houses or pipe (rigid flowpath), we wanted to look at the option between pipes and tubes.

Solutions

We wanted to take a closer look at the option between pipes and tubes. This was because we saw that there was a broader selection of fittings for tubes.

The difference between pipes and tubes is in some aspects not much, but sufficient in others. The main difference is that tubes are usually used for structural purposes, but pipes for transporting fluids. Although this is the official difference per definition (Commerce metals, 2017). It seems to be a lot of evolution on the use of tubes for transporting fluids in recent times.

What we also found out was that the dimensions were not the same and we would have problems using both together. This since the tube dimensions were based on the outside diameter and the pipes on the inside combined with different wall thickness it makes it difficult to match them together. Tubing is also made with tighter tolerances, and is more expensive to buy(The engineering toolbox, 2016)

Decision

We therefore went with pipes for the system.

References

Commerce metals (2017). *Tube vs Pipe - The Differences Explained in Plain English.* [Internet] Available at: http://www.commercemetals.com/tube-vs-pipe-the-differences-explained-in-plain-english/ [Accessed: 21 may 2017].

The engineering toolbox (2016). *Difference between tubes and pipes.* [Internet] Available at: http://www.engineeringtoolbox.com/pipes-tubes-d_347.html [Accessed: 21 may 2017].

1.2.2 Choice of boom

Problem statement

This concerns the specific configuration of the boom, the number of booms, and its or their placement on the floor or the wall compared to the turbine and other component within the enclosure.

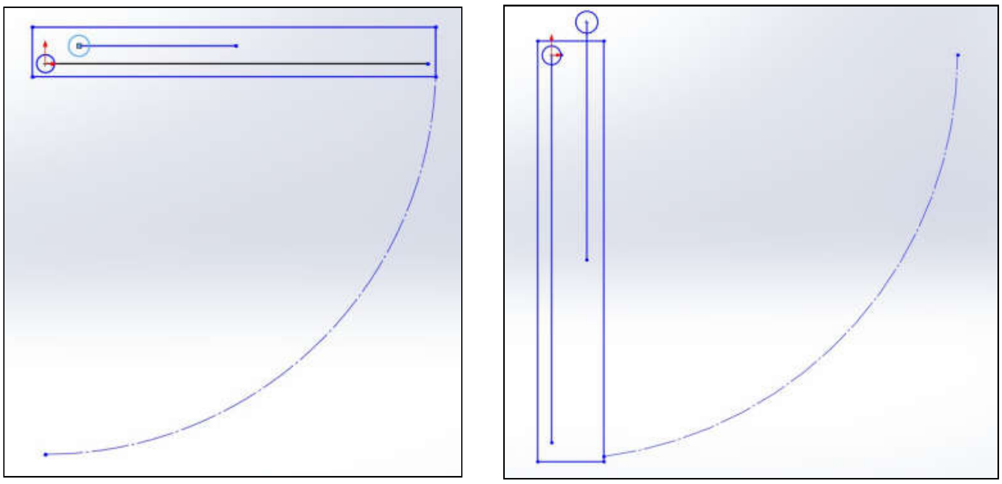
This choice was related to the solution chosen to go through the roof. By choosing a certain configuration or number of booms it altered the way the pipes would go through the roof of the enclosure.

Solutions

Number of booms

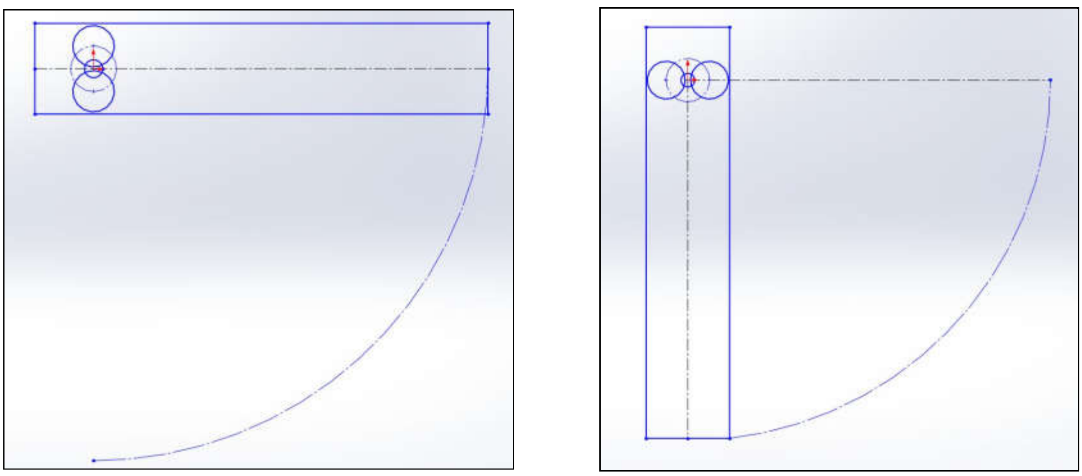
By using only one boom we would have two possible configurations.

1.) The two vertical pipes sections going through the roof could have fixed center points, then the two horizontal pipes could slide relative to each other on top of the boom. For this configuration we could use swivel joints. But this would make it complicated to fix the pipes to the boom.



Picture showing the rotational motion of the first configuration (Designed in SolidWorks by bachelor group).

2.) The other configuration would require the two vertical pipes sections going through the roof to rotate around the center point of the vertical beam of the boom in the same radius, which would require a special solution (rotating disk) for the pipes to go through the roof of the turbine enclosure.



Pictures showing the rotational motion of configuration 2 (Designed in SolidWorks by bachelor group).

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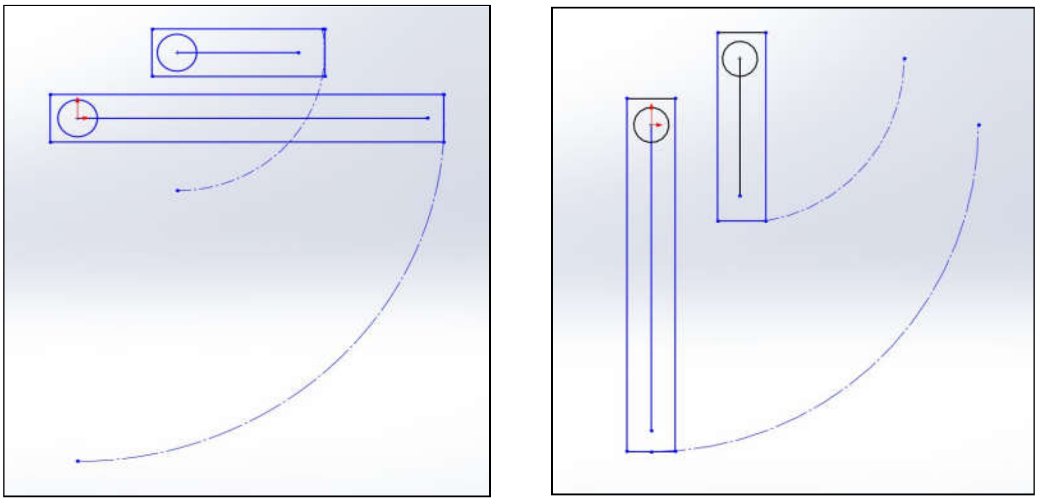
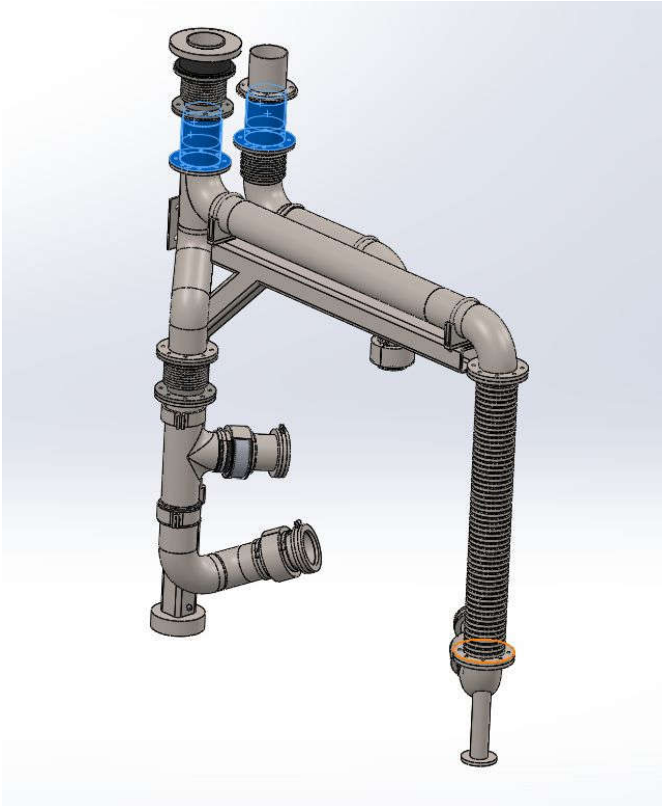
3.) By using two booms we could fix the center of the last elbow before going through the housing to the center of the vertical beam of the boom for both of the booms. This would also require swivel joints.



Pictures showing the rotational motion of configuration 3 (Designed in SolidWorks by bachelor group).



Picture showing the chosen configuration with the swivel joints (Designed in SolidWorks by bachelor group).

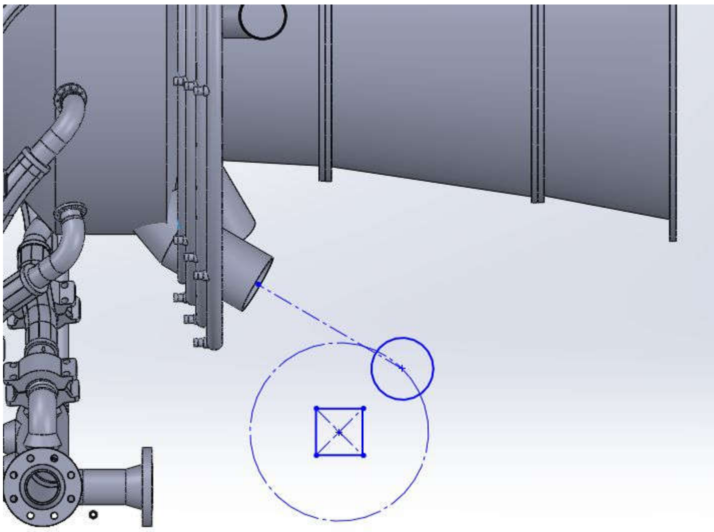
In the end we chose the two boom configuration in spite of having to use more parts which in theory would be more expensive. But because it allowed us to use standard parts, which we think in the end, will make this configuration cheaper.

Standing vs wall suspended booms

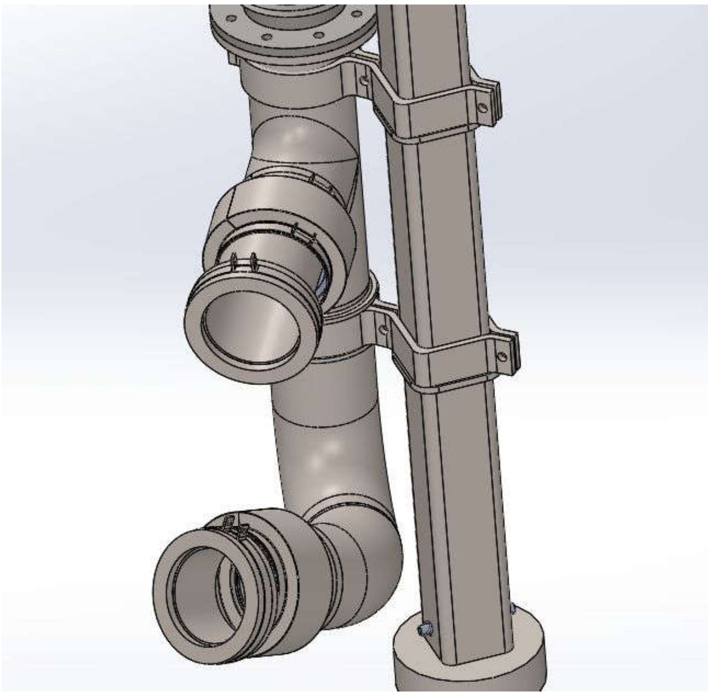
The arguments for using wall suspended booms was that it would provide for a better access in the service area, but we knew it could be difficult to support the heavy load of the whole system from the wall. Additionally floor based booms would provide for a structural attachment point for the bends close to the valves of the turbine, to take up the loads from the flow. Therefore we choose to implement a floor based boom to carry the weight of the (A43, A44 and A51) part of the system, but not to use to much space on the service floor the second boom would be wall suspended since this boom did not have to take so much loading.

Location of boom

There was several important aspects to consider when choosing the exact location for the two booms. First of all if we wanted to use the floor based boom as an attachment point for the piping system, we would have to place the boom in such a manner that the piping system could be routed from the turbine and towards the side of the boom, and then go upwards beside it. This is shown as a sketch in the first picture below and as a 3D model in the picture second below. This way it would be easy to connect the piping system to the vertical beam.

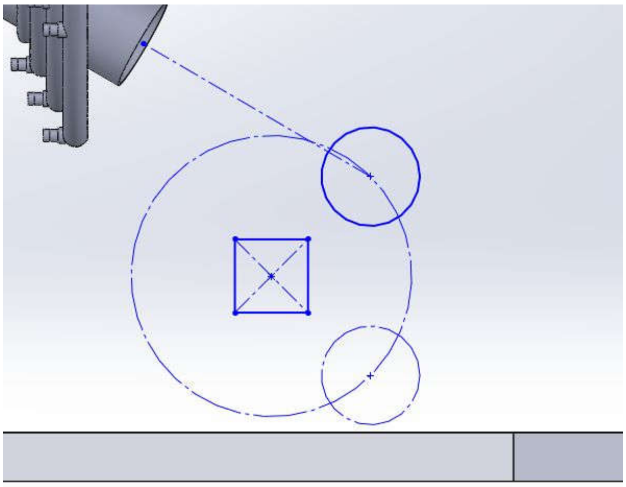


Picture: Showing a sketch in sectional view of the vertical beam of the floor based boom and the position of the pipe going upwards beside it (Designed in SolidWorks by bachelor group).



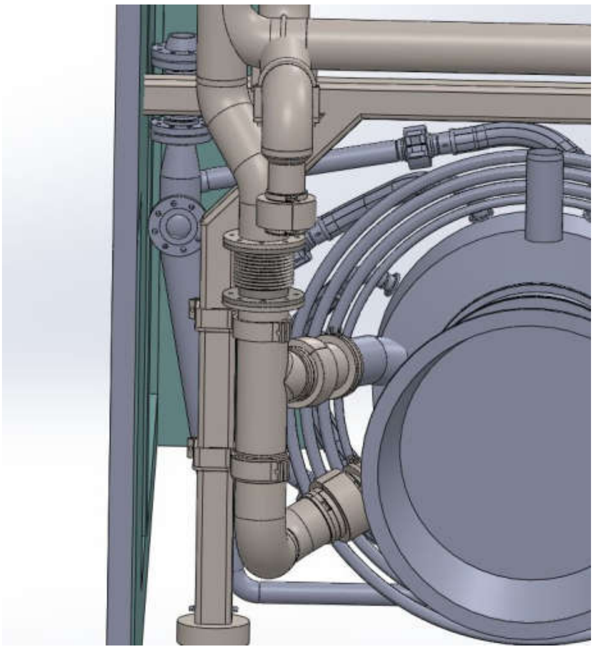
Picture: Showing the pipeline attached to the vertical beam of boom 1(Designed in SolidWorks by bachelor group)..

Secondly we had to be careful not to place the pipe to long distance from the centerpoint of the pipe. Else it would crash with the wall of the turbine enclosure when rotated. This is demonstrated on the picture below. We can see that when the center beam is rotated 90 degree the attached pipe on the side of it will rotate with it and stop close to the wall.

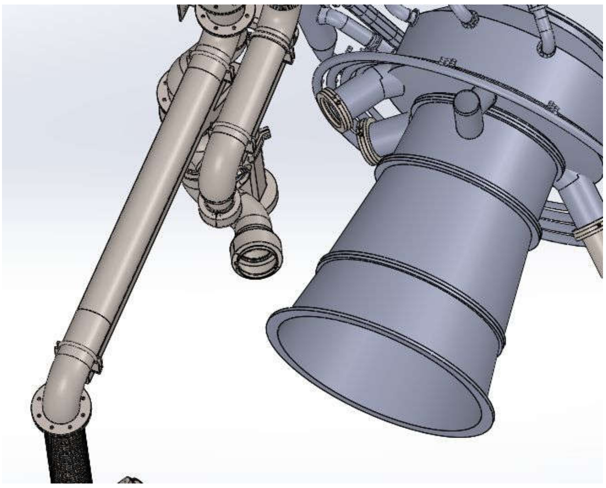


Picture: Showing the start and stop position of the attached piping(Designed in SolidWorks by bachelor group)..

Also the position of the vertical beam of the floor based boom would have a lot of impact on the access for the service personnel working on the system. We estimated that the clearance between the beam and the wall would have to be at least 225mm for a person to get past. Therefore this was the location chosen. This provided for a larger gap on the other side of the beam to the turbine when the boom was in service position (shown on the two pictures below). This way we had good access behind the system and also to other parts on the turbine.



Picture: Showing the clearance between the wall and the bleed system in operational position(Designed in SolidWorks by bachelor group).



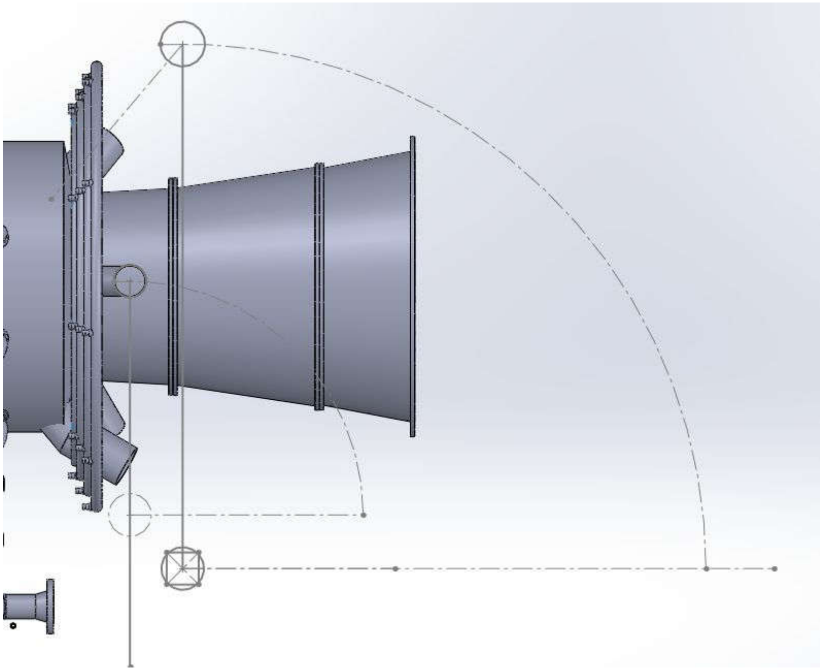
Picture: Showing the space between the turbine and the bleed system in service position(Designed in SolidWorks by bachelor group).

Another consideration we had to take was the clearance between the turbine and the bleed system when lifting the turbine out of the enclosure. Fortunately the turbine would only be lifted a few mm up from the ground during this operation, so we had a lot of room with the location we had chosen.

Also the location of each of the two booms would be important in coherence to each other. The beams would have to be able to rotate without colliding with each other. The location of the second boom would have to be placed:

1 - a bit further back in the enclosure to be in line with the valve A42 and

2 - nearer the turbine for it to be able to swing towards the wall without colliding with the other boom (showed in picture below).



Picture: Showing a sectional sketch of the two beams and their movement(Designed in SolidWorks by bachelor group).

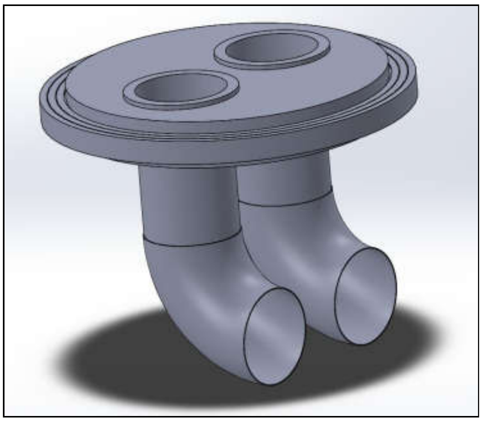
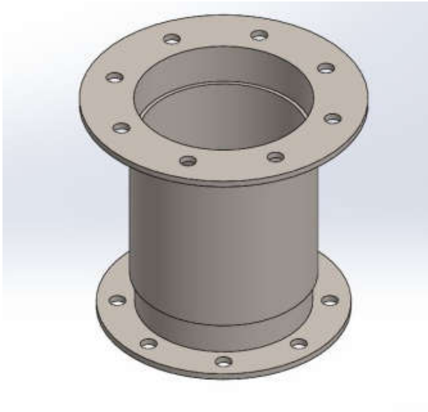
Lastly we had to configure the boom in such a way that the gathered pipes going through the roof of the enclosure would be concentric with the center point of the vertical beam of boom B1 (see attachment about choice between swivel joints and rotating disk for more understanding).

Decision

Considering all the aspects we went with two booms, one wall suspended and one floor based. To have fixed points for the two pipes going through the roof. We found locations for each of the booms for the best possible access, without colliding with each other, the wall or turbine during removal of the turbine. And still be inlined with the outlets of the turbines to make it possible to use the vertical beam as an attachment point for the piping system. We had to configure the boom in such a way that the gathered pipes going through the roof of the enclosure would be concentric with the center point of the vertical beam of boom B1.

1.2.3 Swivel joints vs Rotating roof section

Pictures below shows different type of rotational methods.

First picture:Rotatable roof section(Designed in SolidWorks by bachelor group). Second picture: Rotatable pipes(Designed in SolidWorks by bachelor group).

Problem statement

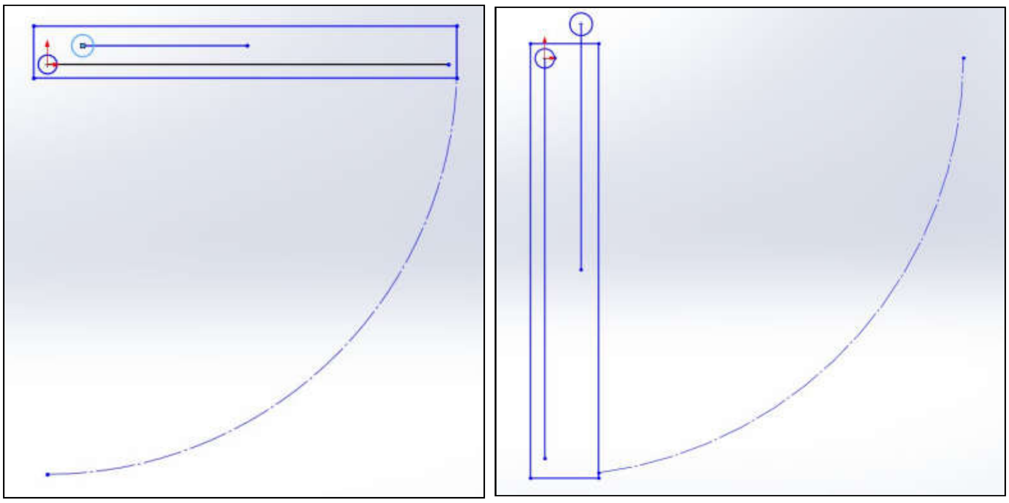
For the bypassing of the enclosure roof with piping we had to choose between several different configurations and part options to get the most optimized method of bypassing the roof. This choice was related to the configuration of the boom. For this choice the following requirements were especially important: S29, S30, S32.

Solutions

By choosing a certain configuration or number of booms it altered the way the pipes would go through the roof of the enclosure.

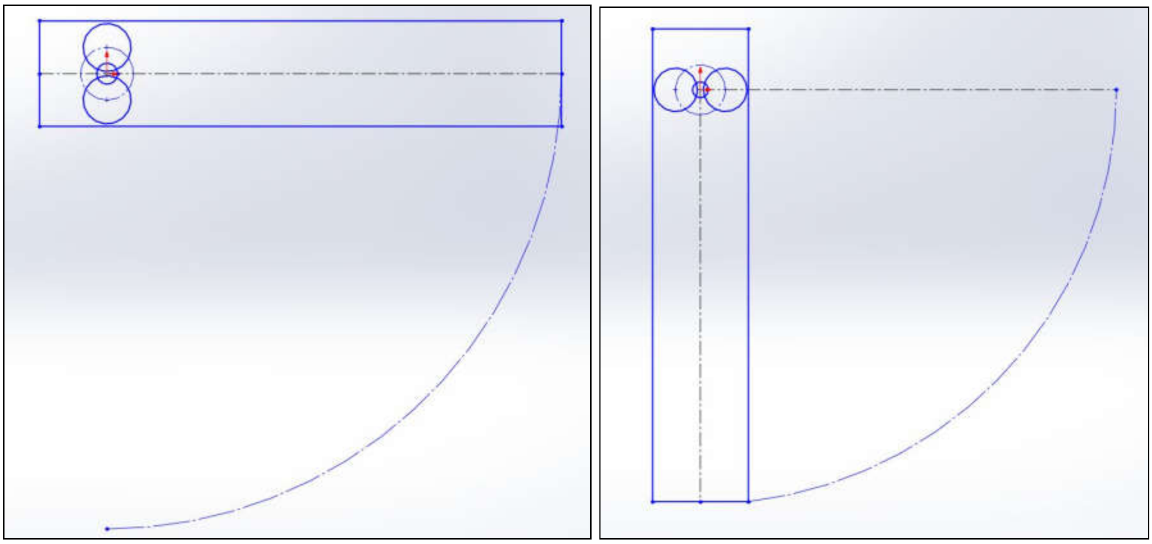
By using only one boom we would have two possible configurations.

1.) The two vertical pipes sections going through the roof could have fixed center points, then the two horizontal pipes could slide relative to each other on top of the boom. For this configuration we could use swivel joints. But this would make it complicated to fix the pipes to the boom.



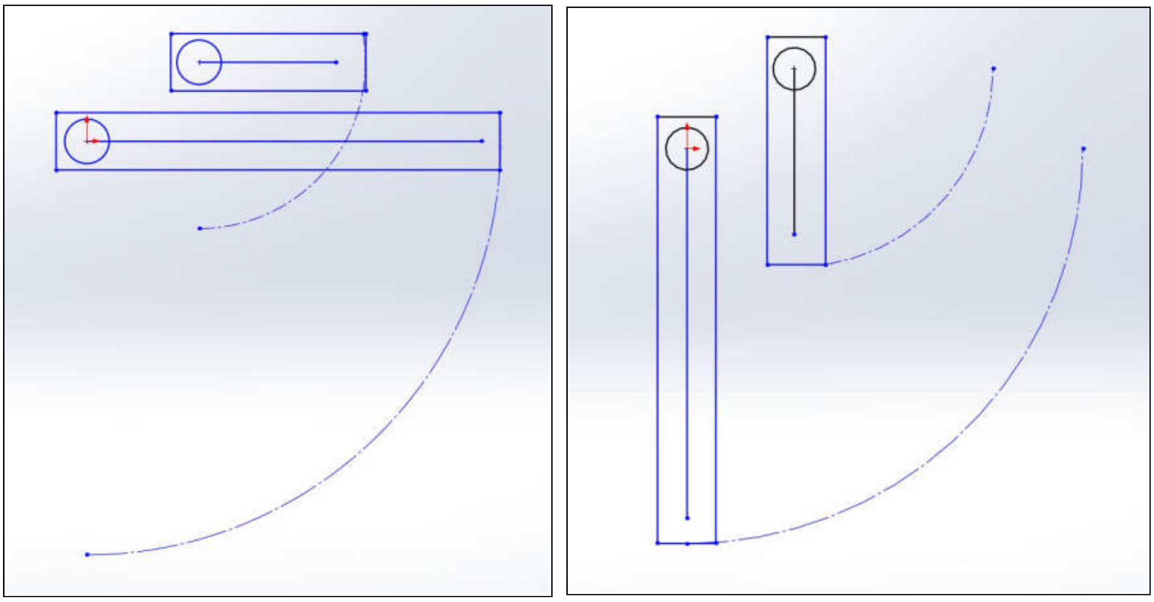
Sketches showing a top view of the sweeping area for the boom with configuration 1 (Designed in Solidworks by bachelor group).

2.) The other configuration would require the two vertical pipes sections going thru the roof to rotate around the center point of the vertical beam of the boom in the same radius, which would require a special solution (rotating disk) for the pipes to go through the roof of the turbine housing.



Sketches showing a top view of the sweeping area for the boom with configuration 2 (Designed in Solidworks by bachelor group).

3.) By using two booms we could fix the centerpoints of the two pipes going through the roof to the point the booms would rotate around. This solution would also require swivel joints.



Sketches showing a top view of the sweeping area for the boom with configuration 3 (Designed in Solidworks by bachelor group).

Decision

In the end we chose the third configuration. Utilizing a fixed concentric position for each of the two pipes going through the roof with two swivel joints, as shown in blue in the picture below. We did this in spite of having to use more parts which in theory would be more expensive, because it allowed us to use standard parts, which we think in the end will make this configuration cheaper.

Picture shows the two swivel joints in blue (Designed in SolidWorks by bachelor group).

1.2.4 Diameter of flow path

Problem statement

The diameter of the flowpath would be altered by the pressure drop in the final design of the concept, and availability of sizes of piping. It would be desirable to use as small diameter as possible.

Solutions

We really didn't have any power to alter this feature much. The goal was always to have as small and light pipe components as possible, but with the shortest and least bended possible configuration of the flow path we ended up with the result we got.

Decision

For concept 16 the initial suggested diameter of the flowpath of 200mm would come to be the right dimension in the end. The final pressure drop calculations show that this dimension gives values close to the maximum allowable amount.

1.2.5 Pipes vs hoses (All types)

Problem statement

When choosing between pipes and hoses we had a lot to consider. It was not as simple as going for one or the other. There were a lot of different types of hoses available, with promising prospects. There was also the question about whether we wanted to use hoses and pipes together in the system, and if so, where would we want to use hoses and where would we want to use pipes.

The reason we wanted to look at hoses for the system was because first of all if we wanted to go forward with concept 16. It consist of a boom where the flowlines are suspended from, it would have to be a flexibility in the suspended flowlines to be able to rotate the swingarm from operational position to service position. We then saw it as a solution for making the system easy to assemble and disassemble during service.

Solutions

Hoses

The most important properties a hose would have to satisfy to be able to use is the ability to withstand the high temperature from the turbine (according to requirements S18 and S19), the large force due to the flow in the bleed system (according to requirement S47, S48 and S49), the backpressure, having a smooth surface on the inside to not cause a large pressure drop (according to requirement S20 and S21), the bending radius, and also the weight was important.

The hoses we looked at were categorized into two types of hoses; metal hoses and composite hoses.

Composite hoses

The options stood between different kinds of vulcanized rubber, synthetic rubber, multi fabric, technical textiles or wire reinforced.

The advantage of using a composite hose would be the light weight and good flexible properties. It would be very easy for installation and service personnel to maneuver. Also the light weight would contribute to lower risk of harming the turbine during assembly and disassembly of the bleed system.

We found that many composite hoses could take the static pressure in the system, and also some producers promised that their hoses should stand the heat, and many hoses had smooth surfaces, which contributes to better flow conditions (Shp primaflex, 2017)(Trelleborg, 2017). But what we could find out for sure was what kind of effect the heat, and forces over a long period of time this load could do of damage. A known problem with composites in heated and loaded conditions is an acceleration in the creep of the material, and none of the suppliers of composite hoses could promise that the hose would last for the needed amount of time. The pictures below show some examples.

Pictures of different kind of composite houses from Trelleborg (the first picture above) (Trelleborg, 2017) and shp-primaflex (the two lower pictures) (Shp primaflex, 2017)

Metal hoses

The common advantage with metal hoses is that we knew that they satisfy all the requirements of the system. They also are a more field proven technology than the composite hoses. The downsides with flexible metal hoses are the rough inside surfaces, and their weight (8-12 kg/m for our application) . They also have a larger bending radius compared to composite hoses (Witzenmann, 2017).

Corrugated hose (Witzenmann, 2017).

The metal hoses that were available and suitable for the application were corrugated hoses and stripwound hoses. By computational fluid dynamics we found that stripe wound hoses had about 25% lower pressure drop at the given temperatures and flows. See testrapport T1.S21 for results on the matter. These also were somewhat lighter than corrugated hoses. Although the stripwound hoses are not usually used for pressurised applications. They can at least withstand 200 kpa without packing (Hoseflex, 2017), and have therefore the maximum allowable pressure drop within the system of 70 kPa, which is within the limits for many of the stripwound hose options.

Stripwound hose (Hoseflex - Stainless steel hose, 2017)

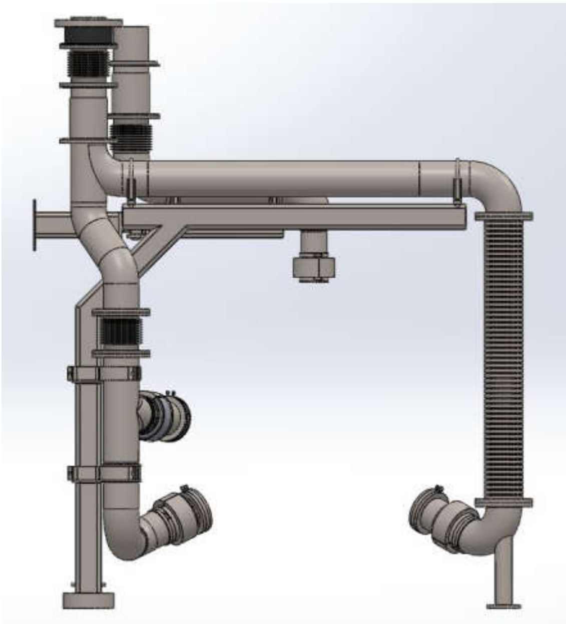
We after a good amount time researching the usability of hoses in the system we decided to go with a a stripwound metal hose.

Pipes

But the results from the flow simulation on the later stages of the system design showed that we in fact were too close to the maximum pressure drop limit to implement hoses in the whole system. See test report T2.S21 for results on this matter. Also we knew for a fact that using pipes would guarantee a lifetime of the system of the requested 25 years, but we couldn't be 100% sure of the same for the metal hoses. Therefore we also saw it as a opportunity to limit the number of parts that possible needed to be changed during service to only one hose. This was the only hose needed to get the system to work, by making it possible to rotate it past the turbine without touching.

Decision

We went with a combination of the two. With the use of mainly pipes, but one hose where we needed it for the function of the system. This was a stripewound metal hose. The reason we couldn't use composite hoses was because we couldn't find proof that they could handle the temperature and the forces in the system for the needed amount of time. And the reason for utilizing mainly pipes in the system was because we needed the smooth inside surface to comply with the maximum pressure drop requirements. Picture below shows the design of the system.



Shows the design of the bleed system combining pipes and hoses (Designed in SolidWorks by bachelor group).

References

Hoseflex - Stainless steel hose (2017). *Light weight engine exhaust interlock.* [Internet] Available at:
https://www.hoseflex.com/wp-content/uploads/2015/06/Light-Weight-Engine-Exhaust-Interlock1.pdf
[Accessed: 21 may 2017].

Shp primaflex (2017) . *Flexible temperature resistant hoses.* [Internet] Available at:
https://www.shp-primaflex.com/en/products/flexible-temperature-resistant-hoses-150-c-1100-c/
[Accessed: 21 may 2017].

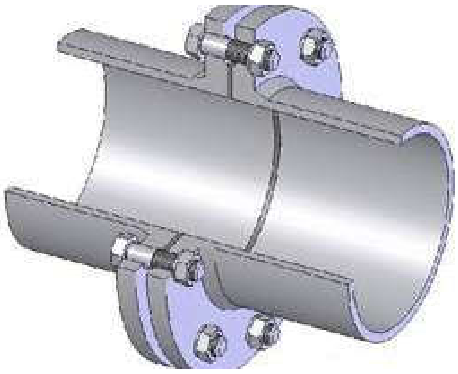
Trelleborg (2017). *Elastopipe* [Internet] Available at:
http://www.trelleborg.com/en/offshore/products/flexible--piping--system/elastopipe
[Accessed: 21 may 2017].

Witzenmann (2017). *Standard program wellsclauche* [Internet] Available at:
http://www.witzenmann.de/repo/assets/Standardprogramm_Wellschlaeuche_1351de_2_05_14_10.pdf
[Accessed: 21 may 2017].

1.2.6 Flanged vs buttwelded piping

Problem statement

We needed to decide on the connection method between the all the pipes and the one hose in the system. This decision had a lot to do with the weight of the system.



Pictures showing flanged and buttwelded pipe (Explore the world of piping, 2017).

Solutions

Using flanges would allow for easy retrieving of parts from the system, and easy assembly, but the weight of a flanged pipe is about double the weight of a pipe without flanges (Explore the world of piping, 2017). Welding all the parts together would require a more comprehensive installation of the system having to weld every single part together. But we figured most of the pipes and parts in the piping system would not require to be retrieved during the lifespan of the system. And the most important time to limit was the service time, not the installation time. (According to: S37 & S38)

Decision

Therefore we went with buttwelding for most of the piping system, but we also needed some flanges around the parts of the system that might need to be changed. This included swivel joints and the hose.

References

Explore the world of piping (2017). *Definition and Details of Flanges - Types of Flanges.*
[Internet] Available at:
http://www.wermac.org/flanges/flanges_welding-neck_socket-weld_lap-joint_screwed_blind.html
[Accessed: 21 may 2017]

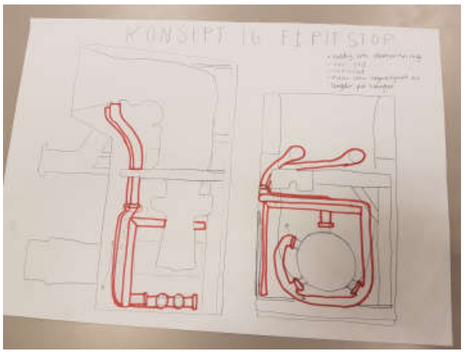
1.2.7 Routing path

Problem statement

For concept 16 there would be several options for the exact routing of the flowpath. Both from the turbine on to the boom structures, and from the booms towards the outside of the turbine enclosure.

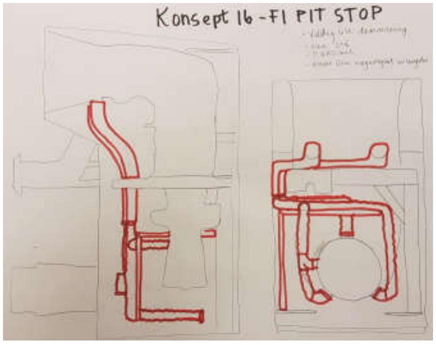
Solutions

For concept 16 the path of the pipe/hose routing configurations considered were; Routing a single hose from valve A43, to A53, then going under the turbine. For A44 going on to the boom, routing one hose on each side of the turbine before being combined on top of the boom, and lead to the exhaust. Picture below shows the drawing at an early stage.



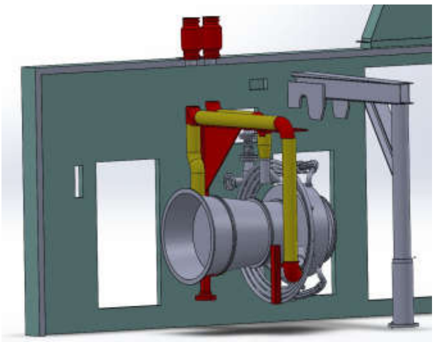
Picture showing configuration 1(drawing by bachelor group).

One containing flow from A43 and A51, and the other from A44, routing the pipes/hoses into the exhaust. See picture below.



Picture showing configuration 2(drawing by bachelor group).

The third option was to rout the pipes/hoses towards the front end of the enclosure, and routing the pipes/hoses directly true the roof. See picture below.



Picture showing configuration 3 (Designed in SolidWorks by bachelor group).

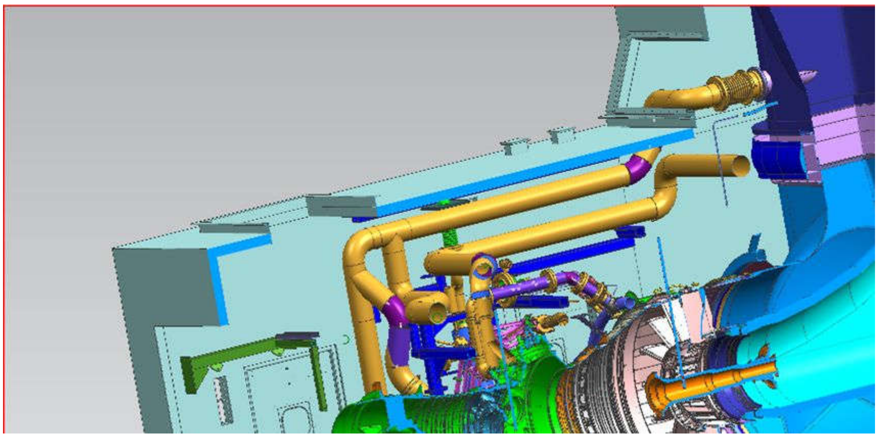
We quickly understood that it wasn't any available space underneath the turbine, therefore eliminating that possibility. We therefore decided on having one flowpath on each side of the turbine. Regarding the rest of the flowpath from the boom to the exhaust, we learned that in this section we had excessive pressure drop per meter. Because we had the combined flow from A43, A44 and A51. The excessive pressure drop was due to the velocity part of the formula for calculation pressure drop being a second degree exponential. This means that only a short section of pipe/hose would result in a large pressure drop, and since we were in the limit with the system, prior to all the other pressure drops that would be added in the detailed stage we decided to rout the pipes/hoses through the roof of the turbine housing.

Decision

In the end we decided in directing the flow path straight up from the mid section of the housing (like shown in first picture above), because trying to route the pipes/hoses towards the front of the enclosure resulted in being in the way of the ventilation air of the turbine enclosure. Since we had no way of testing the effects of this, and the company didn't know either, we went with the other option.

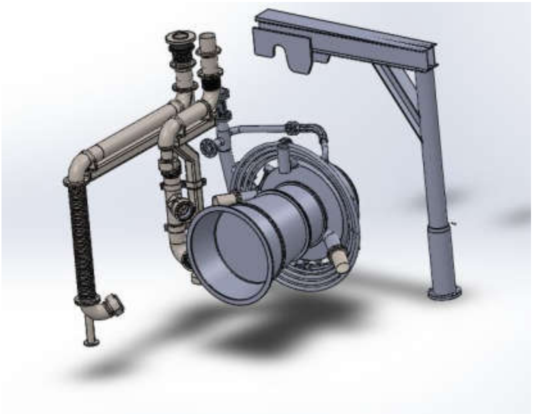
1.2.8 Sound Silencer

When designing a new bleed system for the turbine RB211-GT30-DLE the use of exhaust sound silencer is a possible solution. The disadvantages for doing this is that the distance from bleed valves to the exhaust is quite long and it is tumbling to make bleed lines through this distance. Picture below shows a solution of the bleed lines going to the exhaust.



Picture: Shows the bleed lines going into the exhaust (Picture received from D-R).

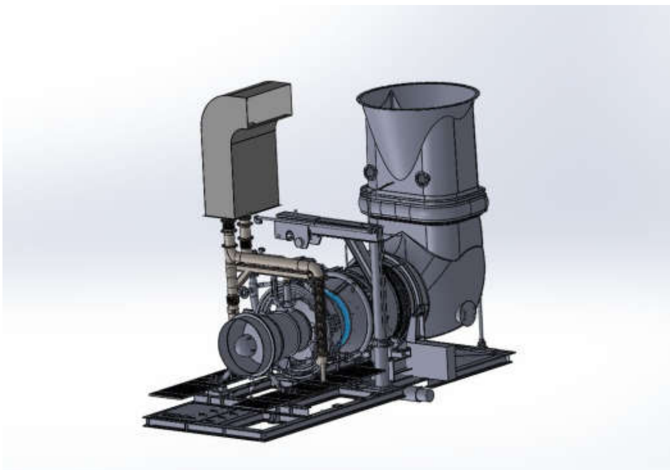
When having a separate sound silencer for the bleed system it reduces the length of the bleed lines markedly. This gives advantages, and the most important one is that it helps to avoid high back pressure. In this concept we have the pipes going through the roof of enclosure, so the length of the pipelines is only from the four different valves to the wall and up. Picture below shows the length of the bleed lines in this concept is greatly shortened.



Picture: Shows the length of the different bleed lines (Designed in SolidWorks by bachelor group).

We also discussed to lead the air back and into the exhaust, but the backpressure would be significant higher, and the requirements to backpressure would not be met. The construction would also take up too much space inside the enclosure. So we decided to cancel this option and instead place it on the roof.

Below the picture shows the duct placed on the roof. This area of the roof is no problem to put a silencer. So the design and the size of the silencer is not so important as long as it doesn't conflict with the ventilation ducts.



Picture: Shows the silencer with elements inside placed on the roof over the duct (Designed in SolidWorks by bachelor group).

The benefits of having shorter pipes made us choose a separate silencer placed over the outlet of the implementation of seiling.

1.2.9 The use of expansion joints

Problem statement

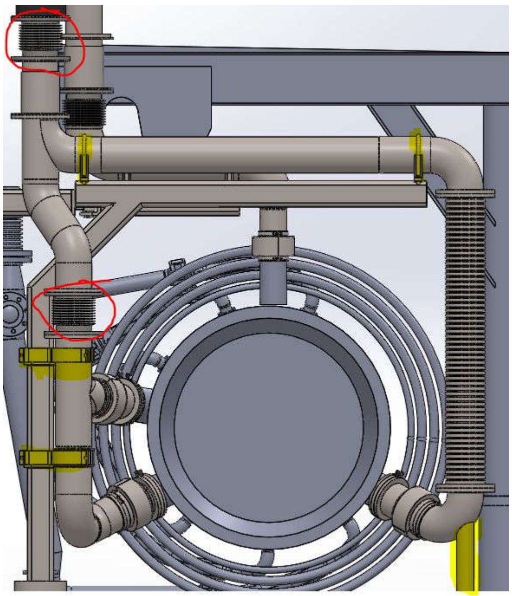
The fixing of the piping to the structural part of the bleed system was mainly based on the heat expansion analysis done of the whole piping system. See test report T1.S84 for results on the matter. The choice using expansion joints or not, and the locations for them was done in coherence to the choice of fixing point of the piping system.

It is recommended to read this document together with technical choice document - fixing of pipes hoses.

Solution

After the fixing points had been set for the piping system the need for expansion joints was evaluated.

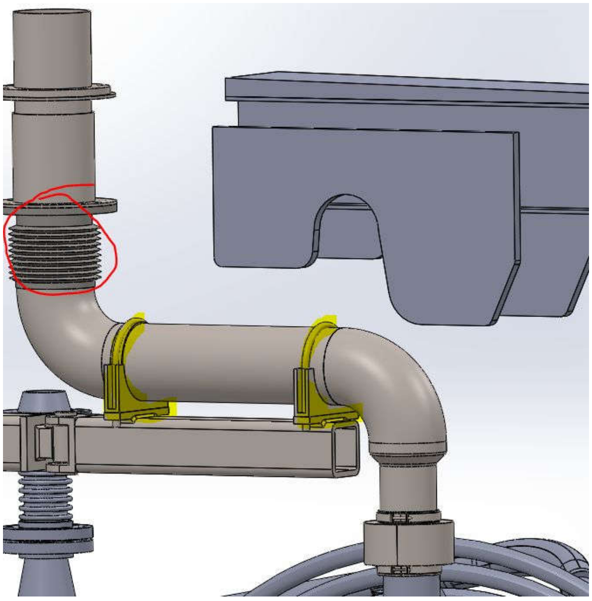
What the analysis showed was that the heat expansion of the (A43, A43, A51) part of the system was about 4mm/meter pipe. This meant that from the left lower fixture to the upper left fixture (the one in the middle only prevents radial movement) was about 5 mm. This turned out to result in stresses past the yield strength of the steel. So we wanted to use an expansion joint in between these fixtures. The expansion joints we found had no problem with compensating for the amount of deformation. With some options able to deform up to 60mm in axial direction (Hoseflex expansion joint, 2016). Picture below show an overview.



Picture showing the fixing points of the piping system and the location of expansion joints (Designed in SolidWorks by bachelor group).

There was limited space to put it if we wanted the joint to only be affected by vertical expansion of the piping system. So it was placed just above the second vertically attached clamp but under the elbow leading the pipeline into concentric position with the beam.

The only other place on the system with excessive stresses due to heat expansion on this branch of the bleed system was between the upper tee joint and the roof. That's why we put a second expansion joint there. See picture below.



Picture showing the fixtures to Branch A42 and the location of the expansion joint(Designes in SolidWorks by bachelor group).

We used the same concept for the A42 branch of the bleed system. Here we also needed to use an expansion joint in between the beam and the roof.

References

Hoseflex Expansion joints (2016). *Single expansion joint.* [Internet] Available at: https://www.hoseflex.com/wp-content/uploads/2015/06/Single-Expansion-Joint-SEJ.pdf [Accessed: 21 may 2017].

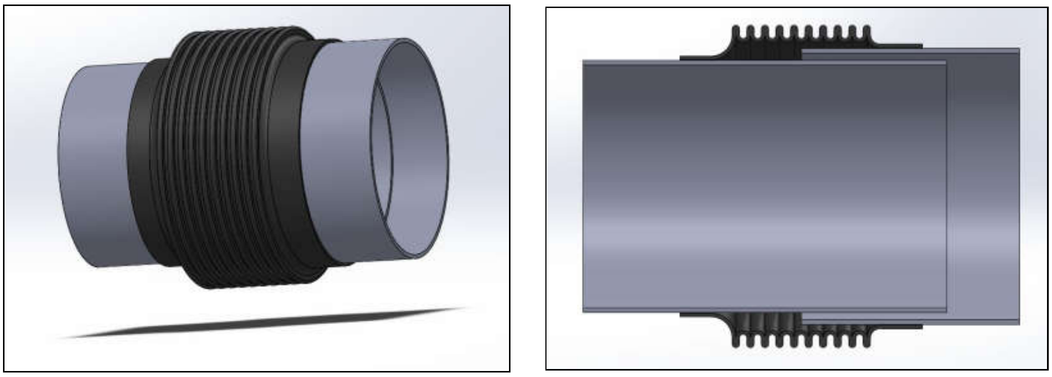
1.2.10 Interface concept

Problem statement

To comply with requirements concerning connection to the turbine it was important not to transfer much forces from the system on to the turbine (According to requirements: S1, S2, S3, S4).

Solution

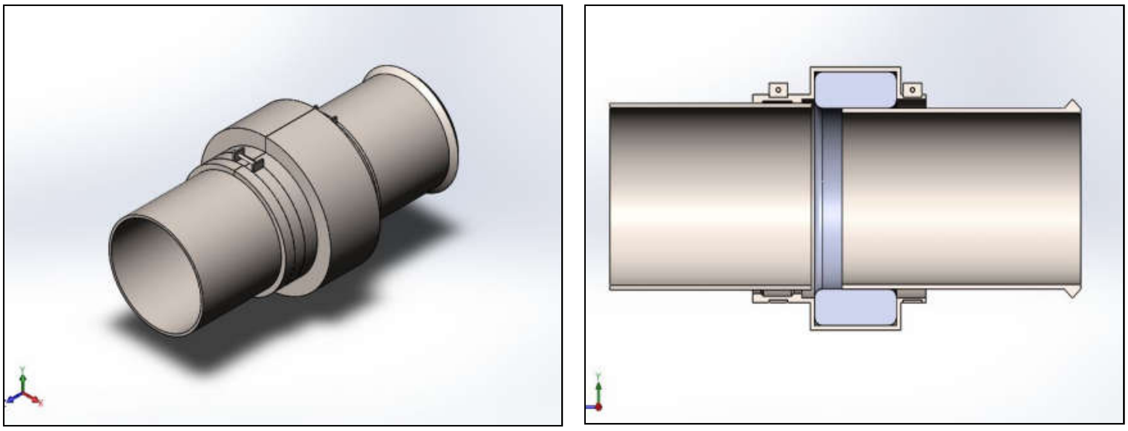
To solve this problem we both looked at optimizing the current solution used by Dresser-Rand, but also came up with some solutions of our own. Picture below shows the existing design of interface.



Pictures of the rubber bewel solution (Designed in SolidWorks by bachelor group).

The current solution in use, utilizing a rubber bellow on the outside of a pipe within a pipe without touching. We thought this would be a good and a cheap solution if only the rubber material would sustain the heat a bit better than it actually did. Therefore we explored the options for the material used, but we unfortunately did not find solutions that would work for the applications. Although a request for a product research from the rubber company Trelleborg was made.

Relatively late in the project we came up with a solution that would utilize rockwool to seal in the interface. It would consist of a pipe from the turbine in line with a pipe connected to the rest of the bleed system. See picture below for details.



Picture showing the rockwool solution (Designed in SolidWorks by bachelor group).

These pipes shown in the picture above would not touch. On the second pipe an interface bowl, which would be clamped on and covering the space in between the two pipes. And to seal we would use a rockwool ring to prevent the flow from just flowing through the wool. This package would be able to move radially and axially in compliance with the requirements. Also the concern of the wool losing it elastic properties due to heat and compression was resolved. The confirmation of this was given by the isolation supplier Iso Partner (Isopartner, 2017).

Another solution would be to use a technical fabric membrane in between the turbine and the bleed system. This was a solution Dresser-Rand discovered from Eagleburgmann, and they wanted us to consider it as an option. The idea was to use it in the same manner as the other two concepts, pulled over a pipe within a pipe, not touching. The advantage of this was the extremely light material, which would contribute to a very easy disassembly of the system during service. According to the supplier Eagleburgmann the product was suppose to withstand the static pressure in the system as well as the temperature, making it a very promising alternative to consider for the interface component (EagleBurgmann, 2017). But unfortunately this solution was discovered a little too late in the project to research enough about it to know if it could be used in the system. Picture below shows a fabric connection solution.

Picture showing a fabric connection solution (EagleBurgmann, 2017).

Decision

Since we had confirmation on the applicability of the rockwool solution and not the other two, we went with that one.

References

EagleBurgmann (2017). *Fabric Expansion Joints.* [Internet] Available at: https://www.eagleburgmann.com/en/products/expansion-joints/fabric-expansion-joints [Accessed: 21 May 2017].

Isopartner (2017). *Teknisk Isolasjon*. [Internet] Available at: http://www.isopartner.no/ [Accessed: 8 May 2017].

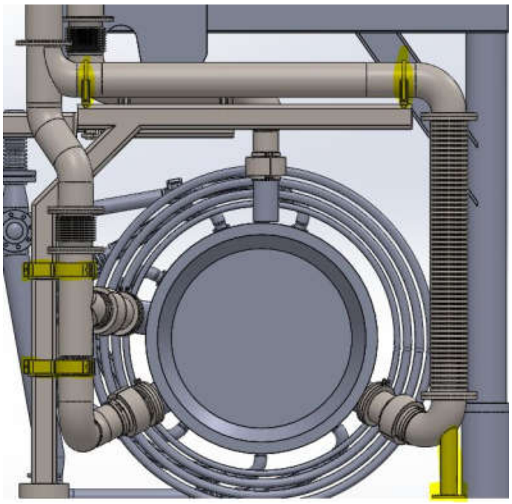
1.2.11 Fixing of pipes/hoses

Problem statement

The fixing of the piping to the structural part of the bleed system was mainly based on the heat expansion analysis done of the whole piping system. See test report T1.S84 for results in this matter, but also an evaluation of the weight of the piping system. The choice of fixing point of the piping system was done in coherence to the choice of effect and placement of expansion joints.

Solution

Picture below shows the fixing point of the piping highlighted in yellow.



Picture showing the chosen fixing points between the piping system and the structural construction of the bleed system on the A43, A44, A51 branch of the system (Designed in SolidWorks by bachelor group) .

At this stage of the project we had an idea about how the pipelines would be routed and that we would connect a hose to outlet A44 (see picture above), and also we had 2 options for interfaces to the turbine. Both with about 10 mm clearance of the valves from the turbine and the bleed system, with sealing in between.

Before the heat expansion analysis we knew that we would have to fix the pipes interface to the turbine in such a manner that it first of all would take up the forces from the flow, but also keep the pipes from colliding and transferring loads to the turbine during heat expansion (according to requirements S3, S4 & S83, S84).

What the analysis showed was that the heat expansion of the (A43, A44, A51) part of the system was about 4mm/meter pipe. This allowed us to fix the pipeline in between the interfaces of A43, and A53 (lowest yellowed fixture on the picture above). Here we chose to fix the pipeline from movement in all directions. With only about 1mm expansion on either side of the clamp. And since we had about 10mm clearance to the turbine in cool conditions the expansion of 1 mm plus the 4 mm radial expansion the expansion was still acceptable.

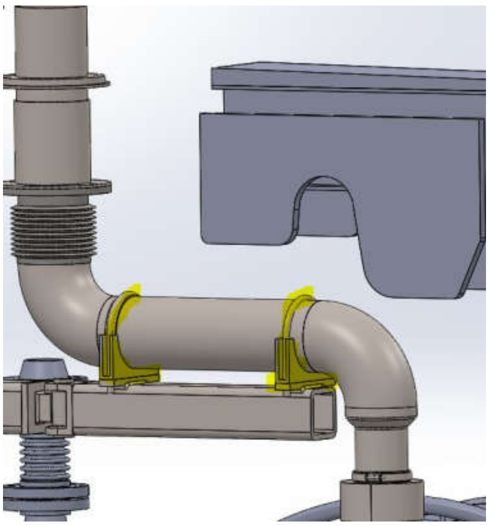
The next consideration was securing a fixture preventing the top portion of the pipeline from becoming eccentric from the hole in the roof in which it should go through during heat expansion. After considering different solutions which fixed the top tee joint on to the boom, we figured it would be easier and cheaper to use a standard hose clamp on the pipe right after the tee joint (see the upper left yellowed fixture on the picture above). Here we would fix the pipe from movement in all directions. Fixing the pipe there would in fact allow for expansion of the pipeline towards the tee joint, but at the small distance it would not be problematic since there would be sealant in the interface of the roof taking up this loading.

At this point we knew we needed an expansion joint in between the two previously mentioned fixtures. And since the pipeline at the lower fixture was eccentric from the pipeline at the higher one, we figured we needed another fixture preventing the expansion of the pipeline from becoming non axial, and which would be a problem for an expansion joint in between the upper and the lower fixture. Because they don't handle tensional forces on the outside of the bellow which becomes the case when the loading is non axial (Amnitec, 2016).

The horizontal pipe lying on the boom would have to be able to expand up to 9 mm. This was enabled by first of all using a hose on the other side which connects to the floor fastened elbow. And secondly by using a hose clamp on the end of the boom that would allow for movement in the axial direction, but hinder the pipeline from any movement in vertical direction.

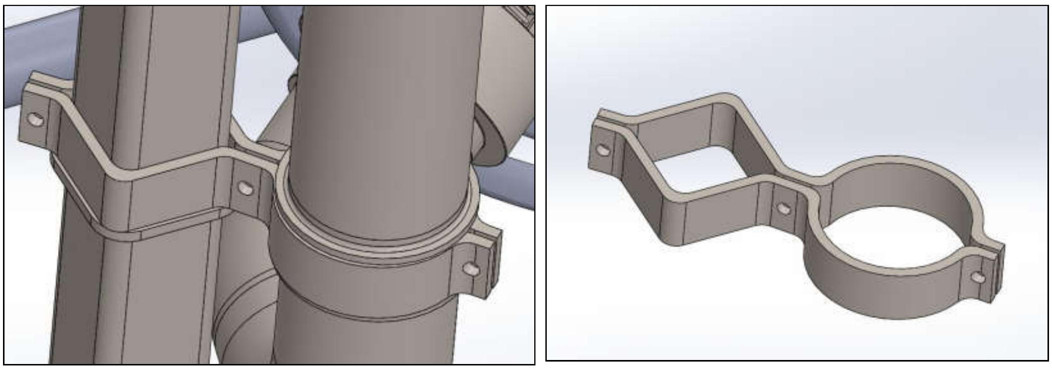
Finally we needed to fix the elbow interface to valve A44 from movement, to take up the forces from the flow on that side, without letting the bleed system “touch” the turbine. This was done with a simple solution consisting of a foot welded to the elbow, which will be bolted to a structure just under the service floor.

On the other branch of the bleed system (the one connected to valve A42) the fixtures were much more easy to implement. We used a pipe clamp preventing movement in all directions. This prevented the vertical section from moving out of place in relation to the hole in the roof. And we used another pipe clamp on the tip of the beam to prevent only movement in radial and vertical direction. Picture below shows the fixture of bleed line A42.



Picture showing the fixtures for the A42 branch of the bleed system (Designed in SolidWorks by bachelor group) .

The reason we are choosing to use hose clamps is due to the low cost and the availability of standard sizes (Hose Clamp King, 2016). It was not to our knowledge possible to implement standard clamps for the two vertical fixtures, and that's why we have designed special clamps for that application, see picture below.



Pictures showing the specially made clamp for the piping system (Designed in SolidWorks by bachelor group).

Since we had to design a clamp of our own we tried to do it as simple as possible to hold the cost down. We did this by using just a clamp that would be possible to produce by bending a simple sheetmetal piece to the needed form. This would be much cheaper than for instance having a clamp made by casting, or machining (Estimating sheet metal fabrication costs, 2016).

References

Amnitec (2016). *Guide to the use of amnitec bellows and expansion joints.* [Internet] Available at:
https://unitedflexible.com/wp-content/uploads/2016/04/Guide-to-the-use-of-AmniTec-bellows-and-expansion-joints.pdf
[Accessed: 21 may 2017].

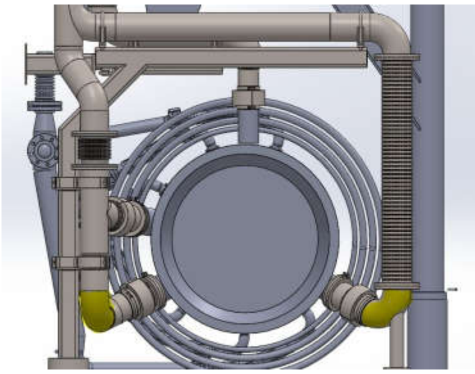
Estimating sheet metal fabrication costs (2016). *A Step-By-Step Guide to Understanding How Fabricated Parts Are Estimated.* [Internet] Available at:
http://etmmfg.com/wp-content/uploads/Estimating-Sheet-Metal-Fabrication-Costs-v3.pdf
[Accessed: 21 may 2017].

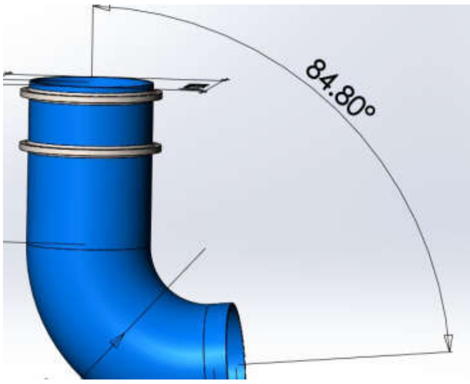
Hose Clamp King (2016). *Prises on hose clamps.* [Internet] Available at:
http://www.hoseclampkings.com/16/home.htm [Accessed: 21 may 2017]

1.2.12 Standard bends vs custom bent elbows

Problem statement

For two of the systems elbows there was need for a bend with a non standard elbow degree. For these two elbows we needed to decide between using a specially made custom bent elbow or cutting a standard elbow to the right size. For this choice the following requirements were especially important: S29, S30, S32. See picture below.





Picture: Showing the location of the problem and the problem itself.

Solutions

If we were to buy custom bent elbows we needed a sufficiently large wall thickness of the pipe. But a slack elbow would not require as thick wall as a sharp elbow. But the price of this work would be considerable (Niras norsk industribøying A/S, 2017). The other solution would be to buy a standard elbow size and angle but cut it and process it to fit. This would be much cheaper than a custom bendt part. There were not really any benefits with buying custom bent elbows for this concept where as it was actually beneficial for concept 30. There the use of custom bent pipes would be beneficial because it would give us a single large retrievable part saving a lot of time during service disassembly.

Decision

We decided to use standard elbows because that simply would be less expensive and sufficiently good enough.

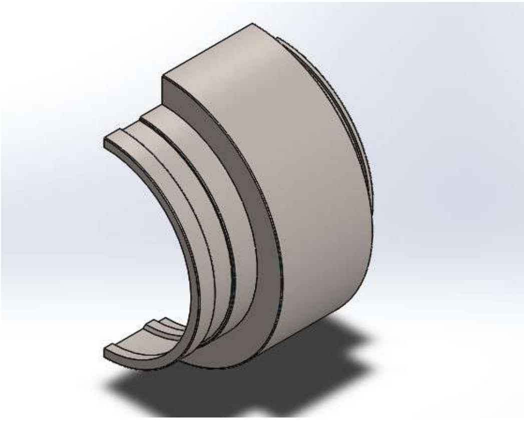
References

Niras norsk industribøying A/S (2017). *Induction bending cut costs* [Internet] Available at: http://niras.no/wp-content/uploads/2017/02/brosjyre.pdf
[Accessed: 21 may 2017].

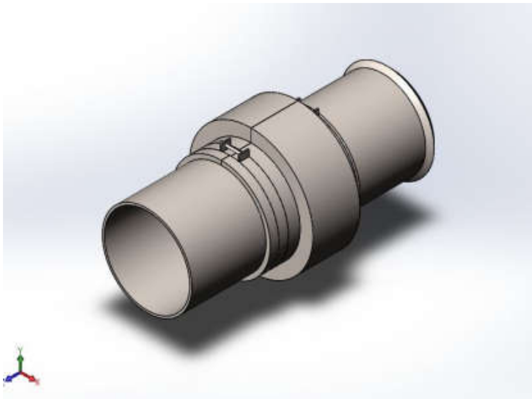
1.3 Components

1.3.1 Interface valve A43, A44 and A51

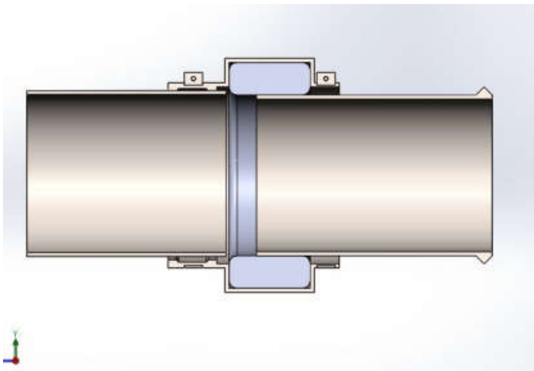
See pictures below for illustrations of the interface bowl.



Picture: Capsule (Designed in SolidWorks by bachelor group).



Picture: Assembly interface (Designed in SolidWorks by bachelor group).



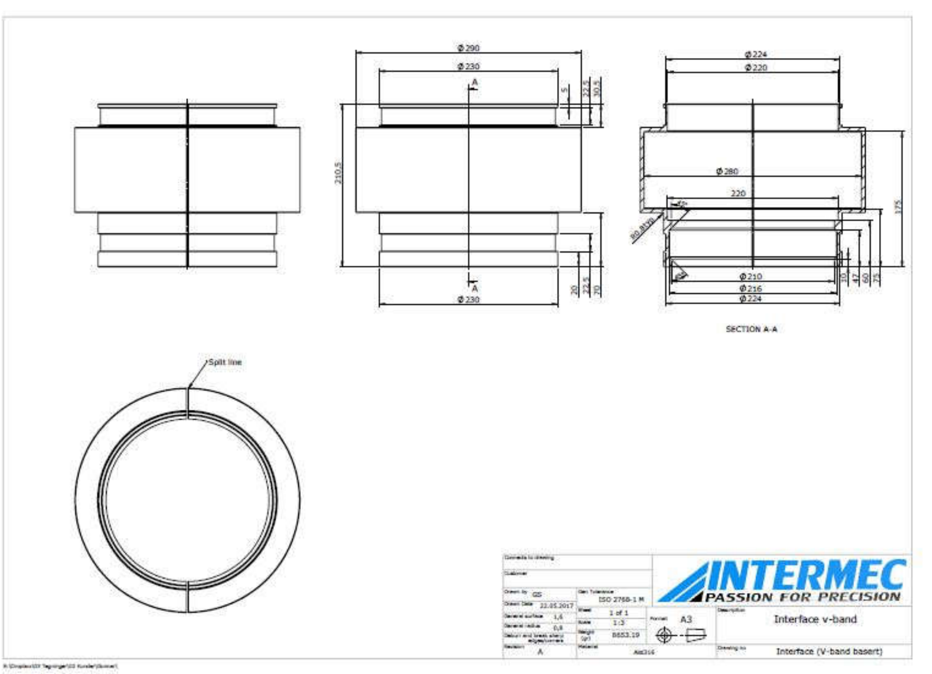
Picture: Assembly section view (Designed in SolidWorks by bachelor group).

When the heat creates movement between the systems, the rockwool shown as the blue ring inside the interface on pictures above will be compressed and allow the pipes to move without transferring any force to the pipes, and without creating more disturbance in the flow. The inlet diameter is 10mm less than the outlet to keep the flow undisturbed through the interface. The flow enters on the right hand side from the turbine through the smaller pipe, enters the sealing, and passes without hitting any sharp edges. The inner diameter of the left hand side is 200mm, while the other have 190mm. This gives possibility to move 5mm in the radial direction, which is within the requirement of 4 mm, and the movement from the rest of the system of 1 mm radially. In the axial direction there is 10 mm clearance, and satisfies the requirement by 2mm. In the later information from EagleBurgmann there is a second option for the interface between turbine and bleed line system (Eagleburgmann, 2017). This product data is unavailable since the EagleBurgmann have classified information in the datasheet received. This product forms a tube which the group had in an earlier iteration round, but never got any data on until the last minute. This is an absolute viable solution, and have not been evaluated.

Choice of material in the interface

Bowl

- Materials chosen in the encapsulation of the wool ring is stainless 316. Early on in the process there was considered using other materials, aluminium titan. The main reasons for choosing stainless steel is the production cost and thermal expansion. When metal gets hot it will grow, but not in the same rate as aluminium. The aluminium connection could lead to a wider gap between the sealed surfaces, and could again lead to failed requirements. 2D picture under is production drawing from intermec.



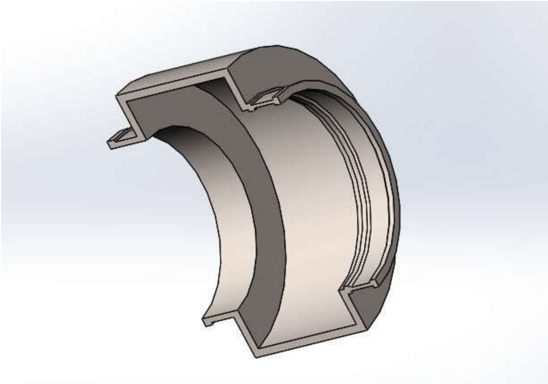
Picture: 2D production drawing interface capsule delivered by Intermec.

Rockwool

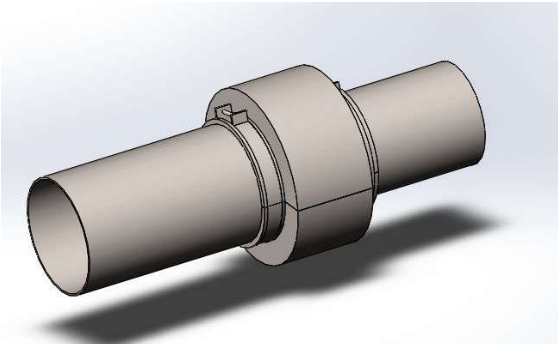
- The material in the sealing ring is rockwool with a thermal resistance to more than 1000 degree celcius. It is soft fabric and will form around the pipe giving a seal for the hot air transported in the pipes when tightened by the clamps. This wool will be encapsulated in a thin sheet of aluminium foil, preventing air escaping through the porous material. The supplier is GLAVA isolation, and is a cheap solution compared to other products. The rockwool will be blocked from moving within its pocket in the encapsulation, and forms a better seal when exposed to pressure. There will be ensured that the material can stand the maximum pressure without losing its characteristics. See picture below for properties for the material.

1.3.2 Interface valve A42

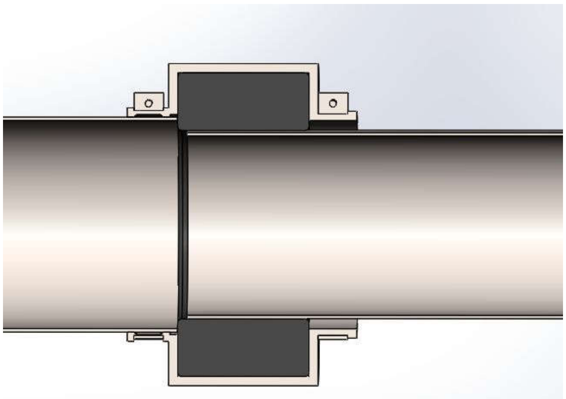
The pictures below shows some details about the interface.



Picture: Capsule (Designed in SolidWorks by bachelor group)



Picture: Interface (Designed in SolidWorks by bachelor group)



Bilde: Section view (Designed in SolidWorks by bachelor group).

When the heat creates movement between the systems, the rockwool showed as the blue ring inside the interface will be compressed and allow the pipes to move without transferring any force to the pipes, and without creating more disturbance in the flow. The inlet diameter is 10mm less than the outlet to keep the flow undisturbed through the interface. The flow enters on the right hand side from the turbine through the smaller pipe, enters the sealing, and passes without hitting any sharp edges. The inner diameter of the left hand side is 150mm, while the other have 143mm. This gives possibility to move 7mm in the radial direction, which is within the requirement of 4 mm, and the movement from the rest of the system of 1 mm radially. In the axial direction there is 10 mm clearance, and satisfies the requirement by 2mm. In the later information from supplier there is a second option for the interface between turbine and bleed line system (Eagleburgmann, 2017). This product data is unavailable since the Eagleburgmann have classified information in the datasheet received. This product forms a tube which the group had in an earlier iteration round, but never got any data on until the last minute. This is an absolute viable solution, and have not been evaluated.

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PRODUCT DATA SHEET: ProRox
PDS 017
Issued: 01 - 10 - 2013

ROCKWOOL Technical Insulation
ProRox - Industrial insulation

ProRox PS 960

NYTT NAVN

Tidligere navn: Rørskål 850

Produktbeskrivelse

ProRox PS 960 er en ferdigformet rørskål i ubrennbar steinull. Produktet er egnet for termisk og akustisk isolering av industrielle rørledninger med høy temperatur.

Samsvar

ProRox PS 960 rørskåler er produsert i overensstemmelse med kravene i EN14303.

Produktegenskaper

	Ytelse	Standarder
Varmekonduktivitet	see below	EN ISO 8497
Maksimum brukstemperatur	650 °C	EN 14707
Brannklasse	Euroklasse $A1_L$	EN 13501-1
Nominell densitet *)	>100 kg/m³	EN 13470
AS Kvalitet	Kloridinnhold < 10 ppm	EN 13468
Vannabsorpsjon	≤ 1 kg/m²	EN 13472
Vanndampdiffusjonsmotstand	μ = 1	EN 14303
Luftstrømmotstand	> 80 kPa.s/m²	EN 29053
Beskrivelseskode	MW EN 14303-T9(T8 if Do < 150)-ST(+)650-WS1-CL10	EN 14303

Varmekonduktivitet:

Tm (°C)	50	100	150	200	250	300	350				
λ (W/mK)	0,040	0,044	0,054	0,064	0,077	0,092	0,111				

*) ROCKWOOL ProRox isolasjonprodukter er i fullt samsvar med EN 14303. Densitet er ikke en isolasjonsegenskap, men beskriver produktets vekt pr m³.

Picture: Rockwool properties data received from Isopartner A/S (Isopartner, 2017).

Clamp

- The clamps is bought from supplier (Precisionbrand, 2017). They are delivered in packages of 10, where the weight for 10 pieces is 2,1kg. See picture below.

Bilde: Worm gear hose clamp (Precisionbrand, 2017).

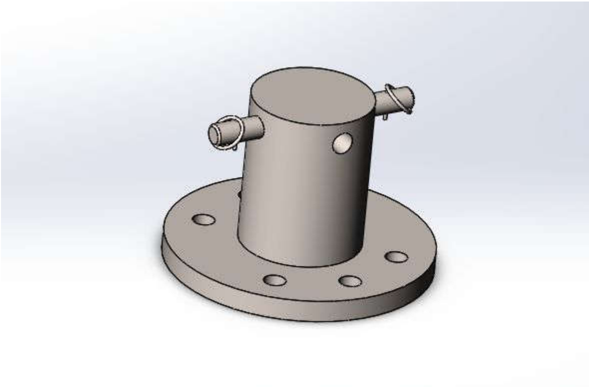
1.3.3. Foot to boom (B1)

Problem statement

During service and operation the boom have to be adjusted in two different angles. When operating the boom it is perpendicular to the sidewall, while during service it will have the position along the wall (parallel to the sidewall). During shipping it will be set in the service position, and the boom have to be locked both in the vertical and horizontal direction.

Solution

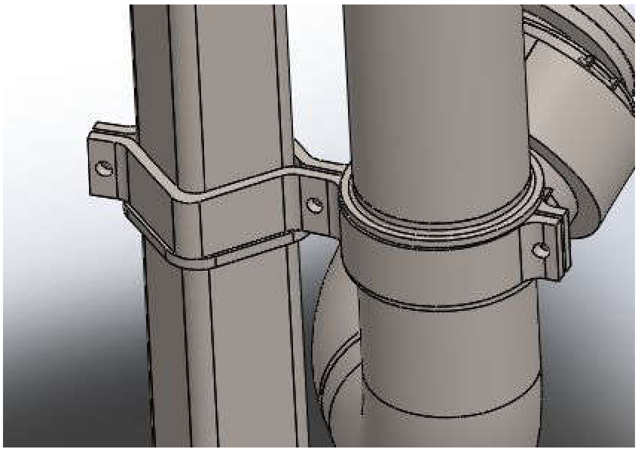
Two different solutions was considered. One was having the boom hanging on the wall, and the other was having the boom at rest on the floor of the turbine package. Due to the forces from the weight and the shipping, the boom was considered to have the best outcome resting on the floor. The solution to use it in both position was a circular foot (see picture below) with the possibility to use a spline to lock it into position. This spline will keep the boom from moving both vertically and horizontally. On each end of the main spline there is attached two small splines to prevent the main spline to loosen from vibrations in the system or during transport. When swinging the boom to the side the moment around the foot is big enough to push it around by using manpower, so the need of bearing is not needed. Since the boom only have to be moved once every three years the wear on the metal will be so small the lifetime of the system will reach 25 years which is the requirement. Material choices in all the parts in the subassembly is stainless steel. Picture under shows the foot connected to the boom.



Picture: boom foot (Designed in SolidWorks by bachelor group).

1.3.4 Brackets (C21 and C22)

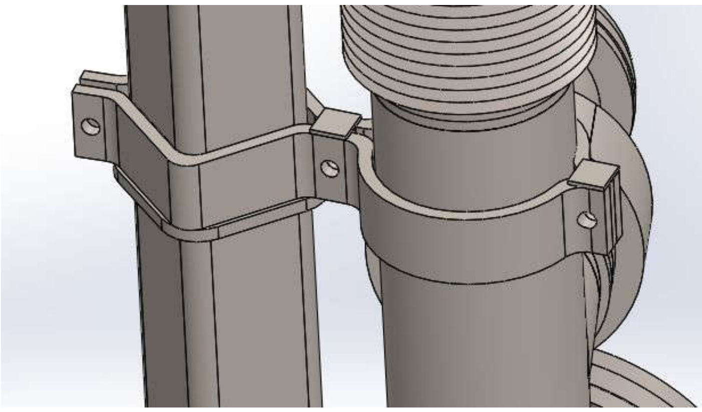
The brackets are there for keeping the bleed system in place, and to give it support. The first picture is the lower brackets which is making the bleed system in a fixed position, while the second picture shows the brackets with a distance to the pipe. One of the problems due to heat expansion was how the place the brackets. In total in the vertical direction there will be a displacement of more than 10mm in the bleed system pipes. Therefore the placing is critical for the brackets. See picture below. One of the problems due to heat expansion was how the place the brackets. In total in the vertical direction there will be a displacement of more than 10mm in the bleed system pipes. Therefore the placing is critical for the brackets. The lower brackets is made out of stainless steel and keeps the bleed system totally fixed. It stops the movement from the heat expansion in the axial and radial direction. This assembly consists of eight parts. Two brackets, three bolts and three nuts. When assembled they have their own support tracks in both the pipes and boom. The tracks ensures the brackets not to slide out of position while operating or moving. These brackets are placed in between the two outlets of the turbine, from valve A43 and A51. The centration makes the displacement due to heat expansion in this area to distribute even to both interfaces. When they are in locked position both pipe and boom is counted as a solid.



Picture: Lower brackets (Designed in SolidWorks by bachelor group).

1.3.5 Brackets (C21 and C22)

These brackets have a slightly different task than the previous. The brackets are the same, but contains more parts. The task done by these brackets is to give the bleed system support, with the pipes have a ability to move freely in the radial and axial direction. The boom on the other hand is fixed, and keeps the brackets from any displacement due to a shims between brackets and boom of 1,7mm thickness. The parts in this assembly is in total of twelve pieces. Two brackets, two shims between brackets, two shims between boom and brackets, three bolts and three nuts. The gap between brackets and pipes are also 1,7mm. The displacement due to heat expansion is 0,8mm, so there is no possibility the brackets will prevent the pipes from expanding.



Picture: Lower brackets (Designed in SolidWorks by bachelor group).

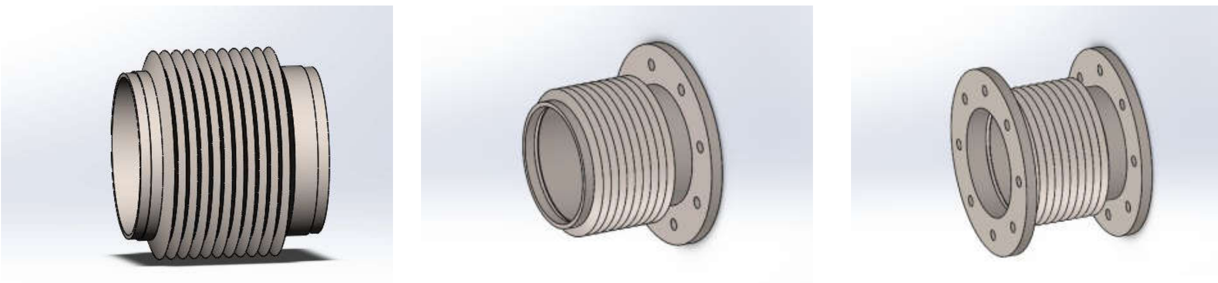
1.3.6. Expansion joint

Problem statement

The bleed line system leads air with high energy out of the enclosure. The heat creates expansion in the pipes, both radially and axially. The axially displacement due to the [redacted] degree celcius air is as high as 10mm from the start of the system until the end. This displacement have to be dealt with, since the tension created in the pipes and support will be tremendous.

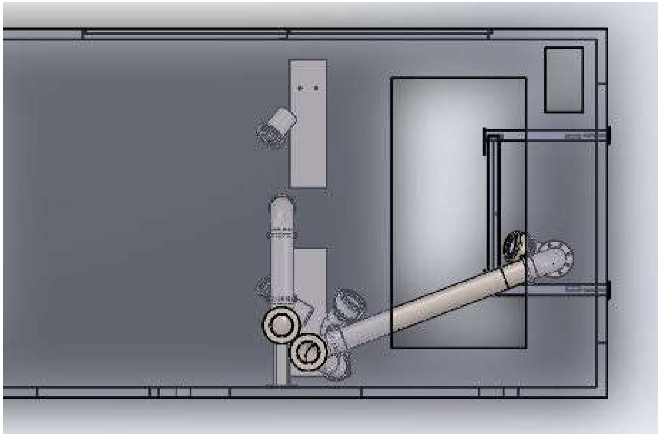
Solution

To absorb the displacement there is three different configurations to the expansion joints. Picture below shows without flanges, picture with one, and with two flanges.



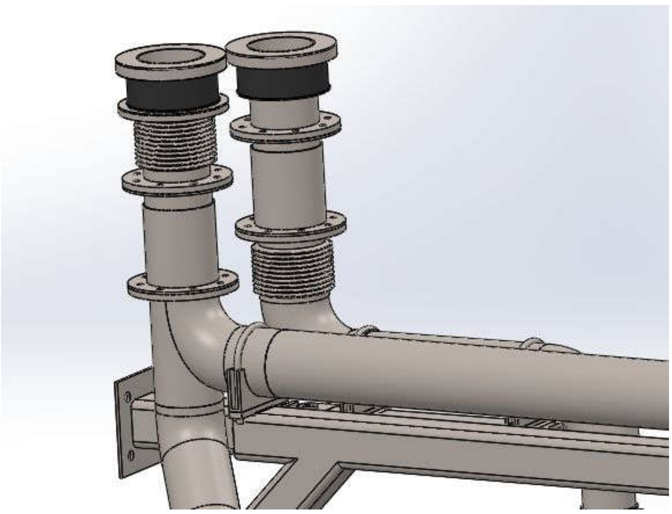
Pictures: 1 without flanges, 2 with one flange and 3 with two flanges (Designed in SolidWorks by bachelor group).

The expansion joints is delivered in a wide range of variants. In the concept 16 all three variants have to be chosen. In the bleed line system on boom B1 the lower expansion joint have to be without flanges. The flanges would have a diameter that prevent the boom to be fully parallel to the side wall. Picture one shows how the boom would be with flanges on. The boom would be in the way when disassembly of the turbine happens, and the turbine shall be lifted out of the enclosure. The placing of the expansion joint was changed when the configuration of the boom was changed.



Picture 1: Bleed line system from above (Designed in SolidWorks by bachelor group).

The other two expansion joints is placed close to the enclosure roof. They will both take up the axial displacement in the bleed line system. See picture below. Expansion joint on boom B2/B3 have one flange due to the spacing between roof and pipes, where the extra flange would make the assembly of the system difficult.



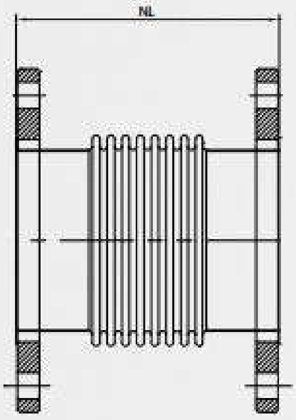
Picture: Expansion joints (Designed in SolidWorks by bachelor group)

The configuration of the flanges is described in the product sheet below, from (Amnitec part of the unitedflexible, 2017). See datasheet below for details.

STAINLESS STEEL EXPANSION JOINT, TYPE US1F »

APPLICATIONS

US types are used in flue gas (exhaust) systems. Exhaust systems in e.g.ships are normally characterized by higher demands of temperatures, vibrations and lower pressures. Designed for general applications with low pressure and high temperatures, small vibrations and relatively large axial and lateral movements.



TECHNICAL DESCRIPTION

Bellow : AISI 321
Van Stone ends (collar) : AISI 321
Flanges : Carbon steel

FLANGES

Swivelling, PN 6, carbon steel.,
Other flanges (PN 10/16) on request.

DATA TABLE

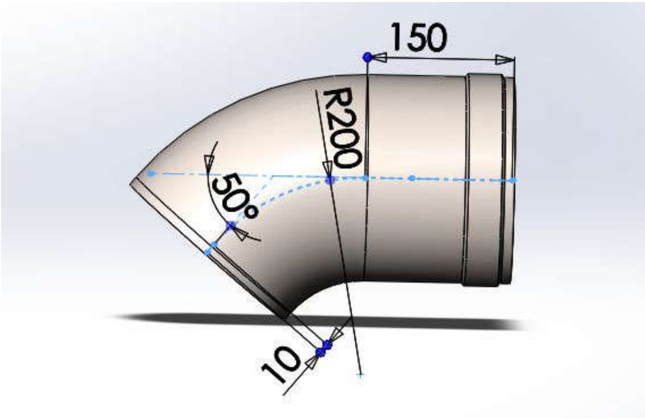
DN	Type	NL Neutral Length	Axial Compression	Axial Extension	Lateral Deflection	Max. Pressure	Max. Pressure
mm (in.)		mm	mm	mm	mm	bar/20°C	bar/550°C
80(3)	US1F80.255/F	255	-49	+49	26	2,5	0,5
100(4)	US1F100.255/F	255	-53	+53	21	2,5	0,5
125(5)	US1F125.255/F	255	-56	+56	19	2,5	0,5
150(6)	US1F150.255/F	255	-46	+46	12	2,5	0,5
200(8)	US1F200.255/I	255	-54	+54	11	2,5	0,5
250(10)	US1F250.255/I	255	-60	+60	10	2,5	0,5
300(12)	US1F300.310/I	310	-69	+69	12	2,5	0,5
350(14)	US1F350.310/I	310	-75	+75	13	2,5	0,5
400(16)	US1F400.310/I	310	-78	+78	12	2,5	0,5

Datasheet shows information about the expansion joint (Amnitec part of the unitedflexible, 2017).

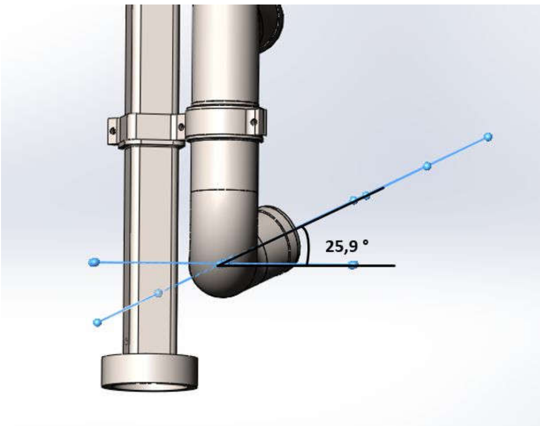
1.3.7 Pipes processed

RB11

The first bend from valve 51. The bend due to the angle of valves needs to be of the standardized 45 degree by 5 degrees. See first picture. The pipe will also needed to be welded to the next section by an angle of 25,9 degrees. See second picture below. This will lead to the adjustment in a rig, and will naturally take some extra time. The elevation in the pipe on the right side is a track for the attachment of the interface capsule, and have to welded to the pipe. The price is estimated for the three welds, attached to next pipe, and two welding runs for the elevation. The pipe is made in stainless steel 316.



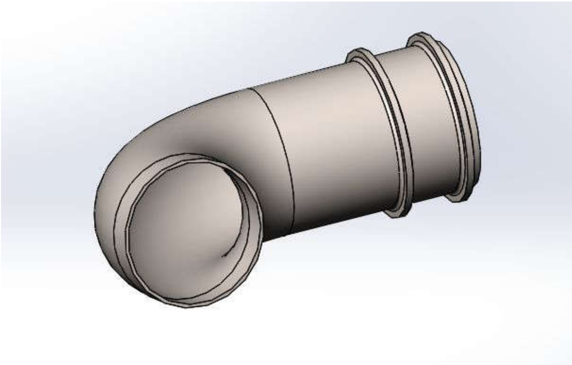
Picture: RB11 (Designed in SolidWorks by bachelor group).



Picture: Angle of attachment (Designed in SolidWorks by bachelor group).

RB12

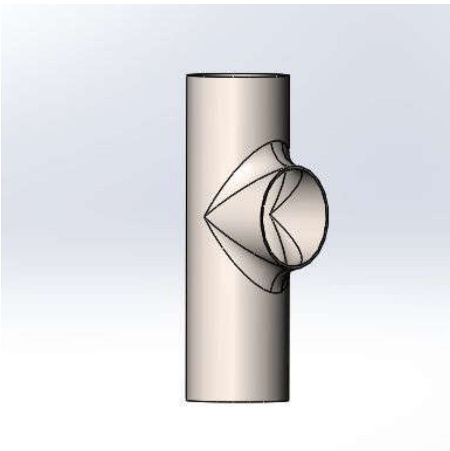
The second bend is a standardized 90 degree bend cut in both ends, and welded to the next section in the bleed line system. To have support and make the precision when attaching the interfaces to the turbine, and to prevent movement of the bleed system during service and operation there is made a path to attach the brackets to the pipes. When mounting the pipes the brackets is tightened no more than it is possible to move the pipe into position by hand before locked. The welding price estimate is from the two weld runs for each path, and the weld to the next section. The weld to first section is already accounted for in the RB11. See picture below.



Picture: RB12 (Designed in SolidWorks by bachelor group).

RB13

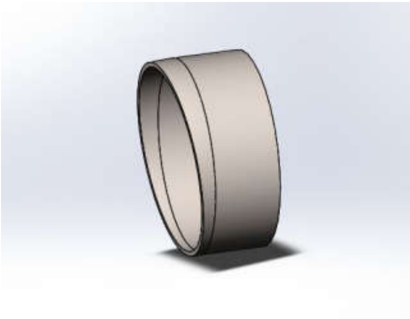
The first section of mixing flow from valve 43 and 51 is the t-joint. See picture below. It is a standardized t-joint, cut to specified length from the center of the vertical pipe. The distance is 285,8mm and 375,8mm. This section needs to be welded to the next section of the joining flows of valve 43 and 51, and needs to be welded to the first section of valve 43. It also have to be locked in a jig to get the correct angles connecting it to both ends that needs welding. The horizontal pipe pointing towards valve 43 have to be at a length of 152,8mm.



Picture: RB13 (Designed in SolidWorks by bachelor group).

RB14

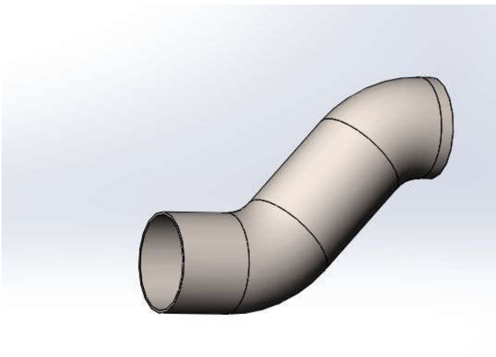
The small piece of a 45 degree bend is cut on both side to get the correct angle. See picture below. The length of the pipe is 89mm. The welding to next section is included in the estimate from RB13. See picture below.



Picture: RB14 (Designed in SolidWorks by bachelor group).

RB15

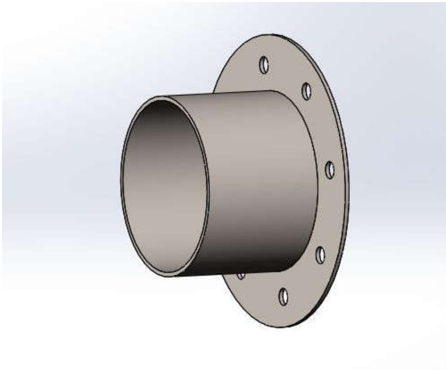
This piece consists of two 45 degree standard bends welded together. See picture below. This part of the system will lead the air up, and swinging into the center axis of the boom. When rotated the upper part of the pipe is centered, while the lower swings with a radius. The price is estimated from the cutting in both ends of a 45 degree bend, and welded together in the correct angle. The pipe endings also have to be welded to a expansion joint on the lower side, and the RB16 on the upper. This stretch will not be affected by the expansion due to heat because of the heat expansion joints in both ends. The lower part will have a slightly longer straight piping.



Picture: RB16 (Designed in SolidWorks by bachelor group).

RB17

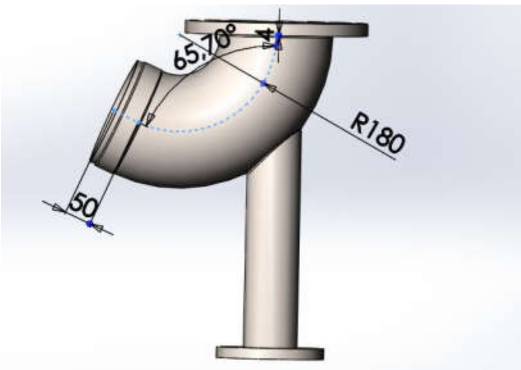
The top pipe is the pipe going through the roof. See picture below. It consists of a 149mm pipe, welded with a slip on flange. The price is estimated from cutting the pipe, and welding two runs on the flange. The flange itself is a standard buyable part.



Picture: RB17 (Designed in SolidWorks by bachelor group).

RB21

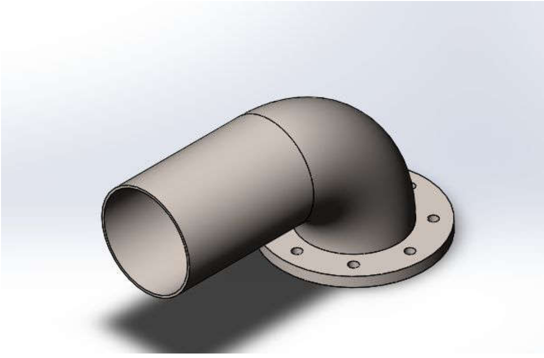
The pipe(see picture below) is specially bend in the process, and have a radius/diameter of less than 1. The price on the bend is estimated from the welding runs for the foot, the flange and for the elevation track to the interface connection. RB21 will take the flow from valve 44 in the inlet, and be connected to the strip wound hose on the other end. It have adjustment possibility in the radial direction of the foot for better position to the valve. The elevational track is to ensure the connection for the interface capsule.



Picture: RB21 (Designed in SolidWorks by bachelor group).

RB22

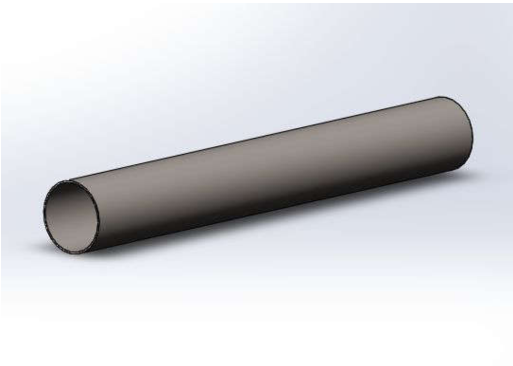
The pipe (see picture below) is supported by a u-bolt connecting the pipe to the boom. The straight pipe is connected to the top pipe of the boom, while the other have a slip on flange welded to the pipe. The price is estimate from the welding to the pipe, and the two welding runs of the flange. It have eight bolts connecting it to the stripwoundhose. The pipe will be loose on the top of the boom, allowing it to move in the axial direction due to expansion from the heat.



Picture: RB22 (Designed in SolidWorks by bachelor group).

RB23

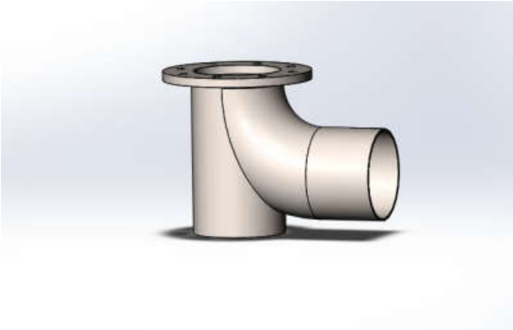
The pipe RB23(see picture below) is a straight part needed to be cut to the right length of 1600mm.



Picture: RB23 (Designed in SolidWorks by bachelor group).

RB16

The standard t-joint (see picture below) is cut on both sides where the flow passes straight. The vertical pipe have its original length. This part connects the flows from the valves A43,A44 and A51, and is subjected to the highest flow in the system. The price to this pipe section is estimated from the earlier mentioned cutting, and from the welding to RB15, and to flange FL2. The flange is a slip on flange and requires two runs of welding, on the inside and outside. The flange is the connector to swivel joint in the next section. The pipe is held to the vertical boom B1, with a clamp ensuring no movement due to heat expansion. The flange is a standard flange bought from a supplier, and is closer described in the budget of the system.



Picture: RB16 (Designed in SolidWorks by bachelor group).

1.3.8 Boom B1

The boom B1(see picture below) is a specially designed boom. The choice of choosing and redesigning the original boom made was the rotation point around the axis of the swing joint. The room for having a expansion joint, a swivel joint and a assembly through roof would be make the system too high. The boom supports the pipes in the horizontal direction to the valve A44, and vertically to the valves A51 and A43. The price of the boom is estimated from the total square steel length, the position and attachment of the elevated tracks for brackets on the vertical part, the welding of the square steel, welding of the foot, the foot itself, and the brackets on the horizontal boom which supports the part of system leading to valve A44. The boom is made of stainless steel, and have a wall thickness of 15mm. The boom have been exposed to testing, and is in its own report. See picture for design.

Picture: Boom B1 (Designed in SolidWorks by bachelor group).

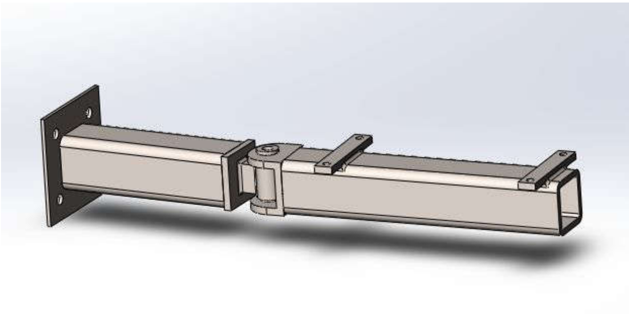
1.3.9 Foot to boom (B2 and B3)

Problem statement

During service and operation the boom have to be adjusted in two different angles. When operating the boom it is perpendicular to the sidewall, while during service it will have the position along the wall (parallel to the sidewall). During shipping it will be set in the service position, and the boom have to be locked both in the vertical and horizontal direction.

Solution

Two different solutions was discussed. One was having the boom resting on sliders along the vertical part of boom B1, and the other was to have a two folded boom. The two folded boom was selected. See picture below. The boom is divided into two sections, where B2 is attached to the wall, and B3 is holding the pipes. The estimation of the price in the boom is taken from the welding of the plate mounting the boom to the wall, the welding of the rotational joint on B2 and B3, the welding of brackets to the u bolts and the cutting of square steel.



Picture: Boom B2 and B3 (Designed in SolidWorks by bachelor group).

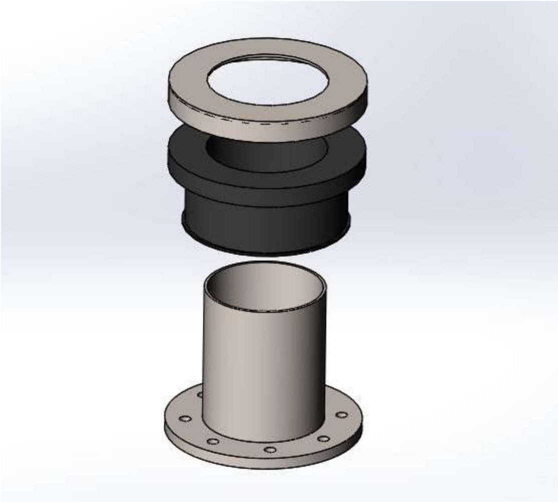
1.3.10 Top pipe boom B2/B3

Problem statement

During service the boom B1 and B2/B3 is swung 90 degree, and the expansion in the pipe due to heat affects the solution for the roof duct.

Solution

The inner pipe is a regular stainless steel pipe, with a slip on flange welded to it. And in the other end it is threaded. The pipe section goes through the roof, and the threads are above the roof. A rockwool isolation is slided onto the pipe, resting on an elevation in the inner pipe. The isolation protects the roof from the heat, and is moving with the pipe when the booms are turned. To secure the isolation a lid is screwed on. See the assembly picture.



Picture: assembly of parts through roof from B1 (Designed in SolidWorks by bachelor group).

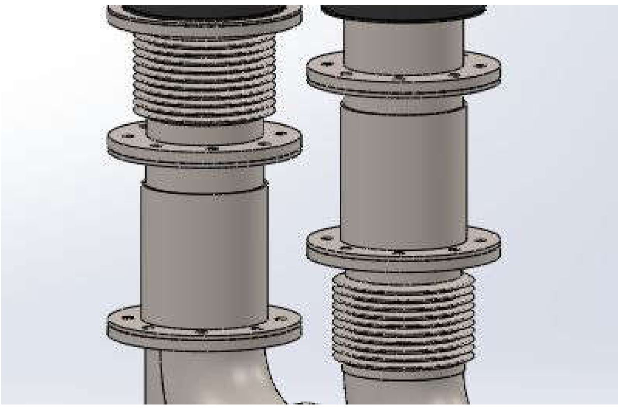
1.3.11 Swivel joint

Problem statement

The bleed line system needs to rotate around an axis, and a rotary joint is needed for the task.

Solution:

The swivel joint from rotaflow will do the task. Both boom 1 and boom 3 needs this movement, and since they are rotating around their own axis, there is the need of two rotary joints. The rotary joints need the correct inner diameter, must stand against temperatures up to [redacted] degree Celsius, and needs flanges to connect to the rest of the bleed system. See picture.

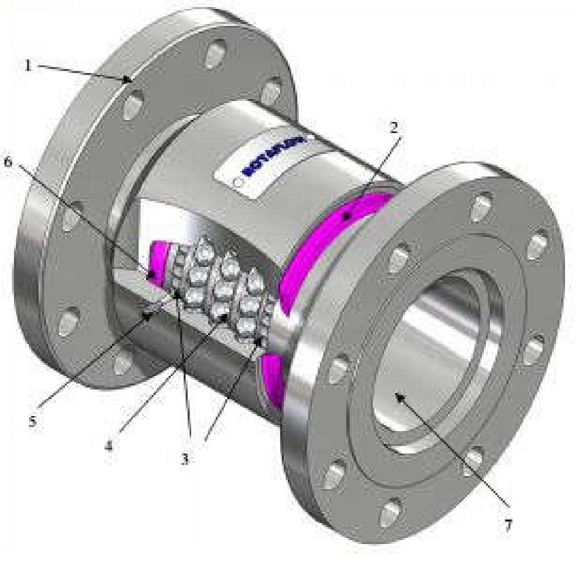


Picture: Swivel joints (Designed in SolidWorks by bachelor group).

Below a datasheet of swivel joint is shown.

SWIVEL JOINTS

Large Bore 8" To 30".



1. ANSI Flanges as standard. Available with most flanges or end fittings.
2. Standard dust seal.
3. Two roller races for high radial and bending loads.
4. Full compliment ball race for high axial/ pressure loads.
5. Grease nipple for lubrication and purging of old grease (through dust seal).
6. PTFE main seal as standard.
7. Clear full flow bore at nominal pipe size for minimal pressure/flow loss.

ALSO AVAILABLE:-

- Sealed for life/submerged duty.
- Negative pressure or vacuum duty.
- High temperature operation (200 Deg C/ 400Deg F)
- Stainless steel units.
- Other metals on application.
- Leak detect port.
- Additional ball/roller races for high loads or pressure.
- Pressure test to 1.5 X working pressure
- DNV-OS-E101/ABS-CDS Compliant

Nominal Size	Bore (Schedule XS)	OD of Body, Allow additional 24mm for clearance of grease nipples and plugs.	ANSI 150 Flange OD. (Max Pressure 20 Bar.)	Max Radial Load	Max Axial Load Per Ball Race*	Max Bending Load.	Max Static Test Pressure per race*	Max Pressure per race* Slow rotating	SK1 #150 Flanged Weight.
	mm	mm	mm	kN	kN	kNm	Bar (PSI)	Bar (PSI)	Kg
8"	193	283	343	77	103	4	42 (611)	24 (349)	85
10"	247	337	406	97	126	5	34 (490)	19 (280)	112
12"	298	388	483	115	145	6	28 (407)	16 (233)	146
14"	330	420	533	126	158	7	26 (370)	15 (212)	177
16"	380	470	597	144	178	8	22 (326)	13 (186)	212
18"	431	521	635	162	199	9	20 (289)	11 (165)	235
20"	482	572	699	180	219	10	18 (259)	10 (148)	278
24"	584	674	813	216	259	12	15 (215)	8 (123)	358
30"	736	826	984	270	322	15	12 (173)	7 (99)	450

*Standard swivel body has one ball race and can accommodate up to three races. To find axial load and pressures multiply the value from the table by the number of races. For higher loads please enquire for a special design. Please consult Rotaflow with actual load details as combined loads (including pressure) require special consideration.

Please note the stated maximum loads can not be combined.

Datasheet shows details about swivel joint (Rotaflow, 2017).

References

Amnitec, part of the unitedflexible (2017). *Stainless steel expansion joint, type us1f.* [Internet] Avaliable at:
https://unitedflexible.com/wp-content/uploads/2016/04/Stainless-Steelexpansion-joint-type-US1F.pdf
[Accessed: 09 may 2017].

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[Accessed: 18 May 2017].

Precisionbrand (2017). *Hoseclamps.* [Internet] Avaliable at:
http://precisionbrand.com/products/b224hsp-all-300-series-stainless-worm-gear-hose-clamp-11-12-14-716-clamping-diameter-pack-of-10/
[Accessed: 11 may 2017].

Rotaflow (2017). *Large bore.* [Internet] Available at:
http://www.rotaflow.com/Tech_spec_sheets/SK_Series_Large_Bore_8to30in/129_Large_Bore_8to30in.pdf
[Accessed: 21 may 2017].

2. Attachments to C30

2.1 Technological Choices

2.1.1 Pipes vs tubing

We wanted to take a closer look at the option between pipes and tubes. This was because we saw that there was a broader selection of fittings for tubes, and that they were available with thinner walls and thus lighter than pipes.

The difference between pipes and tubes is in some aspects not much, but sufficient in others. The main difference is that tubes are usually used for structural purposes, but pipes for transporting fluids. Although this is the official difference per definition (Commerce metals, 2017). It seems to be a lot of evolution on the use of tubes for transporting fluids in recent times.

What we also found out was that the dimensions were not the same and we would have problems using both together. This sins the tube dimensions were based on the outside diameter and the pipes on the inside combined with different wall thickness it makes it difficult to match them together. Tubing is also made with tighter tolerances, and is more expensive to buy (The engineering toolbox, 2016).

For the bleed system we ended up using pipes with dimensions 141,3mm for valve A43, A44 and A51, and 168,3mm for valve A51.

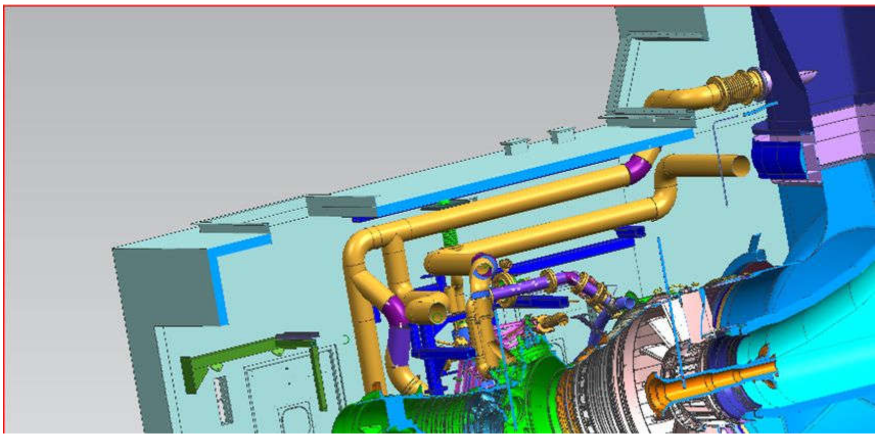
References

Commerce metals (2017). *Tube vs Pipe - The Differences Explained in Plain English.* [Internet] Available at:
http://www.commercemetals.com/tube-vs-pipe-the-differences-explained-in-plain-english/
[Accessed: 21 may 2017].

The engineering toolbox (2016). *Difference between tubes and pipes.*
[Internet] Available at:
http://www.engineeringtoolbox.com/pipes-tubes-d_347.html
[Accessed: 21 may 2017].

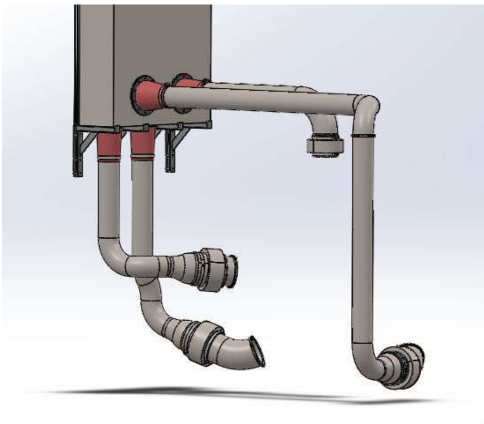
2.1.2 Sound Silencer

When designing a new bleed system for the turbine RB211-GT30-DLE the use of exhaust sound silencer is a possible solution. The disadvantages for doing this is that the distance from bleed valves to the exhaust is quite long and it is tumbling to make bleed lines through this distance. Picture below shows a solution of the bleed lines going to the exhaust.



Picture: Shows the bleed lines going into the exhaust (picture received from D-R).

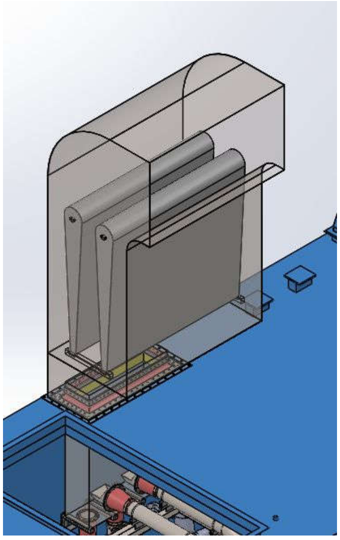
When having a separate sound silencer for the bleed system it reduces the length of the bleed lines markedly. This gives advantages, and the most important one is that it helps to avoid high back pressure. In this concept we have a duct inside the enclosure, so the length of the pipelines is only from the four different valves to the duct on the wall. We now have the possibility to reduce dimensions of the pipes which is an advantage, due to the limited space inside the enclosure, the weight is reduced and it makes the bleed pipes easier to handle during assembly/disassembly. Picture below shows the length of the bleed lines in this concept is greatly shortened.



Picture: Shows the length of the different bleed lines. All the bleed valves have its own pipeline from valve to duct (Designed in SolidWorks of bachelor group).

We also discussed the possibility to have the duct combined as a sound silencer. But challenges here is the space available. The construction can not take too much space inside enclosure since the crane shall be possible to maneuver and the accessibility inside housing shall be possible. So we decided to cancel this option and instead place it on the roof.

Below the picture shows the duct placed on the roof. This area of the roof is possible to put a silencer. So the design and the size of the silencer is not so important as long as it doesn’t conflict with the ventilation ducts.



Picture: shows the silencer with elements inside placed on the roof over the duct.

The benefits of having shorter pipes made us choose a separate silencer placed over the outlet of the duct.

2.1.3 Insulation between duct and wall

To prevent the wall to become too hot behind the duct we need some insulation between duct and wall. Rockwool have good insulation characteristics, and can be used in situations where the heat goes up to 750 degrees celsius. But it is recommended to use a thickness of 100mm at temperatures in the area of [redacted] degrees celsius (Rockwool, 2017). Instead we wanted to use heat shield that prevents heat radiation from duct to wall. This is aluminium sheets that have a reflective surface (Rallynuts motorsport, 2017). It is two sheets with a distance of 10mm that allows cooling between them and another 10mm clearance before the wall. The ventilation air through the housing will also help to reduce the effect of the heat radiation from the duct.

References

Rallynuts motorsport (2017). Nimbus Lite Reflective Heat Shield. [Internet] Available at: http://www.rallynuts.com/heat-management/nimbus-lite-reflective-heat-shield.html [Accessed: 13 May 2017].

Rockwool (2017). Brannsikring av ventilasjonskanaler. [Internet] Available at: http://www.rockwool.no/produkter/brannsikring/brannsikring-av-ventilasjonskanaler/ [Accessed: 28 April 2017].

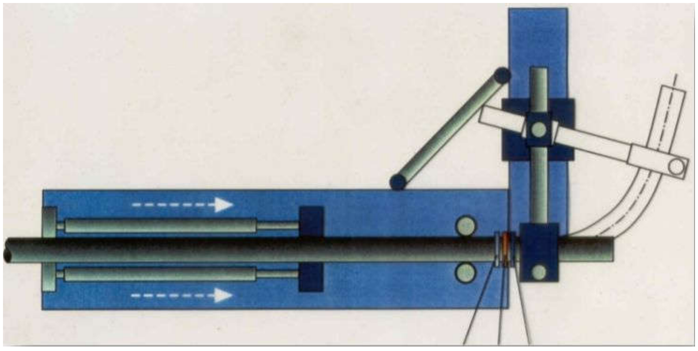
2.1.4 Bleed pipes

Bleed pipes, or bleed lines, is where the air is flowing from the compressor part of the turbine and to the duct where the air is dumped. We have considered different solutions for the bleed system. From the valves, especially 3 of them (A43, A44 and A51), is at a difficult angle to match with standard pipe bends like 45 degrees and 90 degrees. So while researching we found that there is possible to use induction bending for making not series produced angles. This is when we need to have smaller or bigger bending angles than 45 or 90 degrees.

Induction bending

For bending pipes with induction bending the material needs to be a current conducting material.

When using induction bending we need to have thicker pipe wall when bending than standard mass produced bends. This because when reducing the bending radius we need bigger walltickness to not destroy the pipe when bending. The picture below shows the procedure of induction pipe bending.



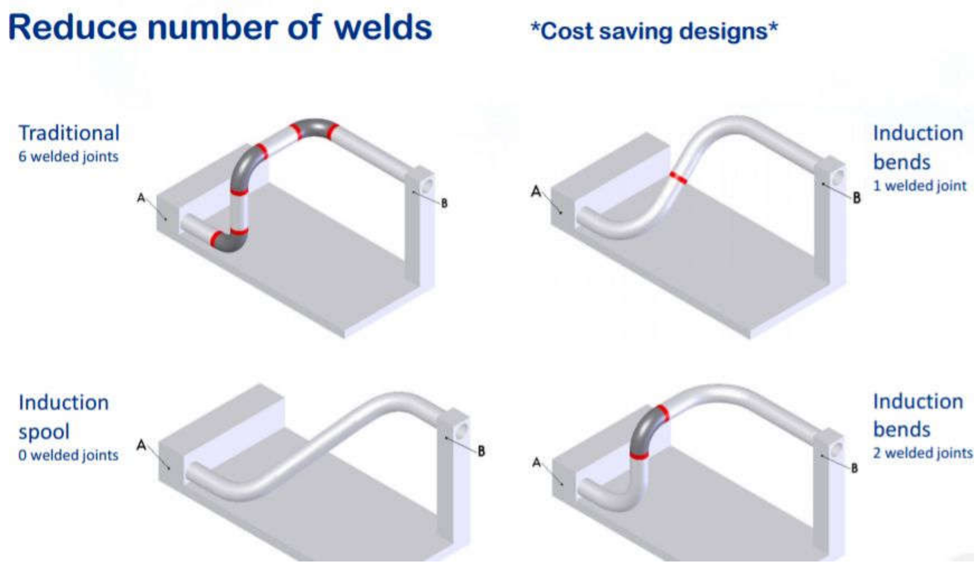
Picture: shows the procedure of induction bending. The metal pipe is connected to an arm that drags the pipe and force it to bend while heated in the bending area (NIRAS, 2016) .

Specifications on types of pipes, bending radius and weight was found to be as described. For valve A42 we found that a 150mm inner diameter is sufficient considering air flow and back pressure. Closest to 150mm inner diameter we have a standard pipe with 168,3 outside diameter and wall thickness of 7,1mm (inside diameter Ø-154,1) and weight ca 29 kg/m. 168,3mm pipe can have a bending radius of 3D (=457mm) carbon steel and 5D (762mm) for stainless steel. It is possible to reduce the wall thickness to 3.5mm that gives a bending radius at 6D (914mm) carbon steel and 7D (1066mm) stainless steel with weight at 14 kg/m.

For the other pipes A43, A44 and A51 we found that a 125 mm inner diameter is sufficient considering air flow and back pressure. Closest to 125mm inner diameter we have a standard pipe with 141,3mm outside diameter and wall thickness of 6,3mm (inside diameter Ø-128,7) and weight ca 22,5 kg/m. 141,3mm pipe can have a bending radius of 3D (381mm) carbon steel and 5D (635mm) for stainless steel. It is also here possible to reduce the wall thickness to 3.5mm that gives a bending radius at 5D (635mm) carbon steel and 6D (762mm) stainless steel with weight at 12 kg/m.

When having more bends on the same pipeline it needs to have a 260 mm of straight pipeline before the next bend. This because the fastening mechanism for bending needs this space to be connected to the pipeline. This will be some limitations when designing this pipelines, but it leads to a much more easier assembly work of the bleed system.

The benefit of using induction bending is that number of weldings can be reduced. The method of heating and strictly cooling will also help to not change the strength of the material (NIRAS, 2016). The picture shows different methods to reduce number of weldings.



Picture: here the number of weldings is reduced from 6 weldings to zero weldings (NIRAS, 2016).

One disadvantage is that the wall of the piping have to be thicker when doing induction bending (NIRAS, 2016). And the weight in kilogram per meter will increase greatly. So when doing service on the turbine the bleed system must have a device that can lift it out of the enclosure since the weight will be more than the maintenance personnel can lift manually.

Making the pipes with welding

The method of cutting and welding is a method that keeps the weight of the bleed system down since the wall of the pipes can be thinner. All the bending parts is connected to the straight pipes with welding. When having bends with not series produced bends the standard 45 degrees or 90 degrees bends needs to be cutted for fitting. All of the pipelines can be in one piece except bleed line from A44 that needs to be cut in two pieces because of the weight.

To keep the weight down we end up with using regular pipes and bends and weld them together. This because we have flexible solutions at the inlet and the outlet of the bleed system, so we can accept some misalignments at the finish product. The length of the pipes will also be shorter with welding since the bending radius will be smaller than with induction bending.

Dimensions of the bleed lines

Dimensions for valve A42 is 168,3mm outer diameter with wall thickness of 2,77mm. This results in an inner diameter of 162,76mm. For A43, A44 and A51 we use 141,3mm outer diameter with wall thickness of 2,77mm. This results in an inner diameter of 135,76mm (The Engineering Toolbox, 2017). The back pressure from valve A42 will then be 10,33 kPa, in A43 it will be 18,9 kPa, in A44 35,1 kPa and in A51 it will be 23,5 kPa.

References

NIRAS (2016). Induction bending. [Internet] Available at:
http://niras.no/wp-content/uploads/2017/02/niras_-_presentasjon.pdf
[Accessed: 12 May 2017].

The Engineering Toolbox (2017). Carbon, Alloy and Stainless Steel Pipes - ASME/ANSI. [Internet] Available at:
http://www.engineeringtoolbox.com/asme-steel-pipes-sizes-d_42.html
[Accessed: 12 May 2017].

2.1.5 Connection to duct

During research we found some possible solutions that makes a flexible connection to duct. Some facts and grounds for what choice is made is explained below.

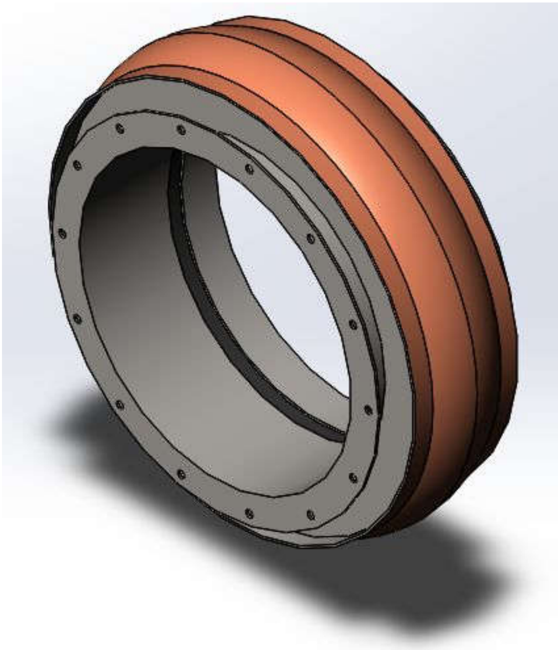
EagleBurgmann expansion joint solution

KE Fabric expansion joint from EagleBurgmann is a flexible connection for, among other things, air piping system. It compensate for thermal expansion, vibrations and misalignments. It is manufactured by combining different materials and takes into consideration the thermal, chemical and mechanical resistance as well as the fatigue properties of the materials. Some of the advantages of this flexible connection will for this concept of bleed line solution be:

- Compensate for movement in several directions
- Transfer almost no loads
- Requires little space for installation
- Good insulation
- It is a proven technology

There are several types of KE Fabric expansion joints. For temperature up to [redacted] degrees celcius we need to use a Fluaflex version that is used for air and flue gas systems with temperature up to 575 degrees celsius (EagleBurgmann expansion joint solutions, 2012).
The operating range for this joint is from minus 35 to 575 degrees celsius. The operating pressure for this joint is limited to 20 kPa (EagleBurgmann Rely on excellence, 2017). This is at the lower limit for this system, but since it is at the duct where the air is dumped the back pressure will then be no problem. Axial movements is 200mm and lateral movements is 80mm (EagleBurgmann Rely on excellence, 2017). This is proven to be sufficient by testing thermal expansion in Finite element analysis simulation.

3D modelling of this expansion joint gives an indication of how this joint will look like.



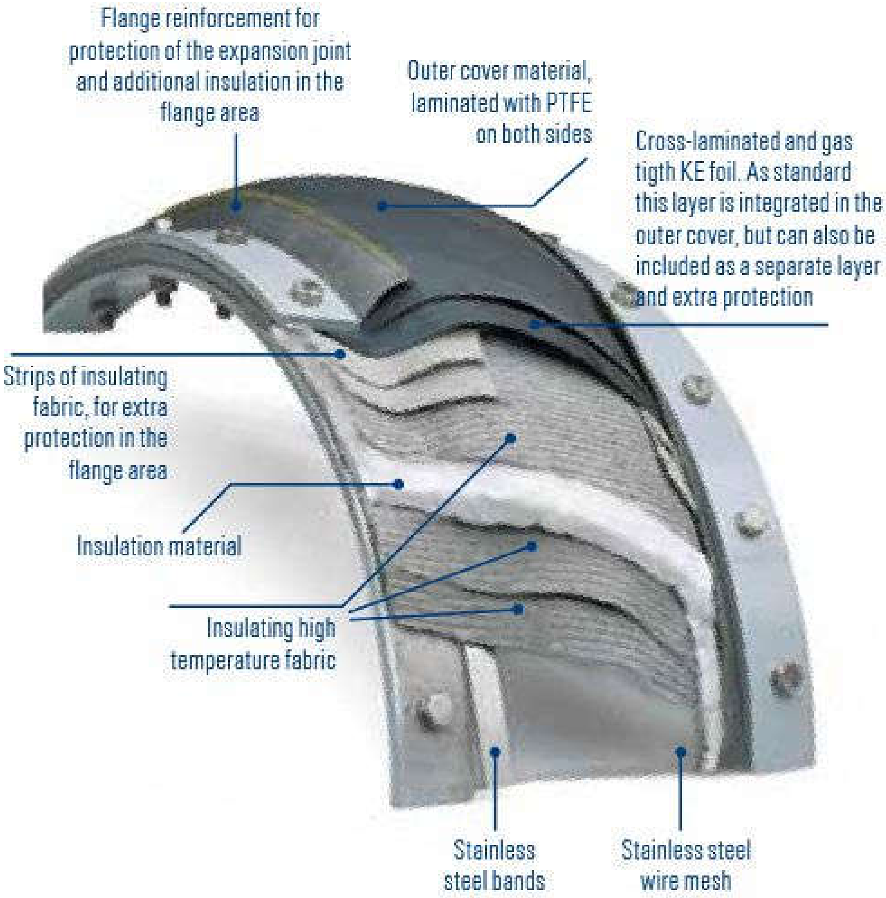
Picture: shows a 3D model of Fluaflex expansion joint (Designe in SolidWorks by bachelor).

Materials

Cross section view (picture below) displays the metal and the heat resistant materials. This layers of material will prevent the heat to come out. That means it works lika a flexible joint and an insulator at the same time (EagleBurgmann Rely on excellence, 2017).

Picture: cross section view of Fluaflex expansion joint (EagleBurgmann Rely on excellence, 2017).

The picture below shows how a KE Fabric expansion joint is build up of the different layers material with different characteristics regarding to temperature (EagleBurgmann expansion joint solutions, 2012).



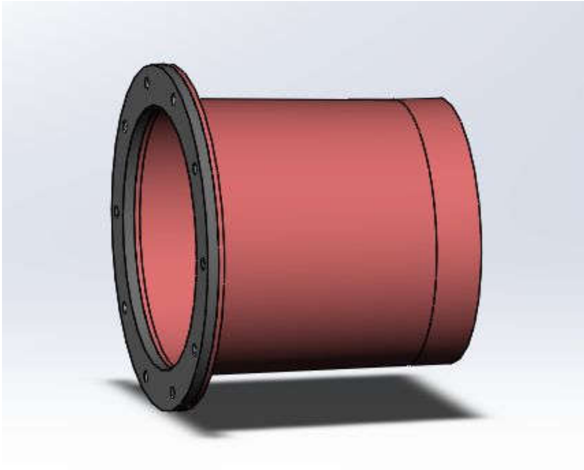
Picture: Shows the different layers on a KE Fabric expansion joint (EagleBurgmann expansion joint solutions, 2012).

Manufacturing

These joints will be manufactured according to customer's needs (EagleBurgmann Rely on excellence, 2017).

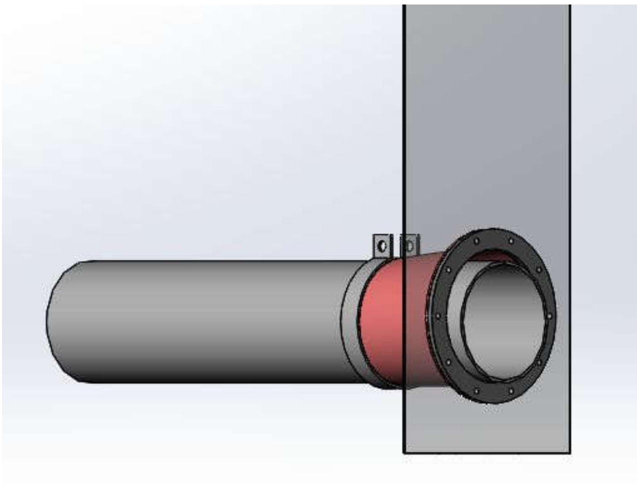
Expansion joint solution with heat resistant material

A solution that is maybe a more easier way of connection to duct is to use the heat resistant material from EagleBurgmann expansion joint - Fluaflex and use it like a membrane between duct and pipe. Here the membrane will be fastened with a clamp to pipe and fit a metal ring to duct. The pipe have the possibilities to rest on the duct while it can move freely during thermal expansion.



Picture: picture of expansion joint solution with heat resistant membrane (red colored) and fastening metal ring (black colored) (made by bachelor group-SolidWorks).

In an assembly it is easier to see the function of this joint. The membrane will be fastened on the inside of the duct with a metal ring and to the pipe with a clamp. The pipe can rest on the duct if needed and the membrane allows the pipe to move freely in all directions.



Picture: shows the assembly of connection to duct (made by bachelor group-SolidWorks).

References

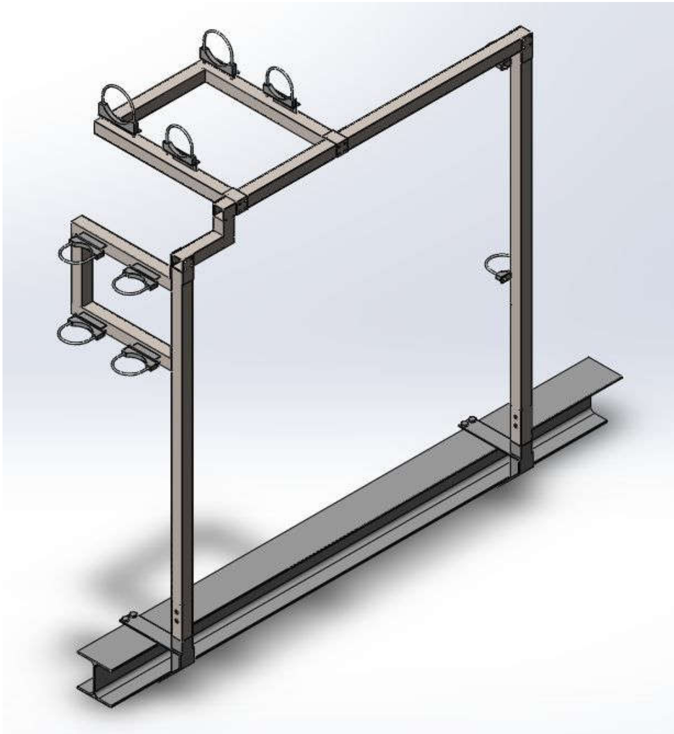
EagleBurgmann expansion joint solutions (2012). *KE Fabric Expansion Joints, brochure.* [Internet] Available at: https://www.eagleburgmann.com/en/products/expansion-joints/fabric-expansion-joints [Accessed: 27 April 2017]

EagleBurgmann rely on excellence (2017). *Fluaflex expansion joints.* [Internet] Available at: https://www.eagleburgmann.com/en/products/expansion-joints/fabric-expansion-joints/fluaflex-br-expansion-joints [Accessed: 27 April 2017].

2.1.6 Frame

The frame will consist of 70x70mm, 4mm thick hollow profile (Smith stål,2010). This let all the parts of the frame be under 25 kg that make it easy to disassemble when doing service. All the frame parts is fastened with 10mm bolts and nuts. Distance blocks must be connected for customizing all the fastening points. Clamps for the pipes used is at different sizes since some of the fastening point must fix the bleed line structure, and some clamps must have clearance because of heat expansion. This clamps is possible to order in almost all different sizes (Exhaust components Online Store, 2017).

The picture show an image of how the frame will look like.



Picture: shows an assembly of the frame and all the fastening points for the bleed pipes (Designed in SolidWorks by bachelor group).

Referanser

Exhaust components Online Store (2017). Truck exhaust pipes. [Internet] Available at: http://rikerexhaust.com/product-category/clamps/clamps-double-saddle-flat/ [Accessed: 13 May 2017].

Smith stål (2010). Lagerkatalog. [Internet] Available at: http://www.smithstal.no/SmithStaal/Produkter/lagerkatalog-smithstal.no.pdf [Accessed: 13 May 2017].

2.1.7 Routing path

Problem statement

Through discussion we designed different solutions to the routing of the pipes in the duct concept.

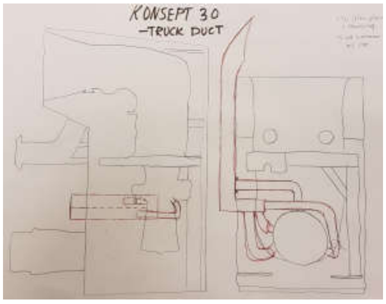
Solutions

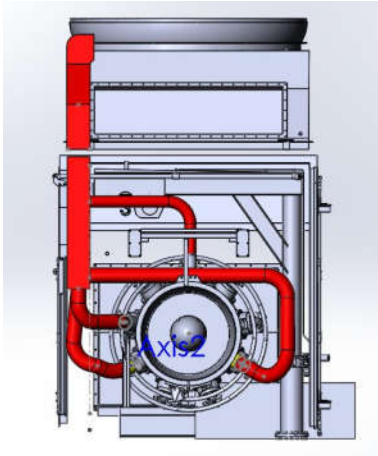
Early in the process we designed two ducts, one on each side of the turbine. This will make the total pipeline shorter since the valves on the turbine is on both sides and the pipes can go directly to the duct. But here it will be some challenges because of the big maintenace door and the crane. The duct could be fastened to the big maintenance doors, but when opening these doors we needed to disassemble the duct or find another mechanism to move the duct. And the duct can not be in the way of the crane even in the standby mode or in operational modus. So we decided to use only one duct on the opposite side of the big maintenance door.

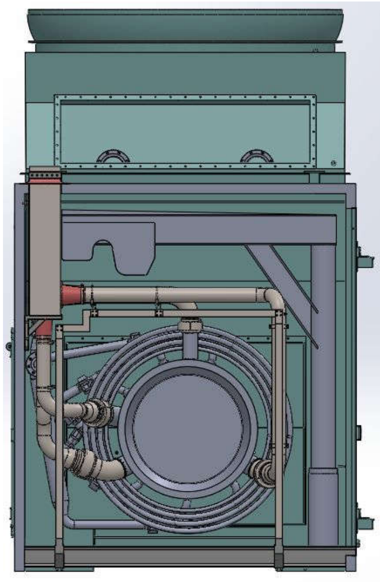
The routing of the bleed lines to the duct have two solutions. If the A44 valve is placed on the same side as the maintenance door, this bleed line can go under the turbine or over the turbine. The valve is pointing a bit downwards so it is easier to continue this direction under the turbine instead of over the turbine. After some research and discussion we found out that it is not much space under the turbine (this is not so easy to see on the simplified model that we are working with, so Dresser-Rand shows us from the real 3D model). So we find out that the pipes from valve A44 needed to pass over the turbine and into the duct.

Solution

In the end we decided to have only one duct. This must be customized with right and left version of the turbine generator package, but in both versions the pipes needs to pass over the turbine before entering the duct. The pictures below shows these concepts from the starting stage to the almost finish 3D model.





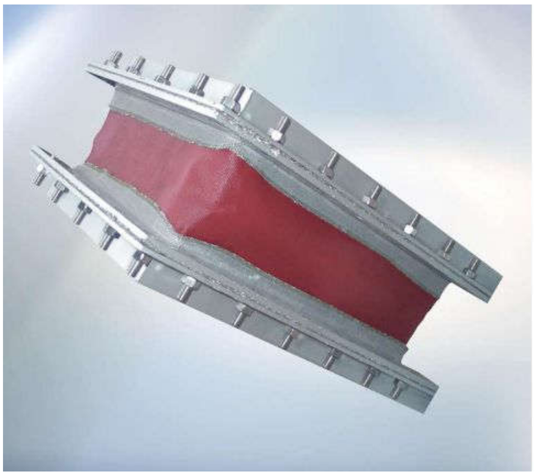


Pictures: left picture shows concept 30 as a draft. Picture in the middle is an early 3D model and to the right we see tha almost finish 3D model of concept 30(Left picture drawn by bachelor group, while middle and right picture is designed in SolidWorks by bachelor group).

2.1.8 Flexible connection between duct and roof

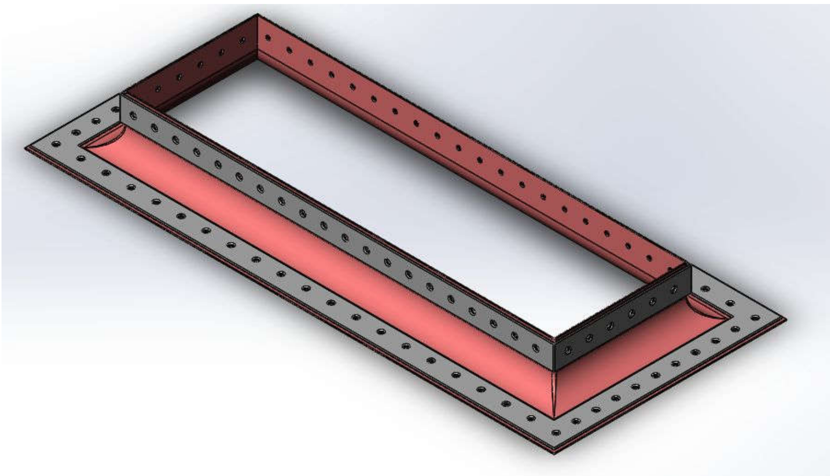
Fastening the duct directly to the roof with flexible connection points is a method that can be considered, but make it airtight can be a challenge. Some insulation material can be used but we end up with another method.

Fluachem expansion joint allows temperature up to 425 degrees celsius and allows movements in several directions simultaneously. This is a good solution for the connection between the roof and the duct regarding to heat expansion from the duct. This expansion joint will be custom made to fit the working conditions (EagleBurgmann international, 2017).



Picture: Shows how the flexible connection may looks like produced by EagleBurgmann (EagleBurgmann international, 2017).

The picture below shows how the fluachem flexible joint will look like in concept 30. The duct will go through the roof, and fastened to the flexible joint which is fastened to the roof. The silencer will come on top of this and cover the duct. The membrane (red color) lets heat expansion be possible in all directions.



Picture: Flexible joint between duct and roof (designed in SolidWorks by bachelor group).

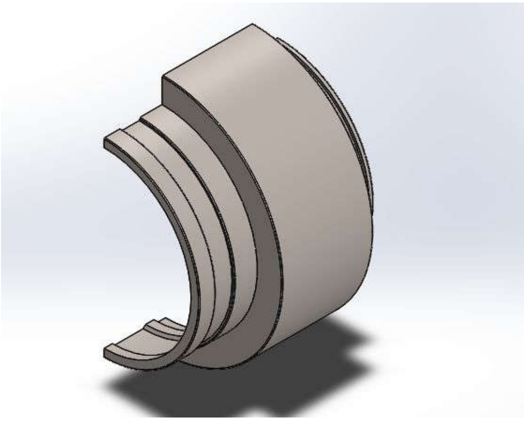
References

EagleBurgmann international (2017). Fluachem expansion joints. [Internet] Available at: http://www.eagleburgmann.com.tr/en/products/expansion-joints/fabric-expansion-joints/fluachem-br-expansion-joints
[Accessed: 28 April 2017].

2.2 Components

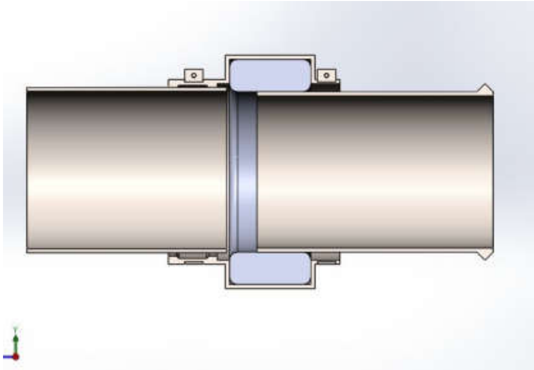
2.2.1 Interface valve A43, A44 and A51

See pictures below for illustrations of the interface bowl.



Picture: Capsule (Designed in SolidWorks by bachelor group).

Picture: Assembly interface (Designed in SolidWorks by bachelor group).



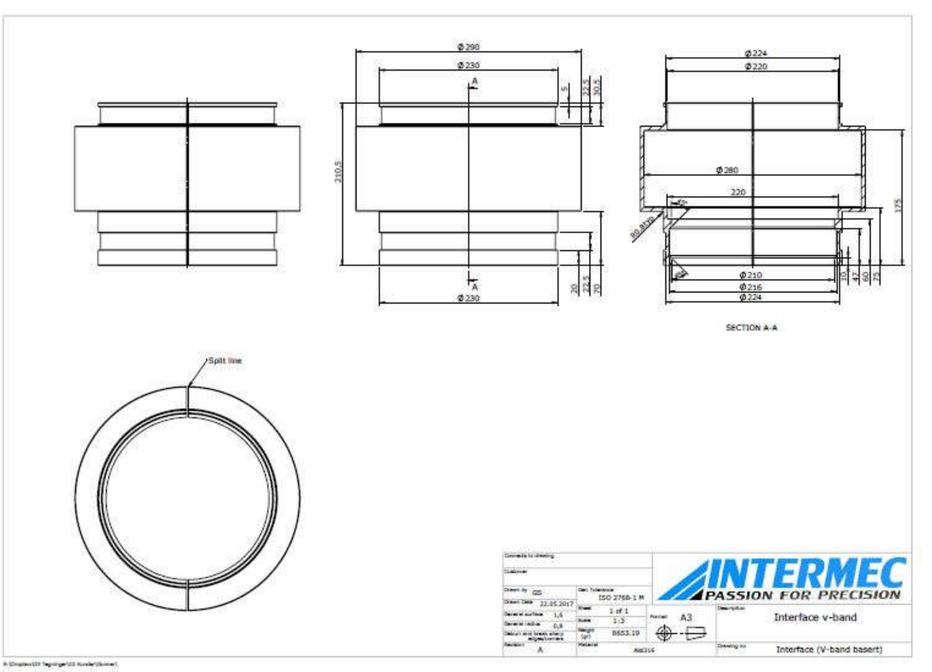
Picture: Assembly section view (Designed in SolidWorks by bachelor group).

When the heat creates movement between the systems, the rockwool shown as the blue ring inside the interface on pictures above will be compressed and allow the pipes to move without transferring any force to the pipes, and without creating more disturbance in the flow. The inlet diameter is 10mm less than the outlet to keep the flow undisturbed through the interface. The flow enters on the right hand side from the turbine through the smaller pipe, enters the sealing, and passes without hitting any sharp edges. The inner diameter of the left hand side is 200mm, while the other have 190mm. This gives possibility to move 5mm in the radial direction, which is within the requirement of 4 mm, and the movement from the rest of the system of 1 mm radially. In the axial direction there is 10 mm clearance, and satisfies the requirement by 2mm. In the later information from EagleBurgmann there is a second option for the interface between turbine and bleed line system (Eagleburgmann, 2017). This product data is unavailable since the EagleBurgmann have classified information in the datasheet received. This product forms a tube which the group had in an earlier iteration round, but never got any data on until the last minute. This is an absolute viable solution, and have not been evaluated.

Choice of material in the interface

Bowl

- Materials chosen in the encapsulation of the wool ring is stainless 316. Early on in the process there was considered using other materials, aluminium titan. The main reasons for choosing stainless steel is the production cost and thermal expansion. When metal gets hot it will grow, but not in the same rate as aluminium. The aluminium connection could lead to a wider gap between the sealed surfaces, and could again lead to failed requirements. 2D picture under is production drawing from intermec.



Picture: 2D production drawing interface capsule delivered by Intermec.

Rockwool

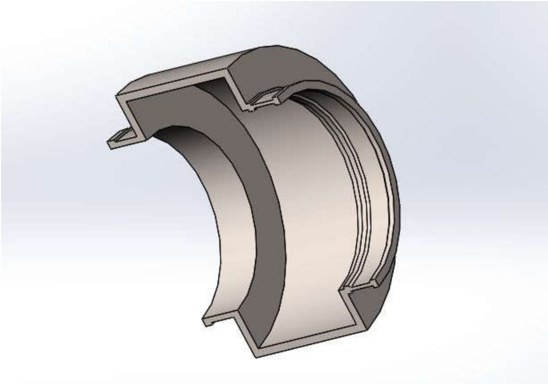
- The material in the sealing ring is rockwool with a thermal resistance to more than 1000 degree celcius. It is soft fabric and will form around the pipe giving a seal for the hot air transported in the pipes when tightened by the clamps. This wool will be encapsulated in a thin sheet of aluminium foil, preventing air escaping through the porous material. The supplier is GLAVA isolation, and is a cheap solution compared to other products. The rockwool will be blocked from moving within its pocket in the encapsulation, and forms a better seal when exposed to pressure. There will be ensured that the material can stand the maximum pressure without losing its characteristics. See picture below for properties for the material.

References

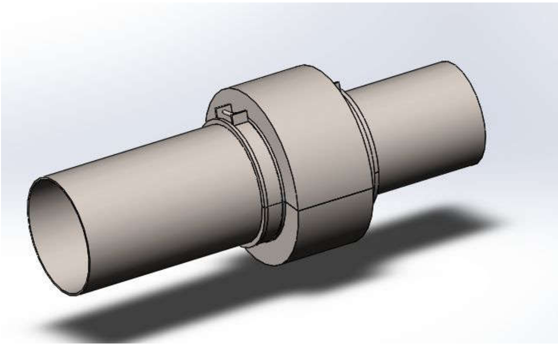
Eagleburgmann (2017) *Sealing solutions for innovative energy production.* [Internet] Avaliable at: https://www.eagleburgmann.com/en
[Accessed: 18 may 2017].

2.2.2 Interface valve A42

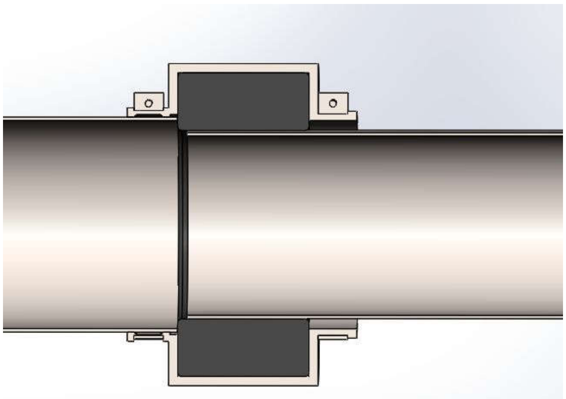
The pictures below shows some details about the interface.



Picture: Capsule (Designed in SolidWorks by bachelor group)



Picture: Interface (Designed in SolidWorks by bachelor group)



Bilde: Section view (Designed in SolidWorks by bachelor group).

When the heat creates movement between the systems, the rockwool showed as the blue ring inside the interface will be compressed and allow the pipes to move without transferring any force to the pipes, and without creating more disturbance in the flow. The inlet diameter is 10mm less than the outlet to keep the flow undisturbed through the interface. The flow enters on the right hand side from the turbine through the smaller pipe, enters the sealing, and passes without hitting any sharp edges. The inner diameter of the left hand side is 150mm, while the other have 143mm. This gives possibility to move 7mm in the radial direction, which is within the requirement of 4 mm, and the movement from the rest of the system of 1 mm radially. In the axial direction there is 10 mm clearance, and satisfies the requirement by 2mm. In the later information from supplier there is a second option for the interface between turbine and bleed line system (Eagleburgmann, 2017). This product data is unavailable since the Eagleburgmann have classified information in the datasheet received. This product forms a tube which the group had in an earlier iteration round, but never got any data on until the last minute. This is an absolute viable solution, and have not been evaluated.

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Rockwool

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PRODUCT DATA SHEET: ProRox
PDS 017
Issued: 01 - 10 - 2013

ROCKWOOL Technical Insulation
ProRox - Industrial insulation

ProRox PS 960 NYTT NAVN Tidligere navn: Rørskål 850

Produktbeskrivelse

ProRox PS 960 er en ferdigformet rørskål i ubrennbar steinull. Produktet er egnet for termisk og akustisk isolering av industrielle rørledninger med høy temperatur.

Samsvar

ProRox PS 960 rørskåler er produsert i overensstemmelse med kravene i EN14303.

Produktegenskaper

	Ytelse	Standarder
Varmekonduktivitet	(see table below)	EN ISO 8497
Maksimum brukstemperatur	650 °C	EN 14707
Brannklasse	Euroklasse $A1_L$	EN 13501-1
Nominell densitet *)	>100 kg/m³	EN 13470
AS Kvalitet	Kloridinnhold < 10 ppm	EN 13468
Vannabsorpsjon	≤ 1 kg/m²	EN 13472
Vanndampdiffusjonsmotstand	μ = 1	EN 14303
Luftstrømmotstand	> 80 kPa.s/m²	EN 29053
Beskrivelseskode	MW EN 14303-T9(T8 if Do < 150)-ST(+)650-WS1-CL10	EN 14303

Tm (°C)	50	100	150	200	250	300	350				
λ (W/mK)	0,040	0,044	0,054	0,064	0,077	0,092	0,111				

*) ROCKWOOL ProRox isolasjonprodukter er i fullt samsvar med EN 14303. Densitet er ikke en isolasjonsegenskap, men beskriver produktets vekt pr m³.

Picture: Rockwool properties data received from Isopartner A/S (Isopartner, 2017).

Clamp

- The clamps is bought from supplier (Precisionbrand, 2017). They are delivered in packages of 10, where the weight for 10 pieces is 2,1kg. See picture below.

Bilde: Worm gear hose clamp (Precisionbrand, 2017).

References

Eagleburgmann (2017) *Sealing solutions for innovative energy production.* [Internet] Avaliable at: https://www.eagleburgmann.com/en
[Accessed: 18 may 2017].

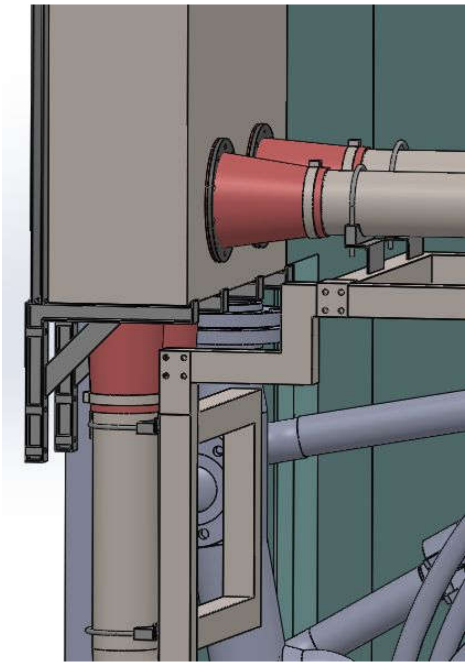
Precisionbrand (2017). *Hoseclamps.* [Internet] Avaliable at: http://precisionbrand.com/products/b224hsp-all-300-series-stainless-worm-gear-hose-clamp-11-12-14-716-clamping-diameter-pack-of-10/
[Accessed: 11 may 2017].

2.2.3 Flexible connection bleed lines duct

Our choice of flexible connection from pipe to duct needs to allow [redacted] degrees celsius and theoretically, up 70 kPa. At the duct side of the pipelines we dump the air in the duct and got some lower pressure in this area so the real pressure will be lower than 70 kPa. We got some information about a membrane solution that allows 200 kPa and [redacted] degrees celsius from EagleBurgmann. This product have some associated information for the different characteristics for the membrane composition. This datasheets we must refer to EagleBurgmann since we are not allowed to publish this datasheets (EagleBurgmann International, 2017).

To keep the system flexible regarding heat expansion we use a flexible connection to duct. We have been in contact with EagleBurgmann by mail and they sent some information about their product. Their product looks a bit different than ours but withstands temperature and movement on the same principles. The price of a flexible connection like this is just under 700 dollars. On the picture you can see the position of the four flexible connections. From information from

EagleBurgmann we see that this membrane is combined layers of fluorotex, kevlar, silaramid and alusil. It allows temperature up to [redacted] degrees celsius and allow pressure of 2 bar (EagleBurgmann international, 2017).



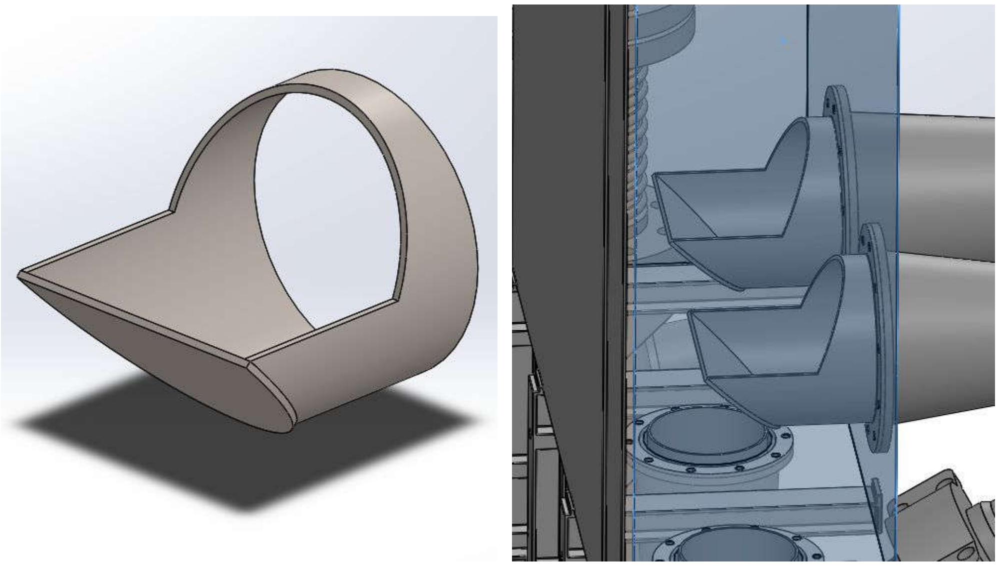
Picture: show the duct and the connected pipelines
(designed in SolidWorks of bachelor group).

References

EagleBurgmann expansion joint solutions, 2012. *KE Fabric Expansion Joints, brochure*. Available at:
https://www.eagleburgmann.com/en/products/expansion-joints/fabric-expansion-joints
[Accessed: 15 May 2017]

2.2.4 “Spoon” inside duct

For changing the direction of the air from bleed lines that is entering the duct horizontally, we placed a spoon inside the duct that helps the air in changing direction. This is a standard pipe that is cutted to custom design and welded on a plate in the end. Below we see two pictures that shows the design of the spoon and how it looks like in the assembly.

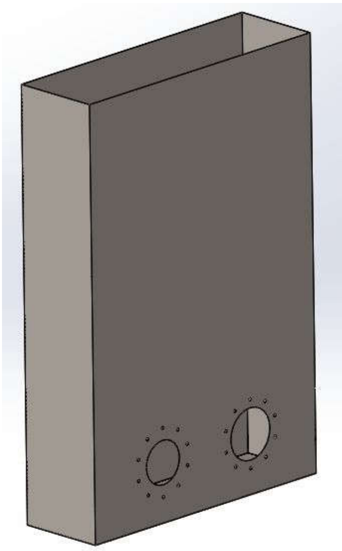


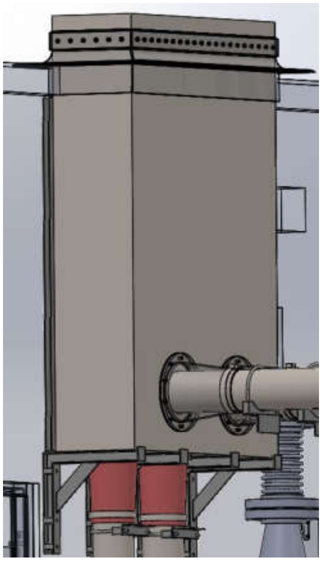
Picture: Left - shows the design of the spoon.
Right - Shows the two spoons in position in assembly.

Manufacturing this part is done by a welding company and is not a complicated task. We have been told that an estimated price is around 60 dollar per piece.

2.2.5 Duct

The duct leads the air through the roof. The duct is built of five pieces of sheet metal that are welded together. The four holes for the pipes are cutted out and the holes for the screws are drilled out from the metal sheets before welded together. The pictures below shows the design of the duct and how it is placed in the assembly.





Picture: Left - shows the design of the duct
Right - shows the duct in position in the assembly

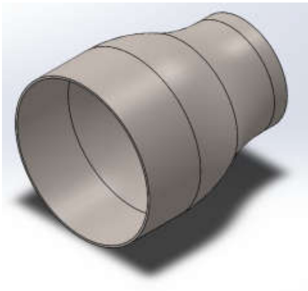
The metal sheets is 1mm thick and costs around 22 dollar and weight approximately 7,85 kg per square meter. For the duct it is needed approximately 4,2 square meter of metal sheet.

References

The Metal Store (2011). Mild Steel Sheet. [Internet] Available at:
https://www.themetalstore.co.uk/products/1mm-thick-mild-steel-sheet
[Accessed: 16 May 2017]

2.2.6 Nozzle

In concept 30 with duct the length of the bleed lines is quite short. This leads to that we can reduce the pipe diameter. When doing this we use a nozzle. We reduce the pipes from 210mm outer diameter who is the size of the valves, down to 141,3mm from valve A43, A44 and A51. The picture below shows a standard nozzle for buttweld pipelines and can be purchased from Wellgrow Industries Corporation (Wellgrow Industries Corp., 2015).



Picture: Shows the design of the nozzle used in Concept 30 (Designed in SolidWorks by bachelor group).

This nozzle will be welded on the pipes instead of a v-band that makes disassembly and assembly of the whole system more easy and timesaving.

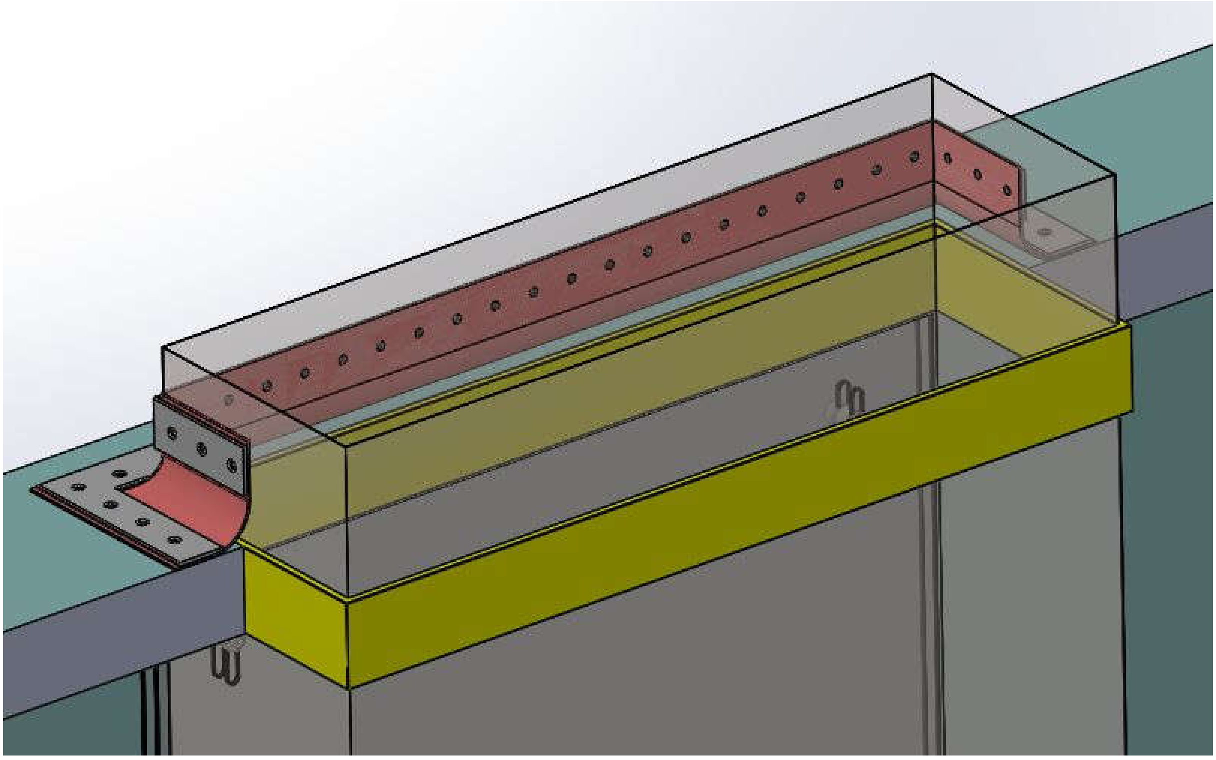
References

Wellgrow Industries Corp. (2015) *Butt Weld Pipe Fittings.* [Internet] Available at: https://lookaside.fbsbx.com/file/butt-weld-fittings.pdf?token=AWzmvOVRNJ8muvUYsx72LRfnortcpe2q-mc69jbPPjvAZE7Dv6LeSLA_4yk85-k-csWIBIV4QOz6Os3d0o7JrVTBeseqDLIPID5EgVQFCoalnkfAt-bVYdtOTQ7TK3xM7xCfr6pJknYKJaIfqLqkoT4J
[Accessed: 16 May 2017].

2.2.7 Insulation between duct and roof

For the insulation between duct and roof it is decided to use rockwool. Rockwool have good insulation characteristics and can be used in situations where the heat goes up to 750 degrees celsius (Rockwool, 2017). In this situation it is temperatures of [redacted] degrees celsius. The insulation can be stuffed in the 10mm gap around the duct so the heat to the roof is greatly reduced. This type of insulation material can be bought standard building supply stores (BM, 2017).

Picture show how the insulation is placed in the assembly.



Picture: shows the insulation material (yellow color) in place with duct transparent and silencer hided (designed in SolidWorks by bachelor group).

References

BM (2017). Glava dyttestrimmel i sekk 25mm. [Internet] Available at: http://www.byggmakker.no/produkter/trelast-og-byggevare/isolasjon/glava-dyttestrimmel-i-sekk-25mm [Accessed: 20 May 2017].

Rockwool (2017). Brannsikring av ventilasjonskanaler. [Internet] Available at: http://www.rockwool.no/produkter/brannsikring/brannsikring-av-ventilasjonskanaler/ [Accessed: 20 May 2017].

2.2.8 Sound Silencer

Dresser-Rand AS wants us to think about sound muffler regarding bleed system outlet. When doing this we have to do some research about sound muffler and the requirement of the magnitude of sound reducing effect.

Some of the aims of controlling the sound level is to reduce the risk of permanent hearing damage to an acceptable level and prevent accident risks, ensure that warning signals are clearly audible, allow communication by speech, telephone and radio (Norsok Standard S-002, Aug 2004) .

Sound Pressure and Sound Power

A sound source radiates power P and this result in a sound pressure p. This means that the sound power is the cause and the sound pressure is the effect. The relationship between sound power and sound pressure depends on the surroundings environment regarding to geometry, acoustic properties like insulation, size of room and presence of other sound sources. When measuring sound pressure this cannot necessarily quantify how much noise that will come from the machine since the sound pressure depends on the surroundings mentioned above. Sound power is more or less independent of the environment and give a better description of the noisiness of the sound source (Sound pressure and sound power, 2009).

The human ear does not respond equally to all frequencies. A human ear are sensitive to sounds in the frequency range from 1 kHz to 4 kHz. Therefore it is used filters from A to D where A is widely used and refers to a normal human ear. So when the A weighting filters is used the sound pressure levels is in units of dB(A) (Sound Power and Pressure Measurements, 2004).

The sound in this situation will use the dB(A) units, that means all sounds are in the A weighting filters which is located in frequencies between 1kHz to 4kHz.

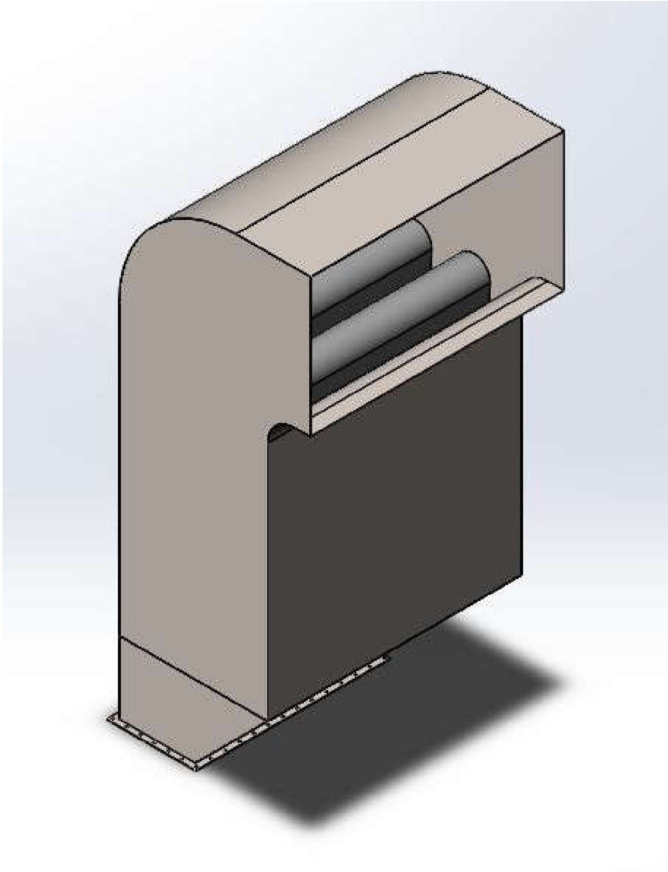
The Situation

From table received from D-R we have the magnitude of noise from bleed system. Maximum sound power is 139 dB(A) at 2000 Hz. Maximum allowed persistent noise at working area is 83 dB(A). This means that the sound must be reduced with 56 dB(A) at working areas with personnel.

By research it is mapped that a silencer that must reduce the sound in this order of magnitude we have to use some kind of industry silencer. In this situation the silencer must withstand the temperature of [redacted] degrees celsius and the amount of flow on [redacted] kg/s with all the pipes connected in one duct.

The Construction of the Muffler

It has been done a lot of research and contacting companies (Camfil, dbNoisereduction, Cullum Detuners) to get an idea of how a sound silencer in this dimension will look like and what price range it is in. We have not yet succeeded in getting a good answer to these questions so the design of the silencer is from what we have seen from other silencers from internet. Picture of the silencer is shown below.



Picture: shows the design of the silencer. Inside is the perforated element that is responsible for noise cancelling (Designed in SolidWorks by bachelor group).

At least, we received some information. It is basically the distance the sound travels in the silencer that decides the magnitude of noise reduction. So it is not only the size of the silencer but more the length or height that matters. This including the sound range, in which hertz the sound is in, is important when doing calculations on sound reduction. Combining this with magnitude of flow and temperature we approach a starting point.

The duration of this project did not gave us the total information about the sound silencer. But since this is a component that will be ordered from external company we must be satisfied with this information we got. Further research from D-R is recommended on this area.

References

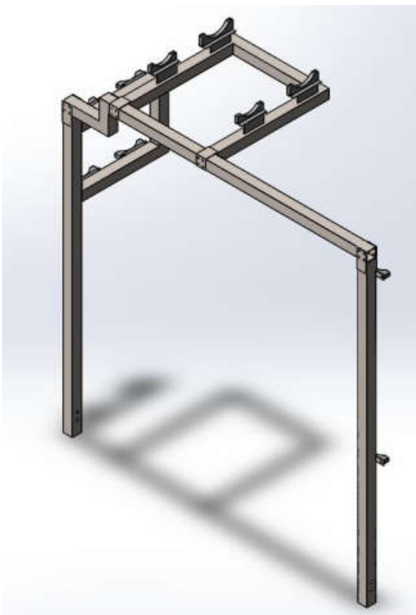
Norsok Standard S-002, Rev.4 Aug 2004, *Working environment*. Rev. 4. Standard Norge.

Sound Power and Pressure Measurements (2004). What is a decibel. [Internet] Available at: https://www3.nd.edu/~atassi/Teaching/AME%2060633/Notes/Sound%20Power%20and%20Pressure%20Measurements.pdf
[Accessed: 20 April 2017].

Sound pressure and sound power (2009). Effect and Cause. [Internet] Available at: http://www.sengpielaudio.com/SoundPressureAndSoundPower.pdf
[Accessed: 20 April 2017].

2.2.9 Frame

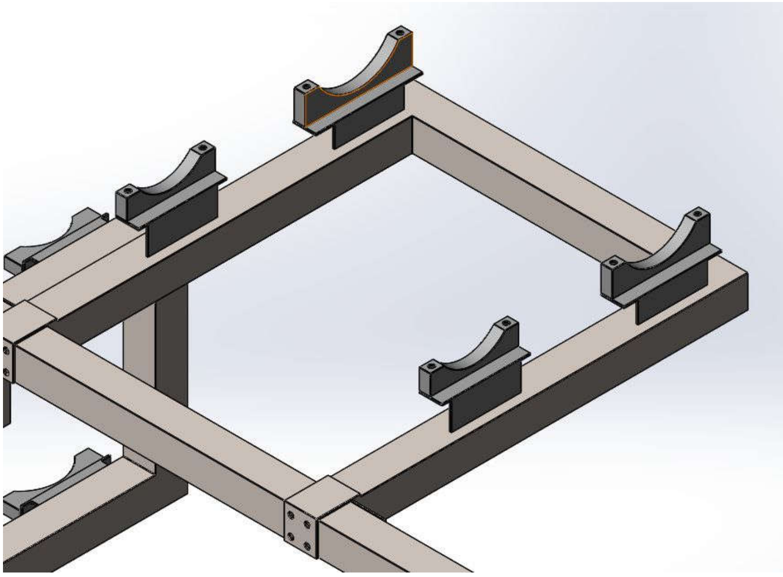
The frame consists of approximately twelve meters of rectangular steel beams. The whole set is put together of five parts because of the weight of the components can not exceed 25 kg per part. Since the frame is not a design we shall spend so much time on we haven't done any analysis of the construction that proves the strength of the design. So this design is only to show how the it can look like and we show the parts that is consists of. Picture below shows the design of the frame.



Picture: shows how the frame looks like (Designed in SolidWorks by bachelor group).

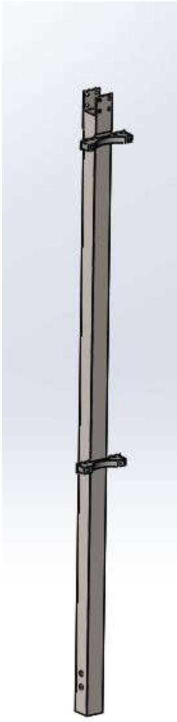
| When doing service on the turbine the bleed system and the frame for the bleed system must be disassembled. To save time when disassembling the frame we decided to weld on the

distance parts and the saddle for u-bolts on the frame. Then it just needed to disassemble the nuts from the u-bolts and move the pipelines. Picture below shows how it will look like.

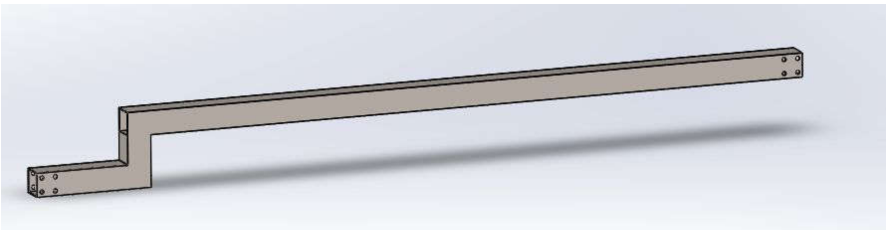


Picture: Shows the distance parts and the saddle welded to the frame part (Designed in SolidWorks by bachelor group).

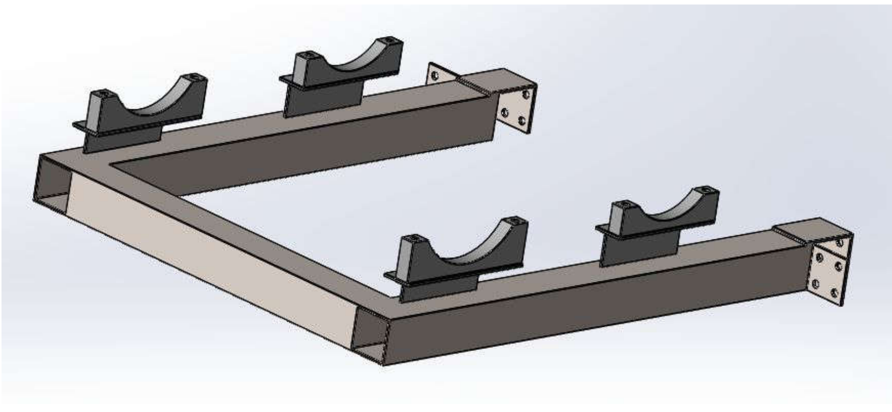
As said the frame is divided into five different parts. Pictures below shows the different parts separated from each other.



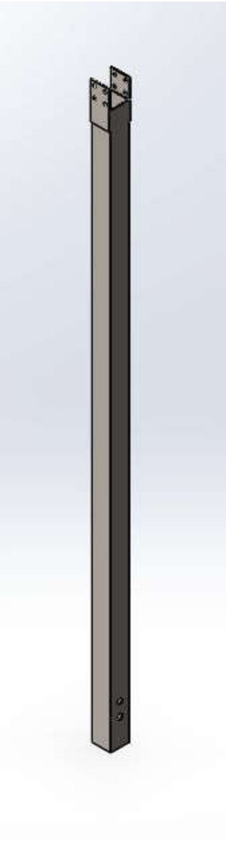
Picture: shows the frame part that holds pipeline A44 (Designed in SolidWorks by bachelor group).



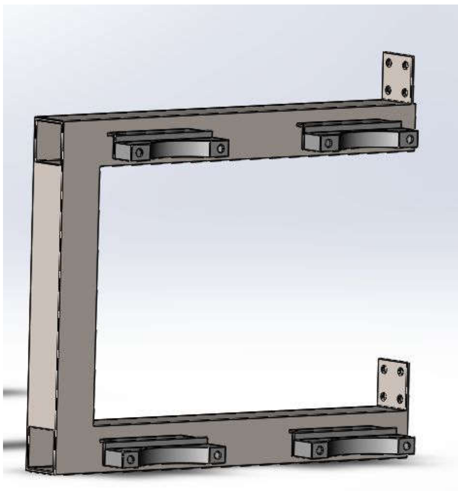
Picture: Shows the horizontal frame part that crosses over the turbine. THis part holds the frame part for A44 and A42 (Designed in SolidWorks by bachelor group).



Picture: This part holds the pipelines from valve A42 and A44 and is connected to the horizontal frame part (Designed in SolidWorks by bachelor group).



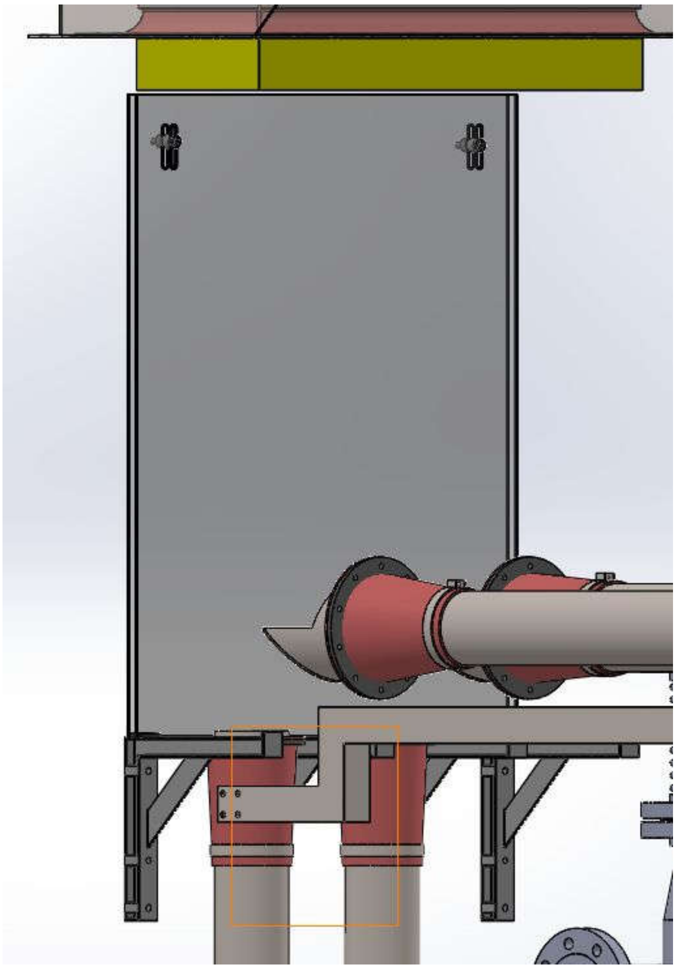
Picture: shows the vertical frame part at the A43 and A51 side (Designed in SolidWorks by bachelor group).



Picture: Shows the frame parts that holds the bleed lines from A43 and A51 (Designed in SolidWorks by bachelor group).

2.2.10 Heat shield

To prevent the heat radiation from duct to wall we decided to put two heat shield between the duct and wall. This plates is covered with reflective surface that reflects the radiation and prevents the heat from passing (Rallynuts motorsport, 2017). The metal plates is 5mm thick and approximately 1,3 square meters surface (The metal store, 2017). As seen on picture, these tho heat shields rests on the brackets for duct and have cleaves in between so the ventilation air can help to cool down.



Picture: shows the heat shield that rests on the brackets for duct. The duct is hided for better picture. The shields is fastened in the upper parts of the plates (Designed in SolidWorks of bachelor group).

References

Rallynuts motorsport (2017). Nimbus Lite Reflective Heat Shield. [Internet] Available at: http://www.rallynuts.com/heat-management/nimbus-lite-reflective-heat-shield.html [Accessed: 19 May 2017].

The metal store (2017). Mild steel sheet. [Internet] Available at: https://www.themetalstore.co.uk/products/5mm-thick-mild-steel-sheet [Accessed: 19 May 2017].