KONGSBERG

UiT NORGES ARKTISKE UNIVERSITET

Master of Science

Part A: Concept of Operations

Project: Wire Gear for Small Rotary Actuator

Contraction Authority: Kongsberg Space Systems

Rev:	Date:	Author:
16	220118	VOA

i. Abstract.

Concept of operation [1] is a document that describe the main characteristics of a system. In this case CONOPS will define the following characteristics regarding development of a wire gear small rotary actuator:

- A statement for the project/system goal and objectives.
- Which strategies, tactics and constraints that will be followed within the development process.
- A statement of involving parts, such as organizations, activities and stakeholders.
- A comprehensive iteration feasibility analysis – risk analysis.
- An initial design study will be performed to identify key requirements related to the wire gear small rotary actuator. The focus on this initial design study is to replicate the environment the wire driveline will operate in.

Stakeholders, project model, project plan, verification and validation method and system requirements are key aspect which are to be defined during this part.

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iii. Figure List

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vi. Abbreviations

APM	-	Antenna Pointing Mechanisms
CoM	-	Center of Mass
CONOPS	-	Concept of Operations
CUS	-	Customer
EREQ	-	Environmental Requirement
ESA	-	European Space Agency
KDA	-	Kongsberg Defence and Aerospace
KSS	-	Kongsberg Space Systems
LEO	-	Low Earth Orbit
QDA	-	Quick Design Analysis
QDR	-	Quick Design Review
REQ	-	Requirement
SAM	-	Supplier and manufacture
SKF	-	Svenska kulelagerfabrikk AB
SRA	-	Small Rotary Actuator
TBC	-	To be complied
TBD	-	To Be Determined
TREQ	-	Technical Requirement
UIT	-	The Arctic University of Norway
VOA	-	Vebjørn Orre Aarud
WG-SRA	-	Wire Gear Small Rotary Actuator

1. Introduction.

This Part A of the thesis will give a detailed description of the project. It will discuss the assignment, objectives, participants and more. In addition, key features such as stakeholders, requirements, risk analysis and initial design study is defined.

The main goal for this part is to give an accurate introduction to the assignment/system and provide as a foundation to Part B which is the design of a new SRA with wire driveline.

It is important to deliver an accurate introduction to the system which are to be developed. This since we would like to trace back in time when the first iteration is done. The traceability is important because its desirable to verify and validate that the right product is being build and build right.

To achieve an accurate introduction, product/system development and verification/validation of the product/system, system engineering is applied as the backbone for this thesis.

The characteristics regarding development of a wire gear small rotary actuator (WG-SRA) can be found in the following selections

- Project/systems goals and objectives in selection 1.2
- Strategies, tactics and constrains, in selections 1.5, 1.6, 1.7 and 1.8
- Involving parts in selection 1.4
- Feasibility study in selection 2
- Initial design study in selection 3
- Requirement identification in selection 4
- Initial verification and validation methods in selection 5

1.1. Assignment.

KDA division Space System have to this date one APM for downlink satellites, named KARMA 7. KARMA 7 is a full scale and "heavy" APM in use today costing €1M per unit [2].

The Bachelor thesis [3] which this master thesis builds on found that low-cost satellite systems are a new and interesting market and developed a fully functional APM prototype. With an azimuth stage with a mass of 2211.82 gram and a backlash error of ± 0.06965 deg (pointing error) [4].

Kongsberg Space Systems (KSS) wants to take the development to the next level and has suggested to keep the goals of a low cost, low mass and high performance APM. KSS by Karl Patrik Mandelin, Product Manager Antenna pointing Systems, has suggested to redesign the actuator and investigate the possibilities of wire driveline to achieve the global goal of close to zero pointing error, total actuator mass of less than 1000 gram and a total cost of €5000

Figure 1 shows a Gimbal APM where the red ring is the azimuth SRA.

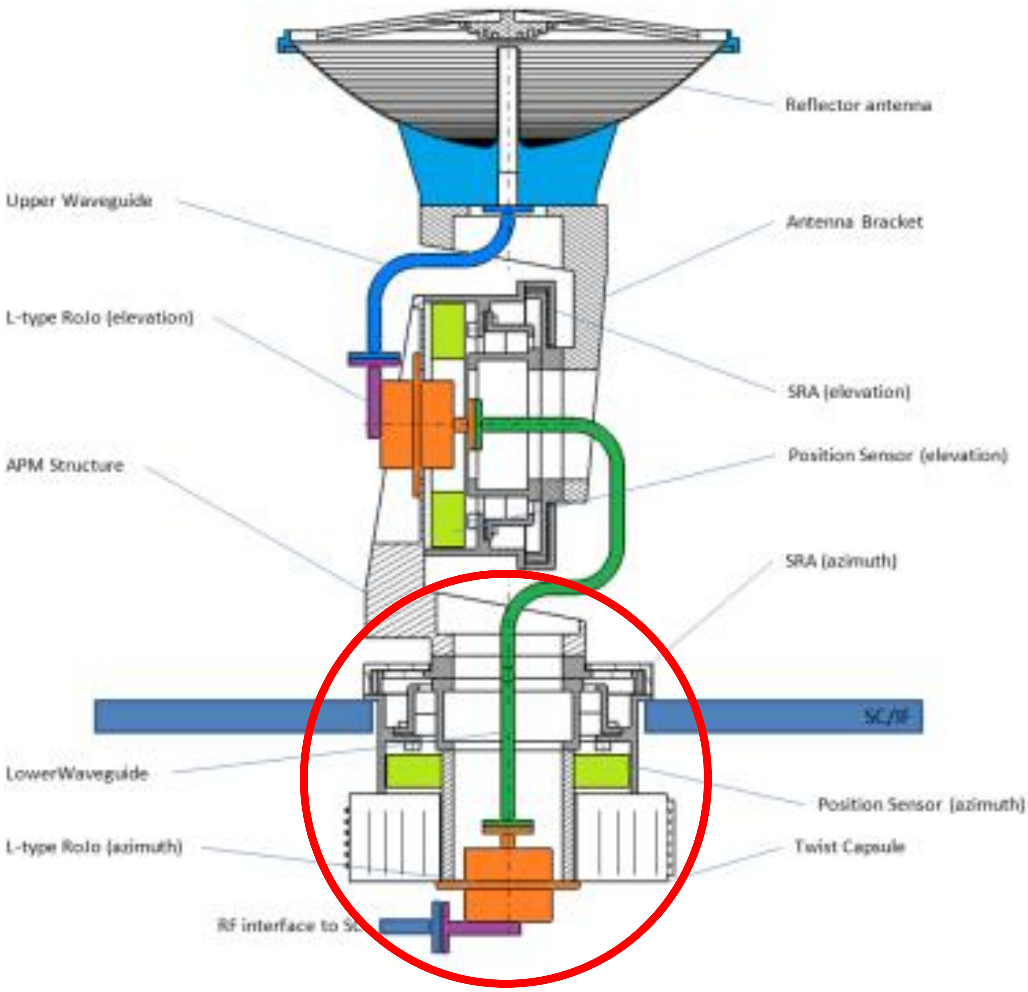


Figure 1: Gimbal APM [2].

1.2. Objectives.

This thesis aims in detail, to design and develop a wire geared small rotary actuator intendent for space usage. The main objectives are, to implement and optimize for a wire driveline and comply with all requirements for a lifetime/endurance test of 5 million cycles in vacuum. The parts, materials and system must be as accurate as possible to ensure that the right product is designed to simulate the final product.

A test report is the total goal for this thesis and should give a good insight if a wire geared SRA can be used as a solution. The test report can be found in Part C.

1.3. Kongsberg Space Systems.

Kongsberg Defence and Aerospace is one subdivision within the Kongsberg Group and one of Norway's supreme manufacture and developer of defence and aerospace related products and systems. KDA delivers systems for command and control, weapons guidance and surveillance, communication solutions and missiles and advanced composites and engineering products for aircraft and helicopter [5].

The subdivision inside KDA, Kongsberg Space Systems delivers a broad spectrum of systems and services related to space and maritime surveillance customers in more than 40 countries. This included satellite components such as SADAM for Rosetta and KARMA-5 for the BepiColombo MTM spacecraft. [6]

Figure 2 shows the BepiColombo MTM spacecraft that uses parts from Kongsberg Space Systems.

Figure 2: The BepiColombo MTM [7].

1.4. Stakeholders.

To better understand what stakeholders are in this thesis a definition is used. “Stakeholders are anyone or anything that can or have interest in the system/project which are to be developed such as companies, government, engineers and more [8]”.

Stakeholders are often categorized into 2 types of stakeholder’s, audience and presenter. Audience is stakeholders which may have devises, systems, regulations and more that can affect or interfere the system, while presenters are the buyers, users or customer that are going to be using the system [9].

In addition, these stakeholders, audience and presenter are often selected into primary and secondary stakeholders. Primary stakeholders directly affect the system and secondary stakeholders indirectly affect the system [9].

Stakeholders will therefore be marked with marks to easily identified which category they belong to with the following marks: P – Primary and, S – Secondary for the sake of tractability to requirement, tests and more.

By following this method, the following stakeholders are identified and shown in Figure 3.

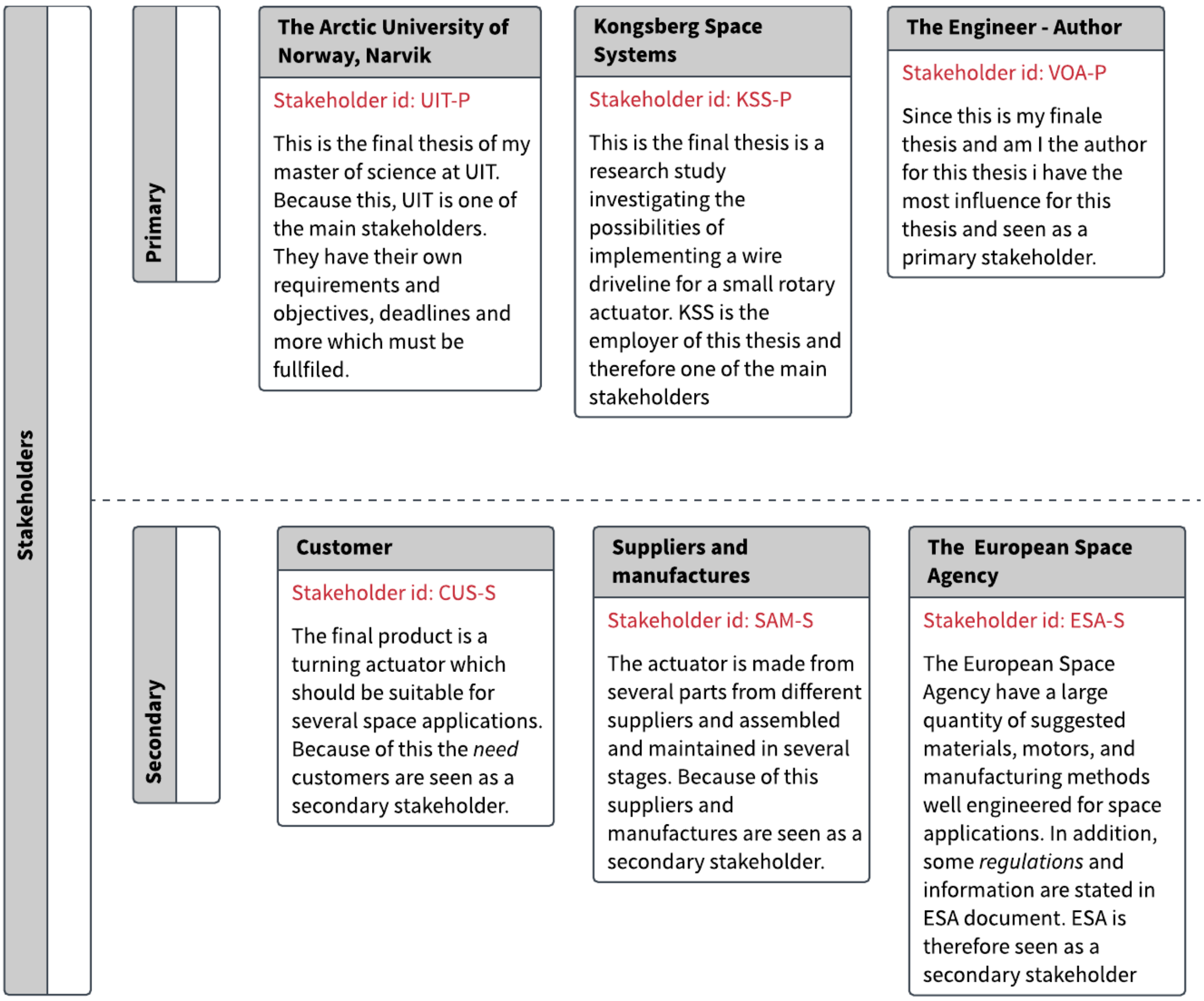


Figure 3: Stakeholders.

Each of these stakeholders are expected to influence in the project in some way, it can be technically, formal or personal. To better understand how each stakeholder, affect the project in relation to influence and interest, an interest-influence chart is made and illustrated in Figure 4. See appendix 7.1 Part A for additional information.

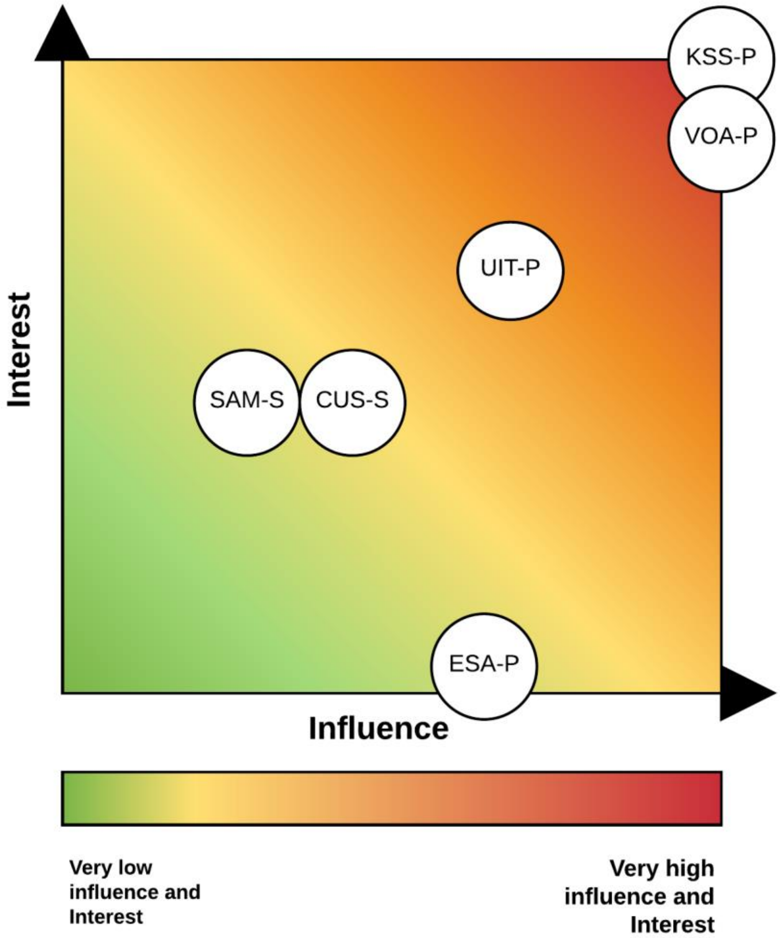


Figure 4: Interest-influence chart.

Based on the interest-influence chart, KSS, UIT, VOA and ESA are the most noticeable stakeholders in this project, and need special attention and guidance to ensure that the stakeholder is satisfied in the correct way.

In selection 4 stakeholders *need* will be translated into stakeholder's requirements and categorized accordingly to system and stakeholder's requirements.

Note that this is the first developing iteration of the SRA and its feasible to assume that stakeholder's relations (influence/interest) change during the life-cycle of the project. Even new stakeholders may be added or removed during more iterations and it's important to revisit this selection after each iteration (One iteration will be completed during this thesis).

1.5. Prerequisites.

This thesis will be written accordingly to a document standard agreement with KSS. This means that the document font, language and more is set from this agreement. Note that this standard is an oral agreement between the author and KSS.

KSS has made a budget for this thesis and is funding the prototype and parts related to the development and testing. All referred document standards and regulations provided by KSS is seen as barrowed information and is regulated by KSS only.

All figures are mainly made from lucidchart.com. [10] This is an online tool much like Visio [11] for making figures, illustrations, process drawings and more.

Major changes in the requirements/thesis given by UIT or KSS will not be accepted after the concept is selected and ready for production. Estimated 18 February 2018.

1.6. Focus areas.

The thesis description in selection 1.1 states that a wire geared small actuator is to be developed. The system will be taken apart into subsystems and focus areas. This includes both electronics, mechanics and mechatronics.

Given that a complete functional WG-SAR are to be developed some parts of the system will be excluded. An Initial design study will be performed which will focus on the external areas for the WG-SRA such as additional mass from other subsystems.

The main focus area of this thesis is to develop a wire driveline for a SRA. The SRA developed in this thesis is made only to replicate and estimate the environment the driveline will work in. Specifics will be discussed in selection 4 regarding the environment (Environmental requirements).

1.7. Project model and tactics.

The selected project model for this thesis is partly based on the famous Vee-model [12] and the framework of system engineering [13]. The model follows the top down-bottom up approach of the Vee-model and with additional tools from the framework such as QDR–Quick Design Review and QDA-Quick Design Analysis for rapid verification, validation and documentation.

The top down view of the project model translates the needs and desires into system/project requirements, while the bottom up view translate the requirements into parts and systems ending with an integration phase with testing and final verification and validation [12].

The major advantages of this kind of project model is that we break down the product/system to identify requirements, challenges or problems – even stakeholders. This gives a very clear and understandable introduction to the product which is to be developed and it's easy to trace back to its source [12].

The major disadvantages are that there is no early prototype to be build. A prototype is first build when the system/product is seen stable and ready for real-life testing and it is a very time-consuming model [12].

Note that QDR and QDA may require breadboard models and not prototypes.

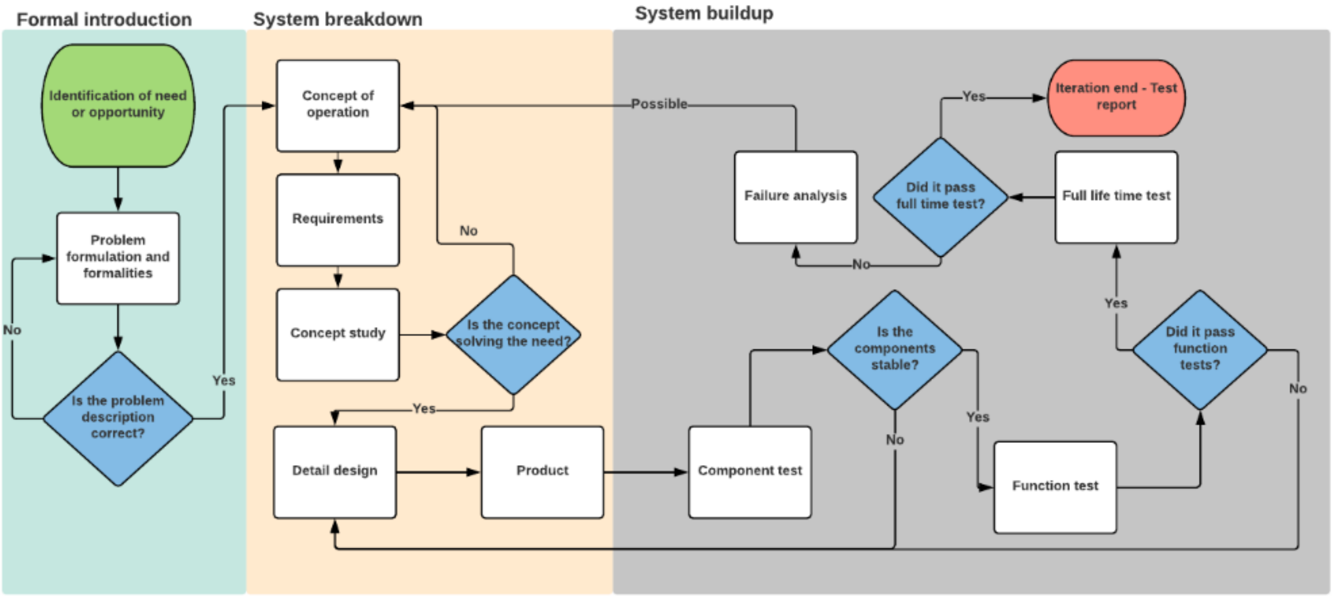


Figure 5: Project model.

Figure 5 shows the selected project model used for this project with three major fields. Formal introduction, System breakdown and System buildup. This illustrate the global process which are to be followed. The blue boxes indicate "hard" verification/validation boxes to ensure that the right product is being build and build right. Additional soft boxes are going to be used such as Pugh's selection matrix [14], and material charts to help select the right features for the product, and QDR/QDA to verify/validate solutions/systems.

Note that the hard boxes behave like a project stop, the project cannot continue before this box is solved – it is an iterative process.

1.8. Project phases, project planner and deadlines.

The Formal introduction phase is the startup for the thesis and should be quite short and concise. The goal for this phase is to establish a formal frame of the project. This includes communication, problem communication, problem description and short time iteration. It's important that the thesis is correctly made so that the right task is being solved. One hard-box is done in this phase to verify this selection.

The system brake down phase is transition from top-level to bottom level. This phase acts as the introduction to the thesis/system with following concept development. The goal for this phase is to establish the foundation for the product. This includes initial risk to estimate the feasibility of the project, initial requirement/stakeholders to generate possible concepts, development plan to ensure project traceability and progress, initial verification/validation plan and method for the concepts and an initial design study to represent the environment the wire gear shall operate. This phase ends with a detail design of the winning product and starts the transition on building up the system. One hard-box is used to verify/validate the concept study.

The final phase system build-up is the transition from bottom-level to top level. The goal for this phase is to translate all the information that was braked down in in the previous phase and build up a new system with rapid verification and validation. Several hard-boxes is used to ensure that the product meet the details, braked down in the previous phase. This phase gradually builds up the system from "on paper" product to verified/validated product. This phase ends with an iteration report – a test report.

A project planner is made to follow this process with hard-boxes and planned QRD/QDA tools. Figure 7 shows the first revision of the project planner on top-level while Figure 8 shows the first revision of formal phase and the start of the system brake down phase. The yellow vertical line shows the deadline for the phase.

Note that the parts in this thesis does not follow the project model but the thesis information. Document structure in relation to project model and project plan is illustrated in Figure 6.

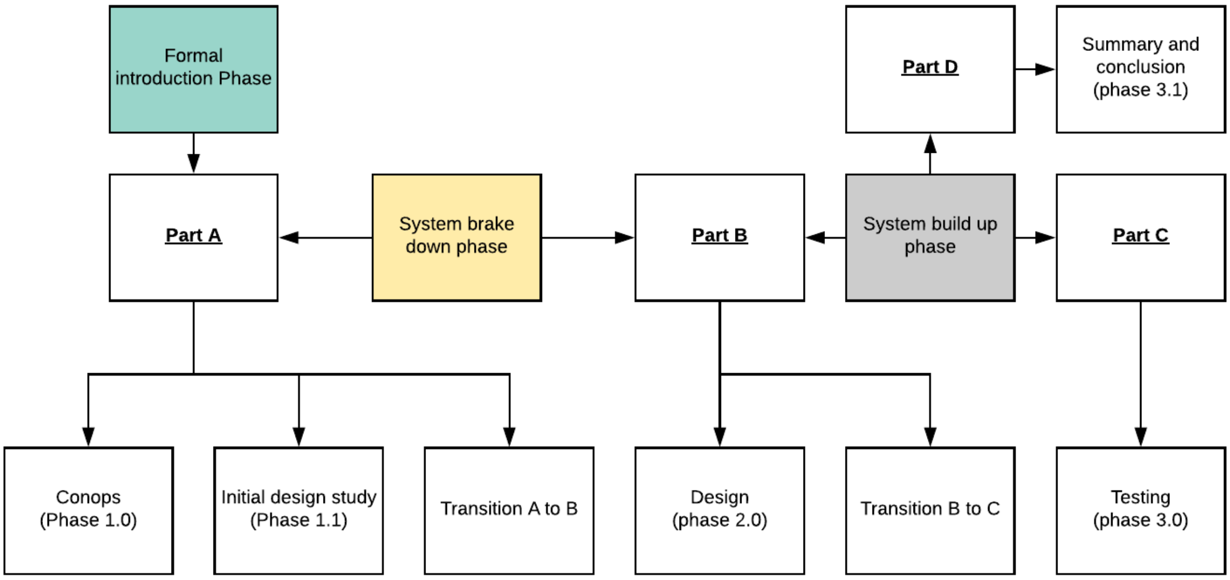
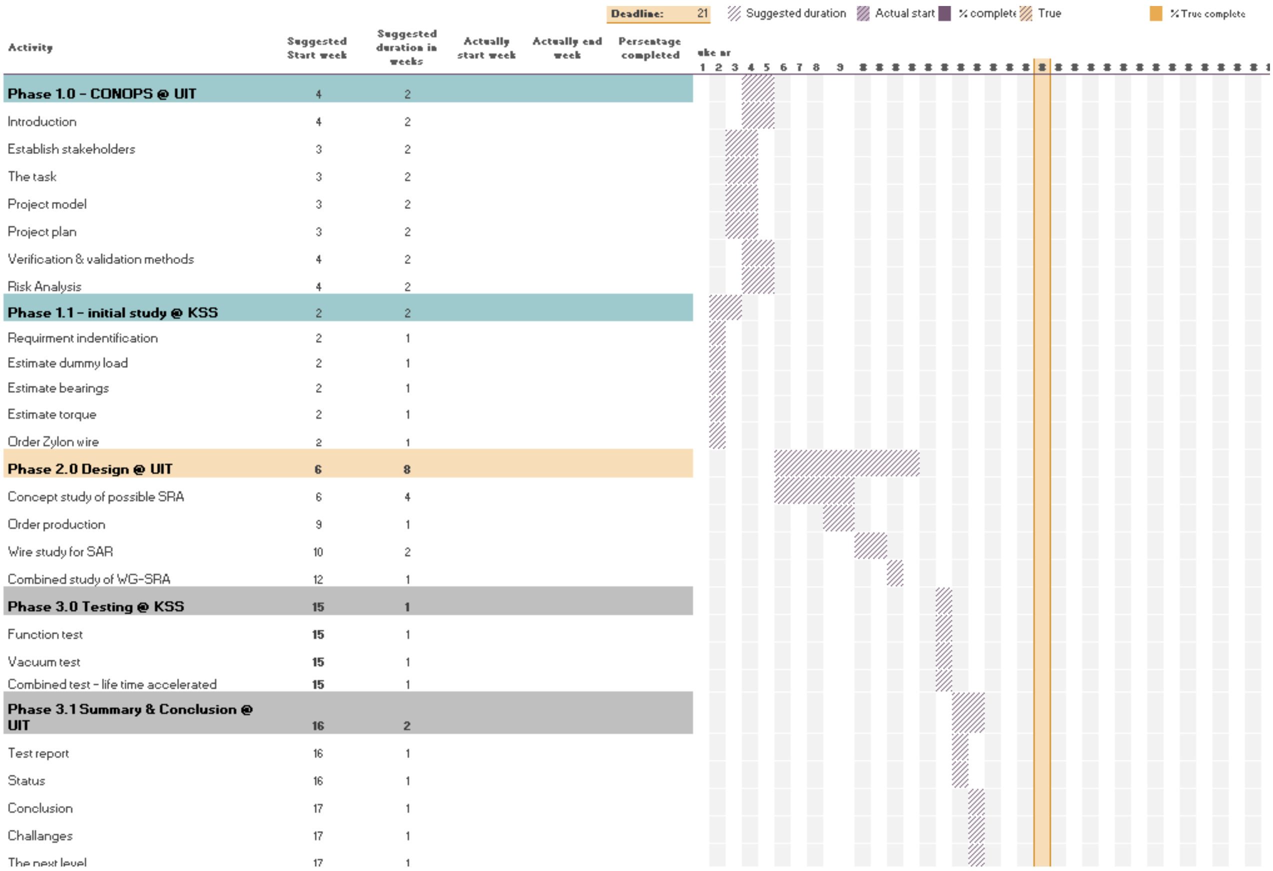
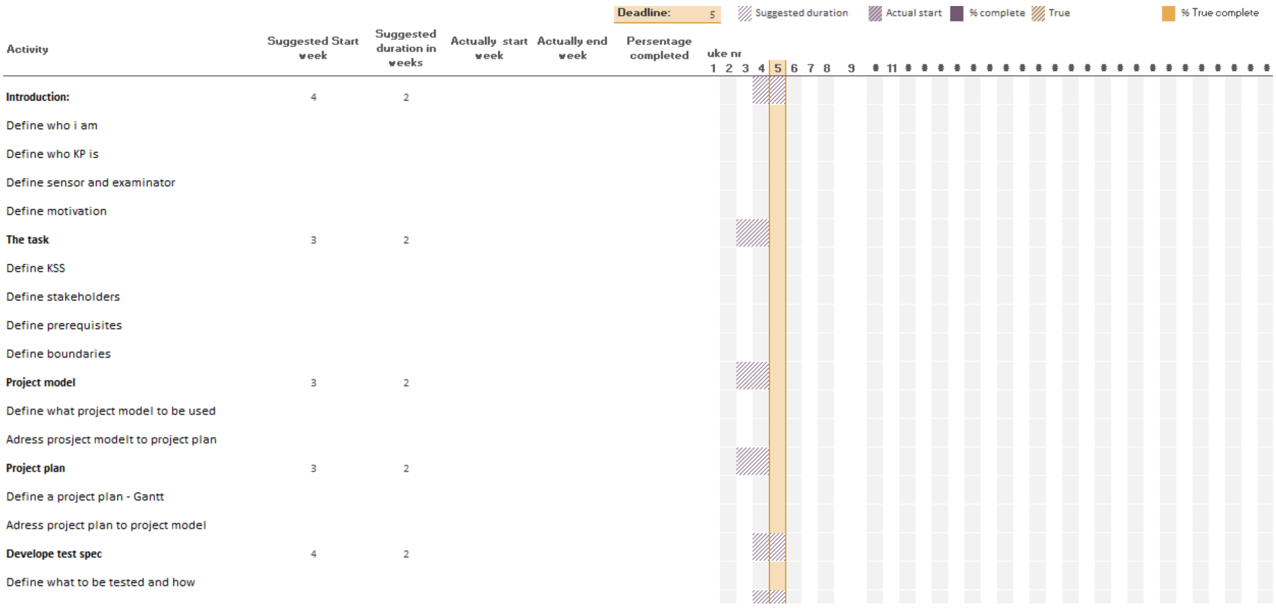


Figure 6: Document structure in relation to project model.



Activity	Suggested Start week	Suggested duration in weeks	Actually start week	Actually end week	Persentage completed
Phase 1.0 – CONOPS @ UIT	4	2			
Introduction	4	2			
Establish stakeholders	3	2			
The task	3	2			
Project model	3	2			
Project plan	3	2			
Verification & validation methods	4	2			
Risk Analysis	4	2			
Phase 1.1 – initial study @ KSS	2	2			
Requirment indentification	2	1			
Estimate dummy load	2	1			
Estimate bearings	2	1			
Estimate torque	2	1			
Order Zylon wire	2	1			
Phase 2.0 Design @ UIT	6	8			
Concept study of possible SRA	6	4			
Order production	9	1			
Wire study for SAR	10	2			
Combined study of WG-SRA	12	1			
Phase 3.0 Testing @ KSS	15	1			
Function test	15	1			
Vacuum test	15	1			
Combined test – life time accelerated	15	1			
Phase 3.1 Summary & Conclusion @ UIT	16	2			
Test report	16	1			
Status	16	1			
Conclusion	17	1			
Challanges	17	1			
The next level	17	1			

Figure 7: Project planner.



Activity	Suggested Start week	Suggested duration in weeks	Actually start week	Actually end week	Persentage completed
Introduction:	4	2			
Define who i am					
Define who KP is					
Define sensor and examinator					
Define motivation					
The task	3	2			
Define KSS					
Define stakeholders					
Define prerequisites					
Define boundaries					
Project model	3	2			
Define what project model to be used					
Adress prosject modelt to project plan					
Project plan	3	2			
Define a project plan - Gantt					
Adress project plan to project model					
Develope test spec	4	2			
Define what to be tested and how					

Figure 8: Project planner detailed.

2. Risk Analysis.

Risk management is an important part of developing a new system or product. A good risk management can early provide information on how feasible the product/system is and can give good strategies to handle upcoming or surprising cases. The goal for this first iteration of risk management is to identify cases that can occur and find a mitigation strategy.

The following process [15], shown in Figure 9 is used during the risk management.

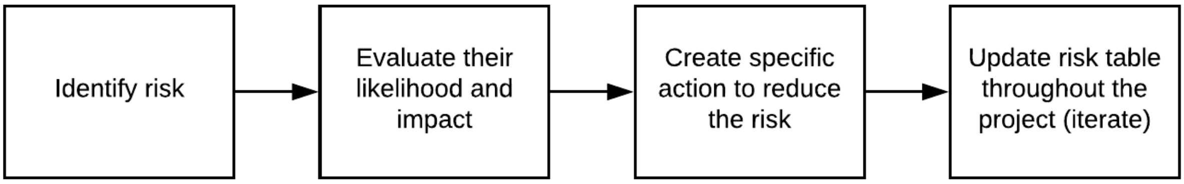


Figure 9 : Risk managment process.

2.1. Risk Analysis Explanations

Each case in the risk management will be rated accordingly to the following, Table 1 and

Table 2.

Table 1: Likelihood explanation.

Probability	Explanation
5	>90 %
4	>80 %
3	>50 %
2	>20 %
1	<20 %

Table 2: Impact explanation.

Impact	Explanation
5	Can major impact on the system/project – very high impact
4	Can cause large delays/problems for the system/project – high impact
3	Can cause small delays/problems for the system/project – medium impact
2	Need to be sorted if the case occurs – small impact
1	Minor bump – no real impact, very small impact

After the cases has been addressed to its likelihood and impact a risk matrix is used to obtain the total risk of the case. Total Risk matrix for this system is shown in Figure 10. With the following explanation for this first iteration.

Table 3: Risk level explanations.

Risk level	Explanation
20-25	Unacceptable. Measures must be take to eliminate the risk
15-19	Unacceptable. Measure shall be take to eliminate the risk
8-14	Unacceptable. Measures should be take to eliminate
4-7	Acceptable. Measures should still be take to eliminate the risk
3	Acceptable. Measures may be take to eliminate the risk
0-2	Acceptable. No mitigation needed

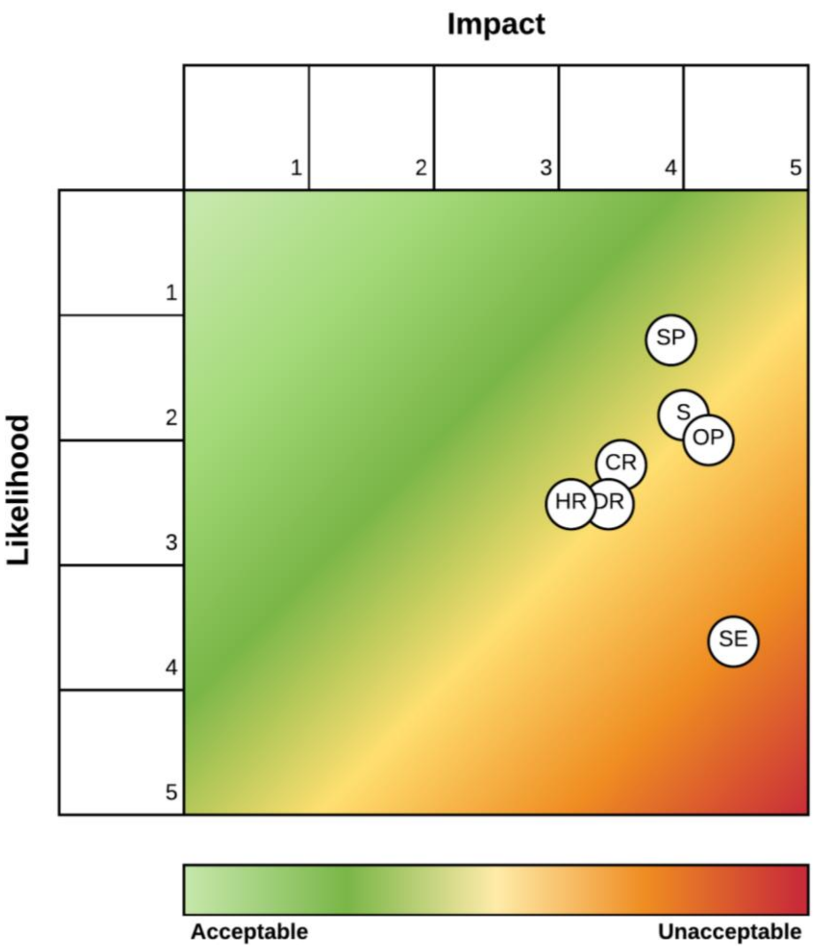


Figure 10: Risk Matrix.

For this first risk iteration the following risk was obtained:

Table 4: Risk results.

Risk:	**Disc code:**	**Risk value**	**Note:**	**Mitigation**
Space Environment	SE	16.4	Unacceptable and measures shall be taken to eliminate the risk	Follow mitigation plan, Table 14: Space Environment Risk
Operation Risk	OP	8.8	Unacceptable and measures should be taken to eliminate the risk	Follow mitigation plan, Table 15: Operation Risk
Human Resources	HR	6.3	Acceptable. Measures should be taken to eliminate the risk	Follow mitigation plan, Table 20: Human Resources risk
Development Risk	DR	8.3	Unacceptable and measures should be taken to eliminate the risk	Follow mitigation plan, Table 19: Development risk
Cost Risk	CR	8.0	Unacceptable and measures should be taken to eliminate the risk	Follow mitigation plan, Table 16: Cost Risk
Schedule Risk	S	7.3	Unacceptable and measures should be taken to eliminate the risk	Follow mitigation plan, Table 17: Schedule Risk
Safety Risk	SP	5.0	Acceptable. Measures should be taken to eliminate the risk	Follow mitigation plan, Table 18: Safety risk
Project risk (Not on figure)		8.6	Unacceptable and measures should be taken to eliminate the risk	

This initial risk management indicates that the project status is unacceptable, and measures should be taken to eliminate the risk. Based on experience, risk management in the first iteration is more to gather information than telling how feasible the project is. This result tells us that there are some challenges that should be dealt with. This is seen as feasible since very little engineering work have been executed. It’s feasible to obtain an acceptable level of risk at the end of this thesis because of this.

See appendix 7.2,Table 14,Table 15,Table 16,Table 17,Table 18,Table 19 and Table 20 for detailed information.

3. Initial design study.

An initial design study is preformed because the SRA connect with other subsystems. These systems normally define the transition from azimuth stage to elevation stage. The major factor that must be estimated for these subsystems are, mass and center of mass. The results from these systems provides information on what bearing that can be used and how this bearing behave under the given preload. The objective for this study is to have information on what momentum is needed to drive the system.

Note that to design the system a system need to exist. Example the natural frequency of the system is needed to calculate the acceleration in vacuum, but there exist no systems. Therefore, all calculations below are estimates and must be verified/validated/adjusted when the first iteration is completed.

The process for this initial study is illustrated in Figure 11.

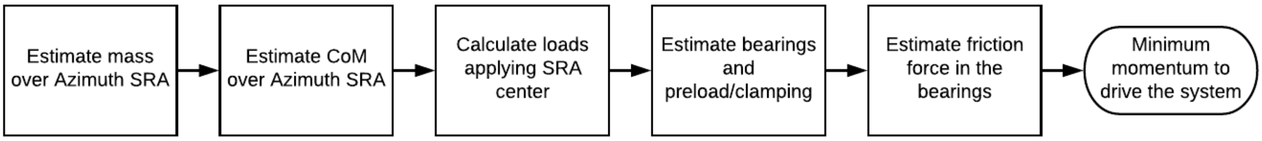


Figure 11: Initial design process.

3.1. Estimated dummy load.

Figure 12 shows an overview of the estimated masses over the SRA. With the following predictions.

The total mass of the antenna, motor, gears and more for the APM developed by SSM was approx. 800g, and the transition – called parabola assembly, having a mass of approx. 815g. Ending up with approx. a total mass of 1615g over the azimuth SRA. [16]

To simplify the new system a gimbal situation is selected and applied much like the APM seen in Figure 1. The total mass over azimuth SRA is therefore estimated to 1450g, which seems feasible with a new and lighter SRA in the elevation stage. (same SRA which are to be developed is going to be used in the elevation stage but scaled down)

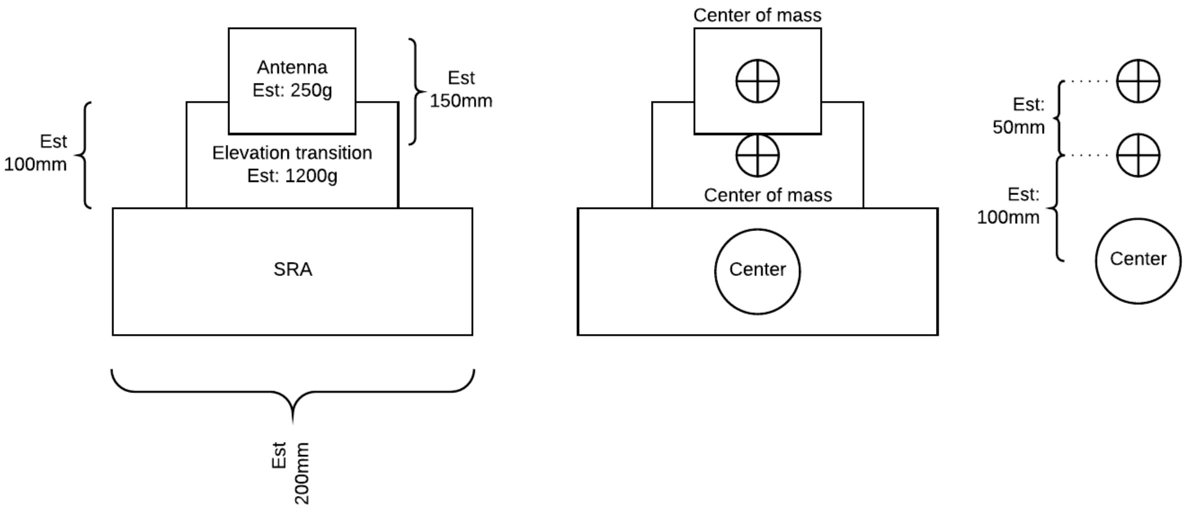


Figure 12: Mass overview - initial design.

Based on these preconditions, we obtain the following center of mass (CoM) for the system above the azimuth SRA illustrated in Figure 13.

For *x* coordinates following equation applies

$$x = \frac{m_1 \cdot x_1 + m_2 \cdot x_2}{m_1 + m_2}, \quad (1)$$

where m_1 and x_1 represent the mass and offset of transition, and m_2 and x_2 represent the mass and offset of antenna. This gives the following x coordinate

$$x = \frac{1200 \cdot 0 + 250 \cdot 0}{1200 + 250} = 0 \text{ mm, which is correct.}$$

For *y* coordinates following equation applies

$$y = \frac{m_1 \cdot y_1 + m_2 \cdot y_2}{m_1 + m_2}, \quad (2)$$

where m_1 and y_1 represent the mass and offset of transition, and m_2 and y_2 represent the mass and offset of antenna. This gives the following y coordinate

$$y = \frac{1200 \cdot 100 + 250 \cdot 50}{1200 + 250} = 91.4 \text{ mm}$$

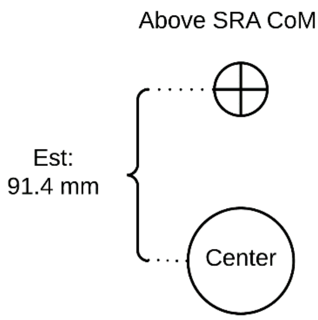


Figure 13: Center of Mass over azimuth SRA.

This implies that the system needs a dummy mass of 1450g with an offset (CoM) of 91.4 mm in *y*-direction.

3.2. Estimated Forces.

To estimate forces applying in the center of the SRA some engineering judgment is applied in collaboration with KSS. A reference bearing from SKF is selected: W63806.

In low earth orbit (LEO) no g-force is applied to the system. The dominant working acceleration during the systems life cycle is *"live"* during launch, but not discussed in this thesis. However random vibrations can replace the known g-force on Earth in LEO environment by applying Miles equation. [17] Miles equation estimate the acceleration caused by the random vibration of the particles i.e the mass.

$$G_{\mathrm{rms}} = \sqrt{\frac{\pi}{2} f_{\mathrm{n}} Q [ASD_{\mathrm{input}}]}, \tag{3}$$

where f_n is the natural frequency of the system, Q is the amplification factor and ASD_{input} the input acceleration spectral density.

The following specification given by KSS is set as the values for Miles equation. The worst case natural frequency of the system f_{n} is set to 140 Hertz, amplification factor Q to 10 and input acceleration spectral density to 1.5.

This gives an acceleration of $G_{\mathrm{rms}} = 57.4 \ \mathrm{m/s^2}$.

Figure 14 shows the forces acting in the system. To calculate F_1 and F_2, Newtons laws of motion is applied. Note that when using Miles equation, the calculated value must be multiplied with 3 during design in order to include 3σ maximum level.

Following values for F_1 and F_2 was estimated $F_1 = 250$ N and $F_2 = 250$ N

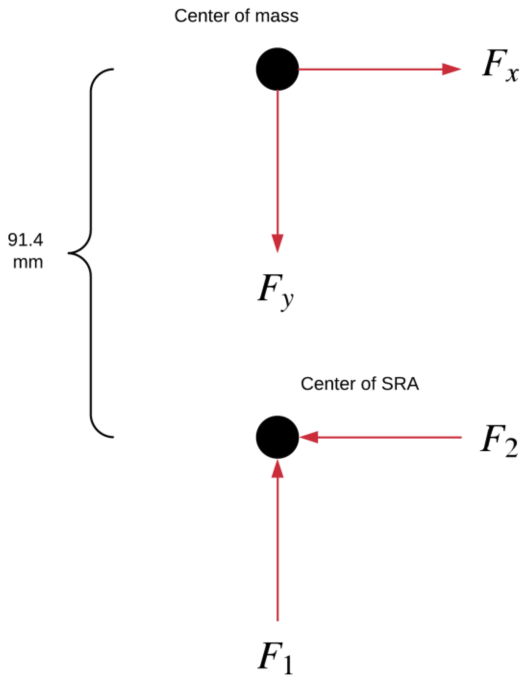


Figure 14: Force overview.

To estimate what loads that applies for the bearing, a bearing placement is estimated 20mm above center of the SRA as shown in Figure 15. The interesting force in this setup is the radial force F_b which was estimated to 1140 N. Detailed calculations can be found in 7.3, Table 21.

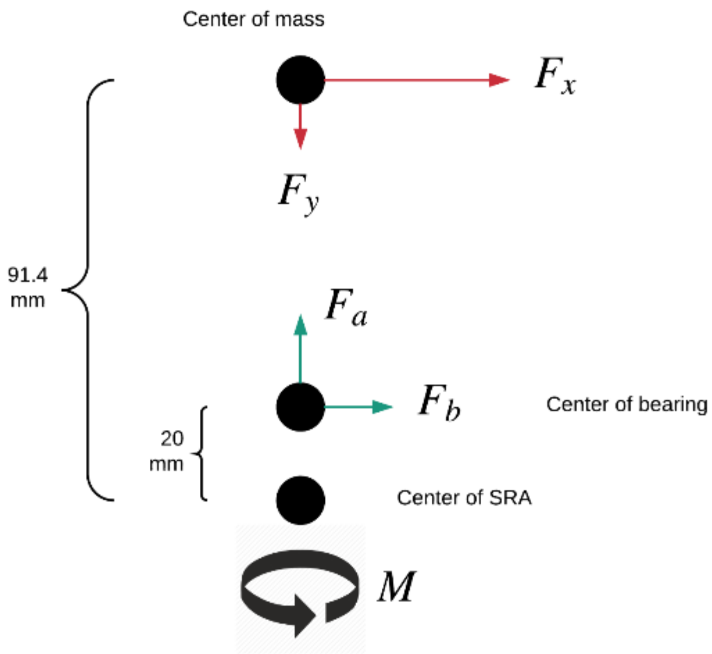


Figure 15: Bearing forces.

3.2.1. Preload.

To ensure that the system behaves correctly a preload must be applied to the bearings. The purpose of this preload is to keep the bearings in position during random vibration in LEO calculated with Miles equation, especially the resulting force in radial direction since it is much greater than the axial force.

If the bearing is not preloaded correctly the result can be huge pointing error due to low rigidity or too high torque friction.

To estimate the preload with the selected reference bearing, maximum contact stress between the ball and the bearing house is calculated. The largest contact stress allowed is found by the maximum static load C_0 for the selected bearing.

Note that this formula is for ball versus a flat plate and not a ball with a guided half sphere curve as normally seen in ball bearings. This is selected for simplification reasons.

The following formula gives the contact stress: [18]

$$P = \frac{1}{\pi}\left(\frac{\frac{6F}{N}{E^*}^2}{R^2}\right)^{\frac{1}{3}}, \tag{4}$$

where F is the load applied, E^* is the combined elastic modulus, R the radius of the ball and N number of balls in the bearing. In this case we have the following resulting contact stress (Hertzian stress) at maximum static load on each ball:

$$P_{\max} = \frac{1}{\pi}\left(\frac{\frac{6C_0}{N}{E^*}^2}{R^2}\right)^{\frac{1}{3}} = 3648.8 \text{ MPa}. \tag{4.1}$$

Based on experience at Kongsberg Space Systems, the suggested contact stress should be between 0.25−0.35 of the maximum contact stress, and suggested a factor of 0.35 to ensure correct lifetime. By applying this factor to equation 4 with $P = P_{\max}$ and solving for F, we obtain the given preload for the system. Note that the contact stress P is proportional with the force applied $F^{\frac{1}{3}}$.

$$3648.8 \cdot 0.35 = \frac{1}{\pi}\left(\frac{\frac{6F}{N}{E^*}^2}{R^2}\right)^{\frac{1}{3}} \tag{4.2}$$

$$F = 132 \text{ N}$$

The system must be preloaded axially with a preload of 132 N with the selected reference bearing.

This implies that the forces acting in the bearing are $F_a = 250$ N (axial) $+ 132$ N preload $= 382$ N and $F_b = 1150$ N

Detailed calculations can be found in appendix 7.3, Table 22

3.3. Estimated bearing.

To obtain a more optimized bearing that is suitable for this system some bearings with a bore of 30mm from SKF is analyzed in an Excel document with parameters from SKF bearing calculator with the following results. Note that the axial load increases with preload and therefore different (appendix 7.4, Figure 18.)

Table 5: Bearing investigation.

Feature:	**Units**	**SKF 16006**	**SKF 61806**	**SKF 6006**	**SKF 61906**
Max Contact stress	MPa	3856.1	3806.5	4056.8	3924.3
Preload	Newton	334.4	131.9	337.65	207
SKF Total Frictional Moment	Newton millimeter	61.3	74.4	60.4	57.6
Bore	millimeter	30	30	30	30
Diameter	millimeter	55	42	55	47
Thickness	millimeter	9	7	13	9
Mass	Kilogram	0.089	0.025	0.12	0.049
Load Accepted	OK/Fail	OK	OK	OK	OK
Life Cycle Accepted	OK/Fail	OK	FAIL	OK	OK

All bearings except SKF 61806 is suitable for the SRA, however SKF 61906 has the lowest mass and lowest total frictional moment of the passing bearings. SKF 61906 is therefore selected as the bearing for this SRA.

Note that SKF provides engineered bearings for special use, these bearings may be more suitable but no data available. This is also an iterative process and more optimizing and analyzing should normally be executed. Detailed Excel sheet can be found in appendix 7.4, Figure 18.

Based on Table 5 and selected bearing, the system need to provide a minimum of 57.6 Nmm torque to overcome the friction in the bearing. Kongsberg Space System want to multiply this torque with 3 to adjust for worst case and uncertainties. Thus, total torque to overcome friction for this system is therefore 172.8 Newton millimeters – 0.1728 Newton meter for each bearing.

3.4. Initial Requirement identification.

The following requirements was generated during initial design.

- The driveline must overcome the friction in the SRA estimated to 0.1728 Nm for each bearing.
- The SRA must use SKF 61906 ball bearings.
- The SKF 61906 ball bearing must be axially preloaded with 207 Newton.
- The mass over azimuth SRA most not be higher than 1.450 kg.
- The center of mass must be concentric with SRA center of mass.

4. Requirement identification.

Based on the previous chapters in this Part A. Project requirements can be obtained by translating the voice of the stakeholder into engineering characteristics. In addition to the requirements generated in selection 3. Figure 16 shows an example on how this voice of translating is executed.

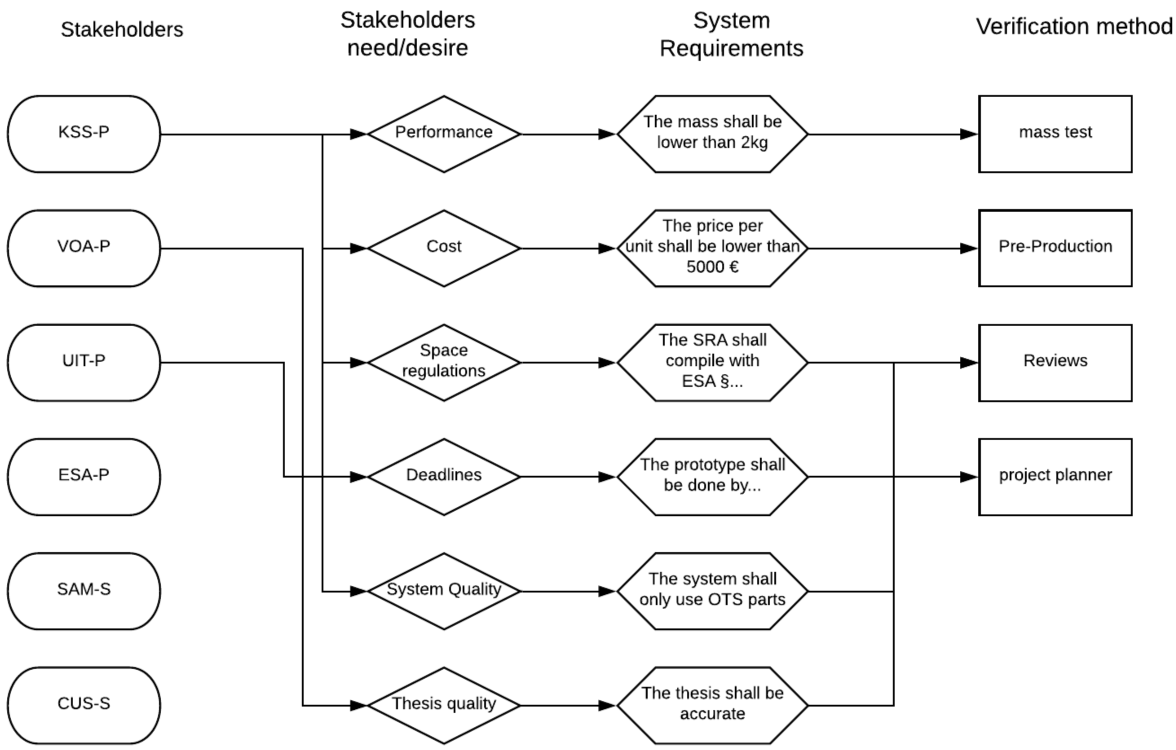


Figure 16: Voice of translating.

4.1. Requirements

In terms of the requirements setups some guidelines are created and followed. The requirements in requirements specification is divided into, environmental requirements, technical requirements and thesis requirements with the following designations, EREQ, TREQ and REQ. The following guidelines that are to be followed are:

Table 6 : Requirement guidelines.

Requirement grade based on owner:	
A	The owner is very important
B	The owner is important
C	The owner is not that important

How important is the requirement to the system stability:	
A	Needed for stability
B	Plausible needed for stability
C	Not needed for stability

How is the requirement going to be validated/verified:	
T	By Test
A	By Analysis
R	By Review

Example requirement over guidelines:

Table 7: Requirement example.

Nr:	Requirement	Class	Originator	Verification method	Evaluated	Compliance status
TREQ-1	The SRA must have a hollow shaft with internal diameter of 30.00mm or more.	AA	KDA	AR	TBD	TBD

Observe that the requirement is a technical requirement with requirement ID TREQ-1 and class of AA, meaning that the requirement is very important with respect to a major stakeholder (originator) and stability of the system. The requirement can be verified by both analysis or review. In the evaluation post it states TBD meaning that where the requirements are to be verified is not determined. The compliance post states if the requirement is compiled or not. In this case no verification method is applied and is to be determined.

Table 8, Table 9 and Table 10 display the initial requirements for this thesis/system. All requirements graded with an A should be obtain for a feasible system for this iteration.

Table 8: Environmental Requirements.

Nr:	**Requirement**	**Class**	**Owner**	**Verification method**	**Evaluated**	**Compliance status**
EREQ-1	The system shall be able to operate at interface temperatures between [-25, +65] ºC	AA	KDA	AR	TST-1 Part B, selection 3.6	**Partly acceptable.**
EREQ-2	The system shall tolerate temperatures between [-25, +65] ºC while not operating	AA	KDA	AR	TST-1 Part B, selection 3.6	**Partly acceptable.**
EREQ-4	The system shall withstand the radiation levels in LEO without degradation.	AA	KDA	R	TST-3 Part B, selection 3.6	**Passed**
EREQ-6	The system shall be compliant with ESA standards for vacuum.	AA	VOA	AR	TBD	TBD
EREQ-7	The SRA shall withstand 10 years in LEO environment	AA	KDA	T	TST-6 TBD	TBD

Table 9: Thesis Requirements.

Nr:	**Requirement**	**Class**	**Owner**	**Verification method**	**Evaluated**	**Compliance status**
REQ-1	The thesis shall compile with thesis description	AC	UIT	R	TBD	TBD
REQ-2	The thesis shall be delivered 11.06.18	AC	UIT	R	TBD	TBD
REQ-3	The thesis shall be delivered by Wiseflow	AC	UIT	R	TBD	TBD
REQ-4	The thesis shall be delivered with UIT standard front page	AC	UIT	R	TBD	TBD

Table 10: Technical Requirements.

Nr:	**Requirement**	**Class**	**Owner**	**Verification method**	**Evaluated**	**Compliance status**
TREQ-1	The SRA must have a hollow shaft with internal diameter of 30.00mm or more.	AA	KDA	AR	TST-7 Part B, selection 3	**Passed**
TREQ-2	Pointing error measured at the output shaft of the drive mechanism shall be less than 0.02 deg.	AB	KDA	TAR	TST-8 Part B, selection 5.5	**Partly passed**
TREQ-3	The mass of the SRA shall be less than 1.0 kg	AB	KDA	AR	TST-9 Part B, selection 5.1	**Passed**
TREQ-4	The SRA shall withstand 5000000 cycles	AA	KDA	T	TST-10 Part C, selection 4	**Still going on.**
TREQ-5	The motors shall have a maximum power consumption of 8 W, TBC	AA	VOA	AR	TST-11 Part B, selection 3.1	**Passed**
TREQ-6	Production post shall be less than 5,000 €	AC	KDA	R	TST-12 Part B, selection 5.7	**Passed**
TREQ-7	The SRA Shall have a limited stroke with physical end stops configurable up to minimum 380 deg	AB	KDA	AR	TST-13 Part B, selection 6	**Passed**
TREQ-8	The SRA shall be able to reach a maximum speed of 90 deg/s	AB	KDA	AR	TST-14 Part B, selection 5.4	**Passed**
TREQ-9	The SRA shall be able to accelerate from 0-90 deg/s within 0.5 seconds	AB	KDA	AR	TST-14 Part B, selection 5.4	**Passed**

TREQ-10	It must be able to adjust the tension in the wire	AB	KDA	T	TST-15 Part B, selection 6	**Passed**
TREQ-11	A loadcell has to be implemented to the design with the wire.	AC	KDA	R	TBD	**Passed**
TREQ-12	The drive line must shall the friction in the SRA estimated to 0.1728 Nm	AA	VOA	TA	TST-16 Part B, selection 6	**Passed**
TREQ-13	The SRA shall use SKF 61906 ball bearing	AA	VOA	R	TBD	**Passed**
TREQ-14	The use SKF 61906 ball bearing shall be preloaded with 207 Newton	AA	VOA	AR	TST-17 Part B, selection 3	**Passed**
TREQ-15	The mass over azimuth SRA most not be higher than 1.450 kg	AB	VOA	AR	TST-18 TBD	**Not evaluated**
TREQ-16	Motorization according to ECSS-E-ST-33-01C shall be satisfied.	BB	VOA	R	TBD	**Passed**

5. Initial verification and validation methods.

Initial verification and validation will ensure that the system, at the end of the thesis meets the initial requirements set for this product/thesis. Verification methods can be done by testing, analysis or review. Recall that each requirement has a designated verification method.

Example:

Table 11: Verification example.

TREQ-10	It must be able to adjust the tension in the wire	AB	KDA	T	TBD	TBD

TREQ-10 is owned by KDA and is needed for stability of the system. This requirement can only be verified by testing.

In addition to verify the system at the end, some QDR and QDA methods are used and explained in Table 12.

Table 12: QDR and QDA.

QDR	QDA
A quick design review is done rapidly when needed. Example, when designing the bearing house, a QDR can be executed to ensure that the house can fit the bearings. No documentation is needed for QDR's.	A Quick design analysis is done rapidly when needed. Example when estimating the gear ratio in relation to bearing friction and motor selection, a QDA can be done by a simple simulation to ensure that the gear ratio is correct. No documentation is needed for QDA's

QDR and QDA is not seen as verification/validation method but guidelines to design correctly.

All tests for verification and validation can be found in appendix 7.5.

6. References

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7. Appendixes

7.1. Interest-Influence Matrix Calculations

The matrix shown in Table 13 illustrate all stakeholders with respect to interest and influence score – coordinates. A stakeholder can obtain a score of 1 up to 10, illustrating how the stakeholder affect the project, where 10 indicates huge interest and influence and 1 very low interest and influence. Each score-set behaves like a point. Scores illustrated in Figure 17.

Very low interest – dose not following the project							Very high interest – dose closely following the project		
1	2	3	4	5	6	7	8	9	10
Very low influence – dose not affect the project significantly							Very high influence – dose affect the project significantly		

Figure 17: Score rating.

KSS is the employer of this task and described as a primary stakeholder because of its relation to the task. By interviews and meetings KSS empathize huge interest for redesigning the SRA that are being developed an obtain a score of 10/10. For the same reason KSS obtain a score of 10/10 within influence with a total coordinate-score of 10,10.

UIT is the second “employer” of this task and described as a primary stakeholder. UIT is not the technical stakeholder, moreover the formal one. UIT regulates formalities such as start/deadlines, supervisor, basic equipment and will grade this thesis. UIT obtain a score of 6/10 for both interest and influence because of this reason with a total coordinate-score of 6,6.

VOA is the author of this thesis and described as a primary stakeholder. VOA is a more personal stakeholder and the engineer executing this thesis. VOA has obtained a score of 9/10 in interest because the author itself selected this thesis and a score of 10/10 in influence due to the fact that VOA is the creator of this thesis ending up with a total coordinate-score of 9,10.

Customer is the first secondary stakeholder for this project. The customer is the one buying and using the end result, many may have ideas or solutions that they want out of the product. However, in this first research and development process the customer only have some interest and influence in the project. The interest and influence may increase over time when the customer starts to believe in the product. Because of this, this stakeholder obtains a score of 4/10 in both interest and influence with a total coordinate-score of 4,4.

Suppliers and manufactures is the second secondary stakeholder for this project. Suppliers are the once who provides parts for the project. Suppliers are usually not so interested in the given product that they are suppling buy may critically affect the product, based on demanded parts. However, in this first research and development parts are kept to a minimum a no series are planned. Because of this SAM obtain a score of 3/10 in interest and 4/10 in influence with a total coordinate-score of 3,4.

European Space Agency is the third and final secondary stakeholder for this project. Since this is a master thesis in research and development of a new actuator in an early iteration of development its feasible to believe that ESA have close to no interest in this project at this point. However, ESA have loads of research and development that tends as regulations and guidelines for developing space solutions. Because of this ESA obtain a score of 1/10 in interest and 6/10 in influence with a total coordinate-score of 1,6.

Table 13: Interest-Influence matrix

Stakeholder	Interest 1-10 [X-axis]	Influence 1-10 [Y-axis]	Score-Coordinate [X,Y]
KSS-P	10/10	10/10	10,10
UIT-P	6/10	6/10	6,6
VOA-P	9/10	10/10	9,10
CUS-S	4/10	4/10	4,4
SAM-S	3/10	4/10	3,4
ESA-S	1/10	6/10	1,6

7.2. Risk Evaluation

Table 14: Space Environment Risk

	Before mitigation					**Mitigation 1**			**After mitigation 1**		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Wrong materials	1,0	4,0	4,0	ESA has good handbooks on selection the right material for space systems.	Wrong materials can cause major mechanical and optical (outgassing) system fails.	Follow ESA standards for materials	VOA	Phase 2	TBD	TBD	TBD
Not defining the right safety factor for components	2,0	4,0	8,0	ESA has good handbooks on selection the right safety factors for space systems.	Wrong safety factors can cause major mechanical systems fails.	Follow ESA and Kongsberg Space systems recommendations	VOA	Phase 2	TBD	TBD	TBD
Collision	5,0	5,0	25,0	The likelihood of Collison with micro meteorites in space is high.	A hole in the mechanism can cause total fail.	Verify sizing with Kongsberg Space System	VOA	Phase 2	TBD	TBD	TBD
Radiation	5,0	4,0	20,0	The SRA will be hit by radiation	Radiation causes the string to degrade	Follow ESA standards for materials and internal testing	VOA	Phase 2	TBD	TBD	TBD
Pressure	5,0	5,0	25,0	The SRA will be operation in vacuum	Vacuum can cause outgassing of selected component. This may interfere with other systems.	Follow ESA standards and internal testing	VOA	Phase 2	TBD	TBD	TBD
Space Environment	3,6	4,4	**16,4**								

Table 15: Operation Risk

	Before mitigation					**Mitigation 1**			**After mitigation 1**		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Performance degradation	2,0	4,0	8,0	Degradation of the SRA can lead to increased pointing error.	Increased pointing error can lead to underperforming or not preforming at all. This makes the SRA useless	Follow ESA standards for materials and create a worst case pointing budget	VOA	Phase 2	TBD	TBD	TBD
Increased power consumption	1,5	4,0	6,0	Wrong motor or gear ratio can lead to increased use of power.	Increased power consumption can lead to system failure	Follow KSS experience and ESA standards for motors	VOA	Phase 2	TBD	TBD	TBD
Consumable articles failure	1,5	4,0	6,0	Selection of wrong lubrication etc can lead to wrong life time of consumables.	This risk can cause decrease the SRA's lifetime.	Following KSS experience	VOA	Phase 2	TBD	TBD	TBD
Unstable architecture	3,0	5,0	15,0	Limited time for verification and testing. High demand of test equipment at KSS	An unstable SRA can lead to project hold.	Following KSS experience	VOA	Phase 2 & 3	TBD	TBD	TBD
Operational Risks	2,0	4,3	**8,8**								

Table 16: Cost Risk

	Before mitigation					**Mitigation 1**			**After mitigation 1**		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Going over budget	2,0	3,0	6,0	The budget is set by KSS. The budget is relative high based on experience	going over budget results in additional meeting. Worst case project delays	Contacting KSS ASAP	VOA	Phase 2	TBD	TBD	TBD
Technical budgets	2,5	4,0	10,0	Technical requirements are highly specified in the requirement selection.	By not meeting a requirement the project can have large delays	Quick design review - consecutively verification	VOA	Phase 2	TBD	TBD	TBD
Cost risks	2,3	3,5	**8,0**								

Table 17: Schedule Risk

	Before mitigation					**Mitigation 1**			**After mitigation 1**		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Wrong model	2,5	3,0	7,5	The selected model is a hybrid between two models	following the wrong model can increase cost and cause delays	Part A - CONOPS	VOA	Phase 1	TBD	TBD	TBD
Failure to follow Engineering model	1,5	4,0	6,0	This is the 3th time following this hybrid model for the author.	following the wrong model can increase cost and cause delays	Part A - CONOPS	VOA	consecutively	TBD	TBD	TBD
Time slips	2,0	4,0	8,0	Some timeslips cannot be controlled	project delays	Part A - CONOPS	VOA	consecutively	TBD	TBD	TBD
Late changes in requirements	2,0	5,0	10,0	Unseen requirements can appear	if fundamentals requirements is added or changed large project delays may happen	Part A - CONOPS	VOA	consecutively	TBD	TBD	TBD
Document setup changes	1,0	5,0	5,0	Document setup is set by KSS.	If fundamentals in document setup is added or changed large project delays may happen.	Part A - CONOPS	VOA	consecutively	TBD	TBD	TBD
Schedule risks	1,8	4,2	**7,3**								

Table 18: Safety risk

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Workplace injury	1,0	4,0	4,0	Norway has strong regulations for school environment.	if a workplace injury has happened, large project delays may happen.	Contact UIT	VOA	consecutively	TBD	TBD	TBD
Work overload	2,0	3,5	7,0	Wrong estimates on work load is feasible	if it is planned to much work, project can be delayed.	Contact UIT	VOA	consecutively	TBD	TBD	TBD
Unanticipated safety situations	1,0	4,0	4,0		If a unanticipated safety situations has happened, large project delays may happen.	Contact UIT	VOA	consecutively	TBD	TBD	TBD
Safety Risks	1,3	3,8	**5,0**								

Table 19: Development risk

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Not vaild test	2,0	3,0	6,0	The author has some experience with testing at this point	Feasible to happen - medium to small delay	Contact KSS	VOA	phase 3	TBD	TBD	TBD
Wrong test	2,0	3,0	6,0	The author has some experience with testing at this point	Feasible to happen - medium to small delay	Contact KSS	VOA	phase 1	TBD	TBD	TBD
Fail during test	2,0	4,0	8,0	The author has some experience with testing at this point	Feasible to happen - medium to small delay	Contact KSS	VOA	phase 3	TBD	TBD	TBD
Design errors	3,0	3,0	9,0	The author has some experience space solution designing. Wire is a new topic	feasible to happen - medium to small delay	Contact KSS	VOA	phase 2	TBD	TBD	TBD
Drawing erros	3,0	3,0	9,0	The author has some experience space solution designing. Wire is a new topic	feasible to happen - medium to small delay	Contact KSS	VOA	phase 2	TBD	TBD	TBD
Communication errors	3,0	4,0	12,0	Wrong communication between KSS, author and UIT may happen	feasible to happen - medium to small delay	Contact KSS/UIT	VOA	consecutively	TBD	TBD	TBD
Development risk	2,5	3,3	**8,3**								

Table 20: Human Resources risk

	Before mitigation					**Mitigation 1**			**After mitigation 1**		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Work environment	3,0	3,0	9,0	distribution of co-workers is known to happen	feasible to happen - medium to small delay	Contact UIT	VOA	consecutively	TBD	TBD	TBD
Supervisors leaving	1,0	4,0	4,0	Contract binding supervisor	Can cause large delays	Contact UIT	VOA	consecutively	TBD	TBD	TBD
Sickness	2,0	3,0	6,0	Normal health assumed	Can cause large delays	Contact UIT/KSS	VOA	consecutively	TBD	TBD	TBD
Human resources risk	2,0	3,3	**6,3**								

7.3. Estimated Forces Detailed Calculation

Table 21 shows the script used to calculate forces discussed in selection 3.2.

Table 21: Detailed Calculation Forces

```
11.01.18 22:27   C:\Users\vebjr\iCloudDrive\MS...\Forces.m    1 of 1

%Given Properties
M = 1.45;            %Mass over SRA, Kilogram
A = 57.4;            %Calculated acceleration via Miles Eq, m/s^2
L1 = 91.4;           %Offset mass y-axis from SRA center, millimeter
L2 = 20;             %Offset Bearing location y-axis from SRA center,millimeter


%Formulas
FX=M*A*3             %Newtons second law times 3sigma factor from Miles Eq - Radial↙
force in the offset mass over SRA
FY=M*A*3             %Newtons second law times 3sigma factor from Miles Eq - Axial force↙
in the offset mass over SRA
FRY=FY               %Newtons first law, summ of a forces in y-direction shall be eqaual↙
to zero FRY= Reaction force in SRA center y-direction
FRX=FX               %Newtons first law, summ of a forces in x-direction shall be eqaual↙
to zero FRX= Reaction force in SRA center x-direction
MM=FRX*L1            %Momentum around offset mass over SRA - Solving for momentum around↙
center of SRA
FA=MM/L2             %Momentume around center of SRA - Solving for Radial Bearing load

%Results
FX = 249.6900         %Radial force in offset mass over SRA ( Newton)


FY = 249.6900         %Axial force in offset mass over SRA ( Newton)


FRY = 249.6900        %Axial force in center of SRA ( Newton)


FRX = 249.6900        %Radial force in center of SRA ( Newton)


MM = 2.2822e+04       %Momentum in center of SRA ( Newtonmillimeter)


FA = 1.1411e+03       %Radial force in Bearing of SRA ( Newton)
```

Table 22 shows the script used to calculate preload and contact stress discussed in selection 3.2.1

Table 22: Detailed Preload and Contact stress script

```
11.01.18 21:58   C:\Users\...\Preload_and_contact_stress.m    1 of 1

%Given Properties
E1 = 210000;          %Elastic modulus steelball(bearing)MPa
E2 = 210000;          %Elastic modulus steel housing(bearing)MPa
V1 = 0.3;             %Poissons Ratio steel ball(bearing)
V2 = 0.3;             %Poissons Ratio steel housing(bearing)
R = 3;                %Radius of one ball millimeter
C0 = 2900;            %Maximum static load (bearing) Newton
G = 0.357;            %Factor for lifttime from KSS
N =17;                %Numbers of balls in the bearing (SKF W63806)

%Formulas
E=(E1/(2-2*(V1)^2))                           %Total Elastic Modulus MPa
PM=((1/3.14)*((6*(C0/N)*E^2)/R^2)^(1/3))      %Maximum Contact stress ( PM at C0)Newton
F=((5.15986*(G^3)*N*(PM^3)*R^2)/E^2)          %Preload Newton

%Results
Total_Elastic_Modulus = 1.1538e+05 MPa


Maximum_Contact_stress = 3.6570e+03 MPa


Preload_F = 131.9480 Newton
```

7.4. Bearing Excel sheet

Feature:	unit:	Refrence:	16006	61806	6006	61906
Material ball	MPa	210000	210000	210000	210000	210000
Material hus	MPa	210000	210000	210000	210000	210000
Poissons ratio ball	-	0,3	0,3	0,3	0,3	0,3
Poissons ratio hus	-	0,3	0,3	0,3	0,3	0,3
Radius ball	millimeter	3	5,25	2,825	5,4	3,725
Max Static load	Newton	2900	7350	2900	8300	4550
Life factor	-	0,357	0,357	0,357	0,357	0,357
Number off balls	-	17	12	17	11	14
Emodul	MPa	115384,6154	115384,615	115384,6154	115384,6154	115384,6154
mass	kilogram	0,035	0,089	0,025	0,12	0,049
Axial force	Newton	382	584,419976	381,9480179	627,6443271	457,0218901
Radial force	Newton	1150	1150	1150	1150	1150
SKF Equivalent dynamic bearing load	Newton		1520	1160	1600	1300
Basic Life time	Hrs		533200	64400	712900	195100
Load Accepted ?	SANN/USANN		SANN	SANN	SANN	SANN
Life time accepted ?	SANN/USANN		SANN	USANN	SANN	SANN
max contact stress	Mpa	3656,971386	3856,1022	3806,478934	4056,816237	3924,307004
Preload	Newton	131,9480179	334,419976	131,9480179	377,6443271	207,0218901
SKF Total Frictional moment	Newtonmillimeter		61,3	74,4	60,4	57,6
Bore	mm		30	30	30	30
Diameter	mm		55	42	55	47
thickness	mm		9	7	13	9

Figure 18: Bearing Excel sheet

7.5. Tests

Test: TST 1

Test ID:	TST-1	**Requirements to be tested:**	EREQ-1, EREQ-2
Pass criteria:	The system shall withstand operation in temperatures between [-25, +65] ºC both in function and not in function.		

Test method:	Analysis or review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 2

Test ID:	TST-2	**Requirements to be tested:**	EREQ-3

Pass criteria:	The system shall not have an outgassing molecules/volume more than TBD.				
Test method:	Test				
Execution:	Conduct a test in vacuum chamber where the outgassing for the system is measured.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 3

Test ID:	TST-3	**Requirements to be tested:**	EREQ-4

Pass criteria:	The system shall not degrade with the radiation levels in LEO				
Test method:	Review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 4

Test ID:	TST-4	**Requirements to be tested:**	EREQ-5

Pass criteria:	The system shall not be affected by humidity levels of TBD				
Test method:	Review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 5

Test ID:	TST-6	**Requirements to be tested:**	EREQ-7,

Pass criteria:	The system shall not be affected by the LEO environment.				
Test method:	Test				
Execution:	TBD				
Result:	Not tested	**Date:**	-	**Sign:**	-

Comment:					

Test: TST 6

Test ID:	TST-7	**Requirements to be tested:**	TREQ-1		
Pass criteria:	The SRA must have a center hole lager than 30.00mm				
Test method:	Analysis or review				
Execution:	Design review.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 7

Test ID:	TST-8	**Requirements to be tested:**	TREQ-2		
Pass criteria:	The SRA can not have large pointing error than 0.02 deg				
Test method:	Test, Analysis or review				
Execution:	Conduct a pointing budget.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 8

Test ID:	TST-9	**Requirements to be tested:**	TREQ-3		
Pass criteria:	The SRA must have a mass less than 1.0kg				
Test method:	Analysis or Review				
Execution:	Conduct a mass budget.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 9

Test ID:	TST-10	**Requirements to be tested:**	TREQ-4		
Pass criteria:	The life time of the SRA must be higher than 500000 cycles.				
Test method:	Test				
Execution:	Conduct a lifetime test				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 10

Test ID:	TST-11	**Requirements to be tested:**	TREQ-5		
Pass criteria:	The motor uses less than 8W.				
Test method:	Analysis or Review				
Execution:	Conduct a power budget.				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 11

Test ID:	TST-12	**Requirements to be tested:**	TREQ-6
Pass criteria:	The total production cost less than 50,000 euro		
Test method:	Review		
Execution:	Cost budget		
Result:	Not tested	**Date:** -	**Sign:** -
Comment:			

Test: TST 12

Test ID:	TST-13	**Requirements to be tested:**	TREQ-7
Pass criteria:	The SRA can move 380 deg from ends top.		
Test method:	Analysis or review		
Execution:	Design analysis		
Result:	Not tested	**Date:** -	**Sign:** -
Comment:			

Test: TST 13

Test ID:	TST-14	**Requirements to be tested:**	TREQ-8, TREQ-9
Pass criteria:	The SRA can move with more than 90 deg/s and accelerate to 90 deg/s faster than 0.5 second		
Test method:	Analysis or review		
Execution:	Design analysis		
Result:	Not tested	**Date:** -	**Sign:** -
Comment:			

Test: TST 14

Test ID:	TST-15	**Requirements to be tested:**	TREQ-10
Pass criteria:	The wire tension can be adjusted		
Test method:	Test		
Execution:	TBD		
Result:	Not tested	**Date:** -	**Sign:** -
Comment:			

Test: TST 15

Test ID:	TST-16	**Requirements to be tested:**	TREQ-12
Pass criteria:	The driveline can overcome the friction in the SRA		
Test method:	Test or analysis		
Execution:	Design analysis		
Result:	Not tested	**Date:** -	**Sign:** -
Comment:			

Test: TST 16

Test ID:	TST-17		**Requirements to be tested:**	TREQ-14	
Pass criteria:	The preload in the ballbearing is 207 newton				
Test method:	Analysis or review				
Execution:	Design Analysis				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					

Test: TST 17

Test ID:	TST-18		**Requirements to be tested:**	TREQ-15	
Pass criteria:	The mass over SRA is less than 1.450 kg				
Test method:	Analysis or review				
Execution:	Design Analysis				
Result:	Not tested	**Date:**	-	**Sign:**	-
Comment:					