Bachelor Thesis

Development of a Tracking Unit for the Payload Recovery of Sounding Rockets

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Course of Studies: Mechanical Engineering, Focus on Product Development

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Abstract

The Bachelor's thesis describes the development of a tracking unit for the payload recovery of sounding rockets. At the beginning, the previous beacon tracking unit is analyzed, and its weak points are defined. The results are used to define the development priorities.

The core of the work is the methodical construction of the tracking unit. In the methodical construction different partial solutions are worked out on the basis of the development priorities. With the help of a morphological box, four complete concepts are generated which are then subjected to an evaluation. According to the evaluation, the preferred concept is worked out with the help of the CAD program Autodesk Inventor.

After production of the new tracking unit, various tests were performed. Finally, a comparison is made between the previous beacon tracking unti and the new tracking unit. In doing so, functionality, complexity of installation and economic efficiency are taken into account.

Kurzfassung

Die Bachelorthesis beschreibt die Entwicklung einer Ortungseinheit für die Nutzlastbergung von Höhenforschungsraketen. Hierfür wird zu Beginn die vorhandene Beacon Tracking Unit analysiert und dessen Schwachstellen festgelegt. Aus den Ergebnissen werden Entwicklungsschwerpunkte definiert.

Der Kern der Arbeit liegt in der methodischen Konstruktion der Tracking Unit. In der methodischen Konstruktion sollen anhand der Entwicklungsschwerpunkte verschiedene Teillösungen ausgearbeitet werden. Mit Hilfe eines morphologischen Kastens werden vier komplette Konzepte gebildet die anschließend einer Bewertung unterzogen werden. Entsprechend der Bewertung wird das favorisierte Konzept mit Hilfe des CAD Programms Autodesk Inventor ausgearbeitet.

Nach der Fertigung der neue Tracking Unit, werden diverse Versuche durchgeführt. Zum Schluss folgt eine Gegenüberstellung des alten Ortungssystem mit der neuen Tracking Unit. Dabei werden vor allem Funktionalität, Montierbarkeit und Wirtschaftlichkeit berücksichtigt.

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List of Abbreviations

Abbreviation	Meaning
BAL	Bristol Aerospace Limited (Magellan Aerospace Corporation)
baro	Barometric
CAD	Computer-Aided Design
D-Sub	D-Subminiature
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ERS	European Recovery System
FH	Fachhochschule
g	Earth Acceleration of Gravity
GPS	Global Positioning System
HD	High Density
HM	Hochschule München
IGY	International Geophysical Year
LED	Light Emitting Diodes
MORABA	Mobile Raketenbasis (Mobile Rocket Base)
MVM	Münchner Vorgehensmodell
OHB	Orbitale Hochtechnologie Bremen-System GmbH
ORSA	Ogive Recovery System Assembly
VSB-30	Veículo de Sondagem Booster – 30” (Booster Sounding Vehicle)

1 Introduction

1.1 Mobile Rocket Base at a Glance

The Mobile Rocket Base (MORABA) emerged in 1965 from the *Arbeitsgemeinschaft für Weltraumforschung* of a joint foundation of the *Max Planck Institut* and the former *Deutsche Versuchsanstalt für Luftfahrt e.V*. Today MORABA belongs to the *Raumflugbetrieb und Astronautentraining,* an institute of the German Aerospace Center (DLR).

[Turner 2016, p. 3]

MORABA made it possible for scientific institutions and universities worldwide to participate in space exploration with experiments in sounding rockets. The MORABA develops, builds and assembles the sounding rockets. In addition, everything is provided for a mobile launch campaign and this is carried out. The first mobile campaign was successfully launched in May 1966 on the Greek island of Euböa.

[Turner 2016, p. 3]

Essential parts of the research campaigns are the successful recovery of the payloads after their suborbital space flight. In order to ensure this, a radio beacon tracking unit is employed in addition to a functioning parachute recovery system. The beacon tracking unit is needed to receive a signal to determine the direction and distance of the payload in the final phase of the descent as well as on the ground.

The work presented here and undertaken under the topic "Development of a locating unit for the payload recovery of sounding rockets" aims to replace the current Beacon system with an Iridium system and to develop this new tracking unit.

1.2 Problem Definition

The tracking unit employed so far by MORABA, which is based on a radio beacon, is sub-optimal. Two of the problems with the unit are the range of the beacon system and that no exact coordinates are sent only the direction and approximate distance. As well, assembly and disassembly of the unit is time consuming, which can lead to errors and delays during launch campaigns. The primary cell that serves as the power supply cannot be charged. To replace them, the entire beacon tracking unit must be removed from the European Recovery System (ERS). The space required in the ERS structure is severely limited by surrounding components and cable trees, which is one reason for the problems described above and must be taken into account during any new development.

1.3 Objectives

The goal is to develop a satellite-based tracking unit that is based on existing Iridium components for the ERS. The main requirements for the new tracking unit are the integration of the new Iridium system as well as the simple modification into existing ERS. Furthermore, the previously used non-rechargeable primary cell shall be improved to a rechargeable system. Besides that, the safe release during flight and ease of integration and handling.

Taking into account the technical requirements, different concepts / variants are worked out and evaluated against each other with regard to manufacturability, feasibility and cost. The selected concept is designed and then manufactured, assembled, integrated and tested.

The development process is supported by a procedure model. This ensures a systematic and goal-oriented execution of the respective work steps in this thesis. This will be based on the *Münchner Vorgehensmodell* (MVM), which is based on the three main steps of problem solving including explaining the goal or problem, generating alternative solutions and make decisions.

[Lindemann 2009, p. 46].

2 Fundamentals

2.1 Sounding Rockets

2.1.1 The Beginning of Sounding Rockets

At the end of the 1940s, the first sounding rockets were used in the USA and Europe to study unexplored features of the upper atmosphere and near-Earth orbit. Until the mid-1950s, however, rocket development was predominantly geared to military purposes.

[Seibert 2006, p. 13]

The breakthrough in the use of missile technology for civilian purposes did not come until 1957 and 1958, which was designated the International Geophysical Year (IGY). The IGY was dedicated to global atmospheric research. The idea came from American geophysicists.

[Seibert 2006, p. 13]

The IGY was the initiator for the launch of around 200 sounding rockets worldwide. The vehicles used were derived from military rockets, or military rockets were used, but under a different name. These were very different with regard to their technical possibilities and ranged from a payload of a few kg to 200 kg. The number of different types of sounding rockets used annually for scientific purposes reached about 90 in the 1960s/early 1970s.

[Seibert 2006, p. 13]

2.1.2 Technical Features of Sounding Rockets

Sounding rockets are unmanned missiles that are launched into the upper atmosphere to reach an altitude of between 40 and 2000 km. The goal of sounding rockets is to carry out scientific measurements or investigations. There are two main areas of application.

The first major area for the use of sounding rockets is the atmospheric research at altitudes which cannot be reached by balloons (max. 40km) and which is too low for low-earth-orbit satellites which have to operate at altitudes of more than 200km. These could be for example meteorological measurements, atmospheric measurements, investigation of the electrical properties of the ionosphere, astronomical investigations or material scientific investigations.

[Seibert 2006, p.3, 14]

The second major area is micro-gravity research, in other words research in zero gravity. The only possibilities for micro-g research still are, for example, drop towers, drop capsules or parabolic flights. The disadvantages were the short research times from a few seconds up to one minute and the low 0-g quality. With sounding rockets, research times of several minutes can be achieved with a high 0-g quality.

[Franke 2007, p. 14-19]

A sounding rocket is usually a ballistic missile consisting of two large assemblies, the rocket motor system and the payload. The term payload includes all systems that are installed above the rocket motor system. A differentiation of the payload itself can also be made between service systems and scientific payloads. Depending on the requirements, the service systems consist of a boost control system, the rate control system, telemetry and the recovery system. The various experiment modules are accommodated in the scientific payload.

[Franke 2007, p. 32]

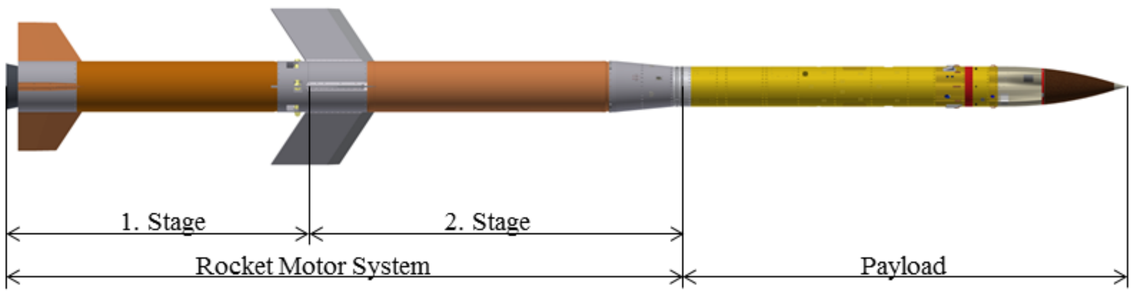


Figure 1: Overview of a VSB-30 two Stage Sounding Rocket

2.1.2.1 Rocket Motor System

The rocket motor system consists of one or more stages filled with solid or liquid propellant. The difference between a solid-propellant and a liquid-propellant motor is that the solid grain burns without interrupting the thrust. The liquid propellant motor, on the other hand, can be modulated, interrupted, re-ignited and has a higher specific impulse than solid propellant. The biggest problems of liquid fuel engines are the complicated handling, the lack of availability and the significantly more complicated design and the high costs associated with it. Therefore, mainly solid fuel motors are used for sounding rockets.

[Seibert 2006, p.3, 14]

In addition to the Motor, the launcher system also requires fins, which stabilize the rocket during the ascent flight. The rocket motor system also contains adapters to hold the various assemblies together and provide a connection to the payload.

2.1.2.2 Payload

The payload is modular, which means that each module is often built autonomously, regardless of whether it is a service module or an experiment module. The modular payload configuration offers the advantages of independent integration and test procedures on module level, easy exchangeability and repair possibilities of components, better adjustment possibilities of the payload with regard to the center of gravity. The disadvantage to a centralized system is the higher overall payload mass and the higher costs.

[Franke 2007, p. 32-33]

The telemetry system consists of a function monitoring system to monitor the service systems during the flight. In addition, the data of all systems and experiments are recorded and transmitted to the ground. [Franke 2007, p. 35]

The rate control system is used to take the remaining spin out of the payload to achieve a high 0-g quality. It also ensures to compensate disturbances occurring during the separation of the payload, disturbances arising in the experiment modules themselves or aerodynamic disturbances. [Franke 2007, p. 37]

The recovery system is used to reuse the various systems and to recover experimental samples or data that cannot be transmitted via telemetry. [Franke 2007, p. 37] The recovery system will be discussed in more detail in the following chapter.

2.2 European Recovery System

The European Recovery System was designed for use on TEXUS and MASER missions and VSB-30 vehicles, based on the BAL ORSA system. The system was developed by *Orbitale Hochtechnologie Bremen-System GmbH* (OHB) formerly *Kaiser-Threde* in cooperation with DLR MORABA

[Saedtler & Hörschgen 2011, p. 1-1]

2.2.1 System Description

The European Recovery System is designed to recover payloads of up to 450kg mass and 438mm diameter. The assembly incorporates a 3:1 aspect ratio ogive whose forward portion is ejected forward after atmospheric exit to permit parachute recovery system operation.

[Saedtler & Hörschgen 2011, p. 2-1]

2.2.2 Mission Scenario

The recovery system activation is controlled by barometric (baro) switches in combination with an electronic timing activation unit. During ground operations the recovery system is inactive and disarmed. During countdown operations, the system is armed.

[Saedtler & Hörschgen 2011, p 2-3]

The scenario during the ascent includes the following events. The safety chain consists of a lift-off pin and a 5kft (1520m) baro switch, normally closed until passing 5kft (1520m) of altitude. The 15kft (4570m) recovery sequence activation switch is closed until passing 15kft (4570m). The activation unit connects the pyrotechnic battery circuit when the vehicle has reached altitudes of approx. 50km. The forward ogive is then timer controlled ejected.

[Saedtler & Hörschgen 2011, p 2-3]

On the descent trajectory the recovery sequence is activated when passing 15kft (4570m). The baro switch closes and activates the heat shield guns for heat shield jettison. Together with the heat shield the drogue parachute is deployed. The payload is now stabilized and decelerated. After 10s of reefing time the drogue parachute deploys to full size and will be released after a total action time of 25s by timer-controlled activation of the drogue parachute release guillotine which is cutting the drogue parachute harness. Before the drogue parachute separates completely from the system, it extracts the reefed main parachute out of the deployment bag. After 10 seconds of reefing time the main parachute opens to full size and remains open until touch down. The sink rate at touch down will be approximately 8m/s.

[Saedtler & Hörschgen 2011, p 2-4]

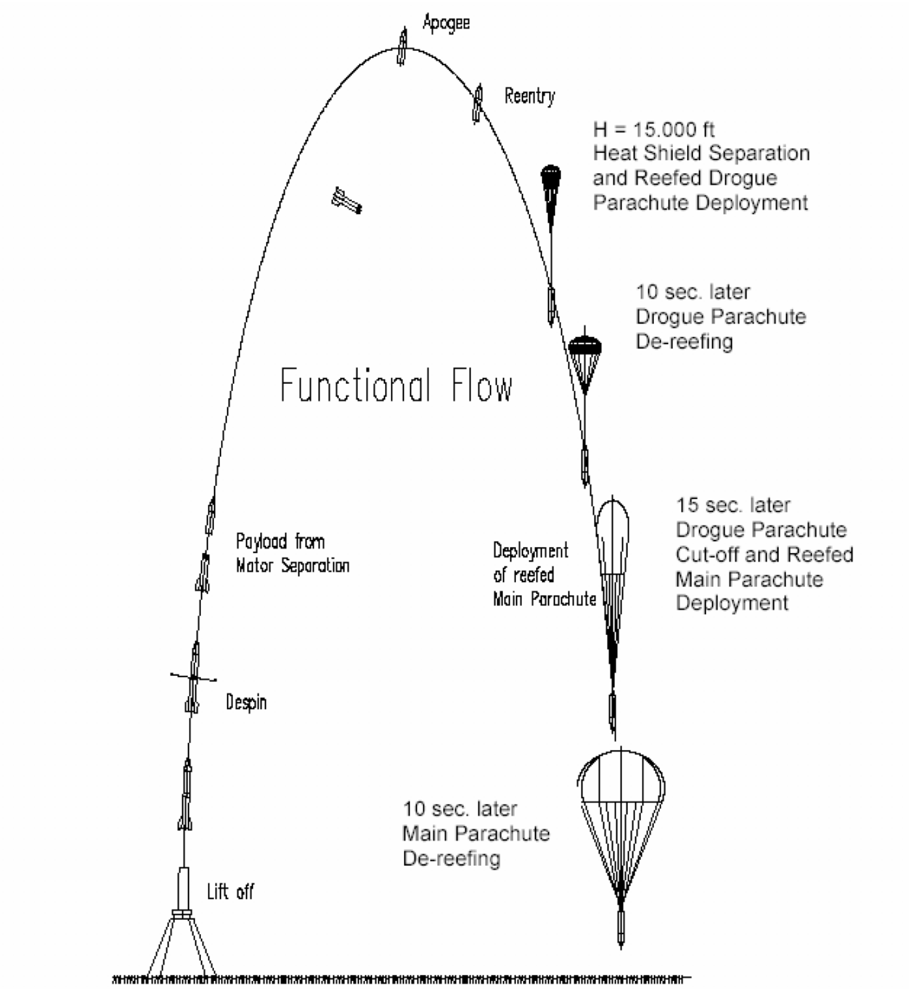


Figure 2: Typical ERS Mission Scenario [Saedtler & Hörschgen 2011, p. 2-4]

2.2.3 Main ERS Design and Functions

The ERS system consists of two large assemblies, the foward ogive and the aft ogive assembly, connected to each other by a manacle ring. The Figure 3 shows the ERS system.

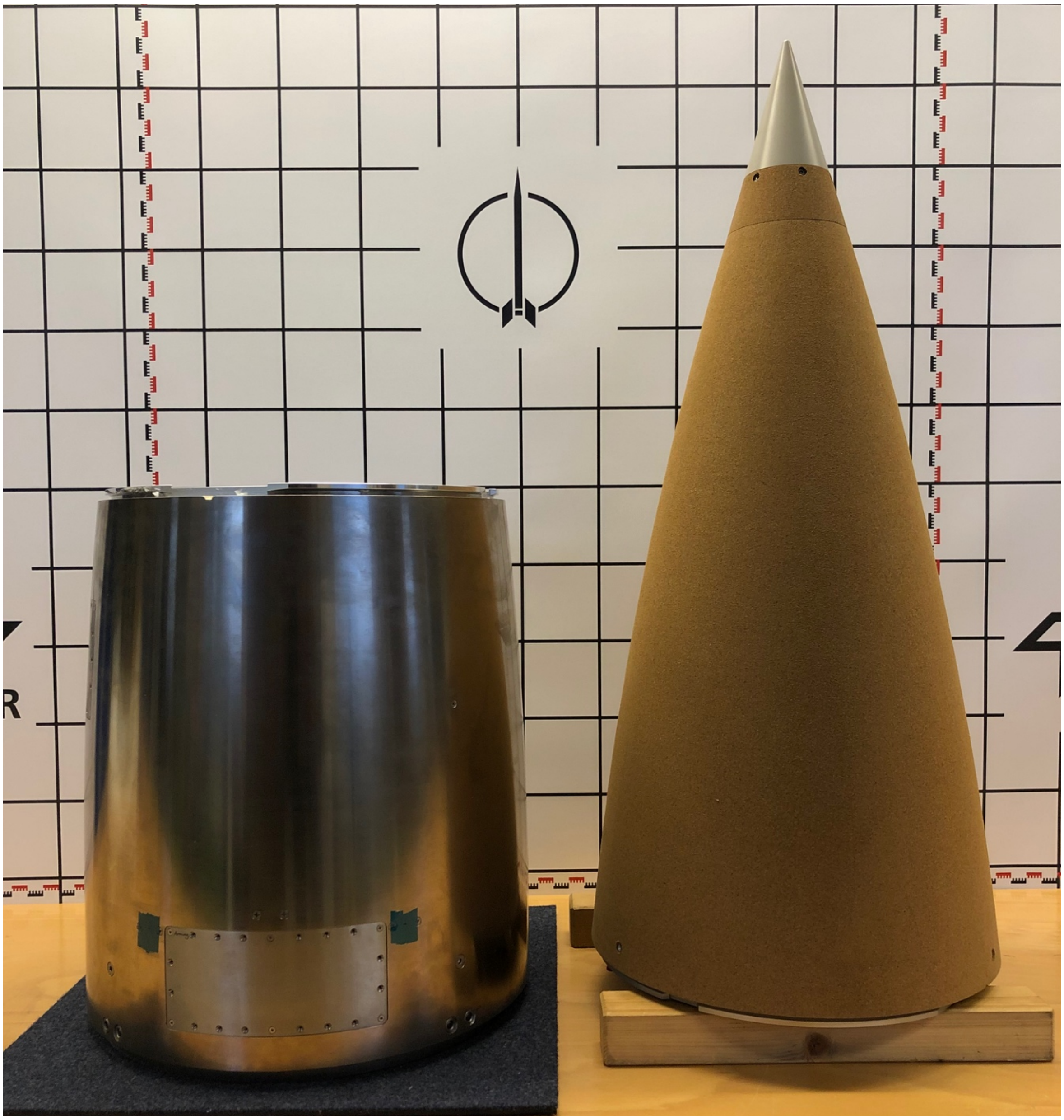


Figure 3: On the Left the Aft Ogive; On the Right the Foward Ogive

The main parts are located in the aft ogive assembly, which is examined in more detail below. The essential parts are listed and briefly described. Figure 4 shows the front and back sides of the aft ogive assembly.

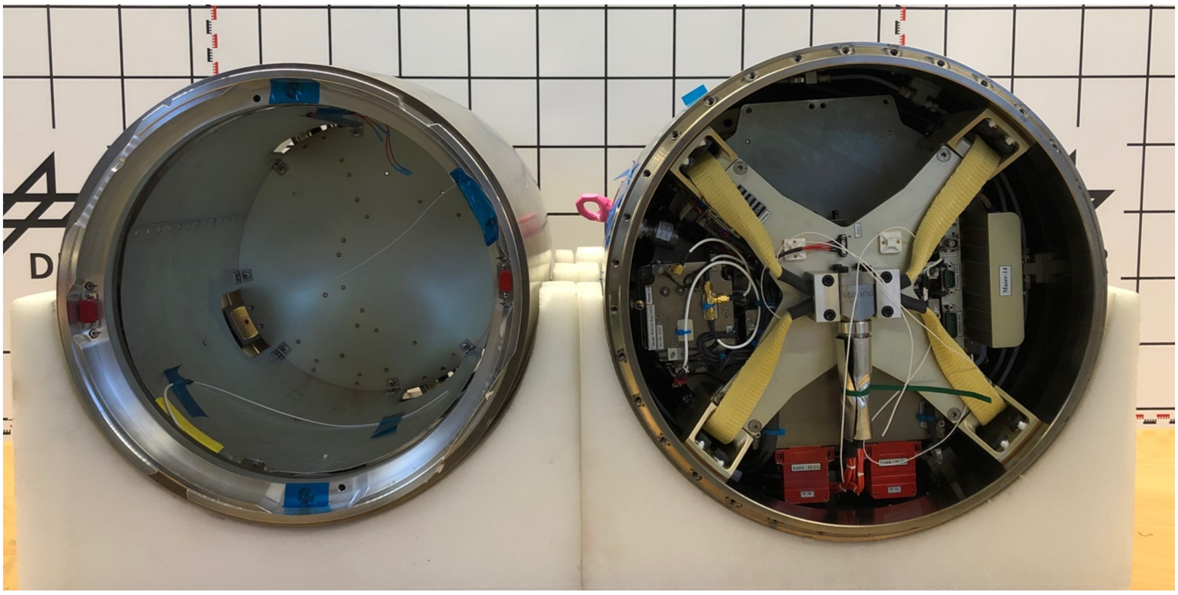


Figure 4: Front and Back Side of the Aft Ogive

The main parts in the aft ogive:

- Heat shield and heat shield gun assembly
- Aft ogive outer structure
- Parachute canister
- Main parachute brackets
- Stage line cutter assembly
- Barometric system
- Battery packs
- Beacon assembly
- Lift of switch assembly and g-switch
- Parachute system
- Ignition unit

The heat shield protects the components after the tip separation from thermal influences during descent. Afterwards, the recovery sequence is initiated by the breaking-off of the heat shield. It consists of a 9 mm thick aluminium structure (AlMgSi1 3.2315) with a layer of thermal insulation material (FIREX 2373) on the outside and cork insulation on the inside. At the back there are four brackets for the attachment of the drogue parachute harness.

[Saedtler & Hörschgen 2011, p 3-16]

The parachute is a two-stage subsonic parachute. The parachute is contained in the parachute canister and is attached to the main parachute brackets on the structure as well as to the heat shield with the attachment lines of the drogue parachute. The first stage of the parachute system consists of a ribbon parachute which partially decelerates the payload, which usually reaches the atmosphere at high speed and in a tumbling motion and stabilizes its position. In order to keep the parachute forces as low as possible, the drogue parachute will be reefed for 10s, after that it will unfold its full size. After the payload has been sufficiently slowed down, the drogue parachute is released. Before it is completely separated from the system, it initiates the removal of the main parachute by pulling a raiser. The main parachute is also reefed for the first 15s and then remains fully open until payload impact.

[Saedtler & Hörschgen 2011, p 3-27]

Figure 5: The Parachute System [Saedtler & Hörschgen 2011, p 3-28]

To locate and recover the payload at the end of the descent and on the ground, the beacon tracking unit is used. The autonomous beacon system consists of the beacon housing, beacon transmitter, beacon battery, beacon electronics and beacon antennas the design is described in more detail in Chapter 3.

2.3 Tracking System

A tracking system is used for position determination and navigation. Within the scope of this work two systems are of relevance, the currently used beacon system and the Iridium system which is based on the functional principle of the Global Positioning System (GPS).

The tracking system is used to determine the position of the payload after a successful flight and then recover them. The recovery is carried out by a helicopter or any other available vehicle. This can lead to various problems which are critical for the selection of the tracking system. Depending on the weather conditions, the recovery cannot be started immediately after the flight and successful touch down. Very low temperatures can prevail, especially in the winter months in North Sweden and Norway. Both systems will be examined in detail below.

2.3.1 Beacon

In navigation, a beacon is a device that marks a position and enables a direction finder receiver to find the relative direction to the beacon. The beacon transmits a continuous signal in the ultra-high frequency (UHF) range with a special modulation. The direction finder receiver receives the transmitted signal and displays it on a compass rose, showing only the direction and no distance.

The theoretical range of the beacon is 10km, which depends strongly on the flight altitude (position of the direction finder receiver) and the position of the antennas. A big disadvantage of the bacon is the limited and strongly fluctuating range as well as the limited transmission time, especially at low temperatures.

2.3.2 Iridium

Iridium is a global satellite communications system operated by Iridium Communicaitions Inc., consisting of 66 active satellites in 6 orbits. The name Iridium comes from the original 77 planned satellites which is the atomic number of the chemical element Iridium.

The basic principle of satellite navigation is to determine the position of the receiver relative to a certain number of satellites. The position of the satellites must and is known, thus the position of the receiver can be derived. The distances between the receiver and the satellites are determined by the signal propagation times. For a clear position determination in three-dimensional space the reception of at least four satellites is necessary. The accuracy of the measured position depends primarily on the accuracy of the time measurement and the exact position of the satellites.

[Tobias Schüttler 2014, p. 2-5]

The advantages of the Iridium system are the position accuracy without restrictions because of the range and the transmission time. Once the coordinates have been transmitted, the position is fixed and remains unchanged in most cases. The disadvantage of the Iridium system, as described above, is that it requires a minimum of four satellites. It is very unlikely that this number is not available on the day of recovery.

3 Existing Tracking Unit

In the first step, the beacon tracking unit is inspected more closely. Therefore, a product and weak point analysis are carried out and, based on these results, the development focus for the following concept phase can be determined.

3.1 Product Analysis

3.1.1 Function

The main function of the Beacon Tracking Unit is to send a signal via the beacon transmitter over a certain period of time. The direction and approximate distance to the payload can be determined by a receiver.

The primary cell supplies the system with power so that the signal can be transmitted.

The baro switch ensures that the tracking unit is activated at the right time.

The housing is necessary to protect the components and to seal the baro switch. In addition, the housing serves as a support for various attachments.

3.1.2 Individual Components

Relevant parts of the beacon tracking unit:

- Housing
- Beacon transmitter
- Baro switch
- Primary cell
- G-switches
- Camera-plug-bracket
- Connectors
- Electronics

The housing of the beacon tracking unit is mostly designed as an integral milled part and divided into two chambers. In the baro chamber the air around the baro switch is calmed. The beacon tracking unit is attached to the bulkhead of the aft ogive structure by four M4 socket head cap bolts. Threaded holes are provided over the entire housing to fasten the various components. The electrical cabling is routed through a cut-out to the Connector. The housing is milled from aluminium alloy (AlMgSi1 3.2315) and then nickel-plated to improve its electrical conductivity.

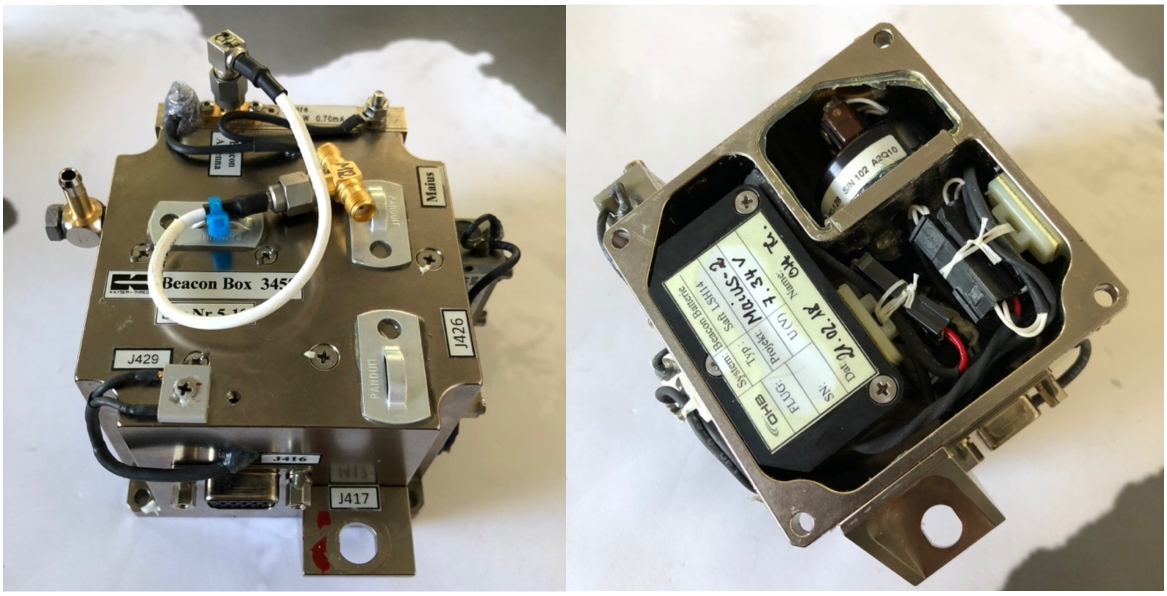


Figure 6: Left: Beacon Tracking Unit; Right: Inside View showing the Two Chambers

The beacon transmitter is a purchased part from Micro Electronics Inc. and is attached to the outside of the B-box with two bolts and matching washers. The transmitter sends a signal with a frequency of about 240,800MHz to the receiver. The required operating voltage is 5-9.5V. Furthermore, the beacon transmitter is suitable for temperatures from -30°C to +70°C.

An LSH-14 Li-SOCL2 primary cell from SAFT is used to supply the beacon transmitter. The battery also supplies power to the recovery camera. Two cells are connected in series to generate a voltage of 7.2V. The battery is fixed in the housing with three bolts. The battery is suitable for temperatures from -60°C to +85°C.

The beacon antennas are directly connected to the beacon transmitter and are routed between the parachute container and the aft ogive structure. Due to the separation of the heat shield the antennas are pulled out of the container. [Saedtler & Hörschgen 2011, p 3-33] The problem is that the position of the antennas on the ground cannot be determined and therefore the signal cannot be transmitted optimally.

The g-switches (6UC-894) made by Inerta Switch with a sensitivity of 2.5g. The g-switches are used for redundant activation of the ignition sequence, each ignition circuit has its own g-switch. The switches are attached to the outside of the housing with two bolts. The Figure 7 shows the two g-switches.

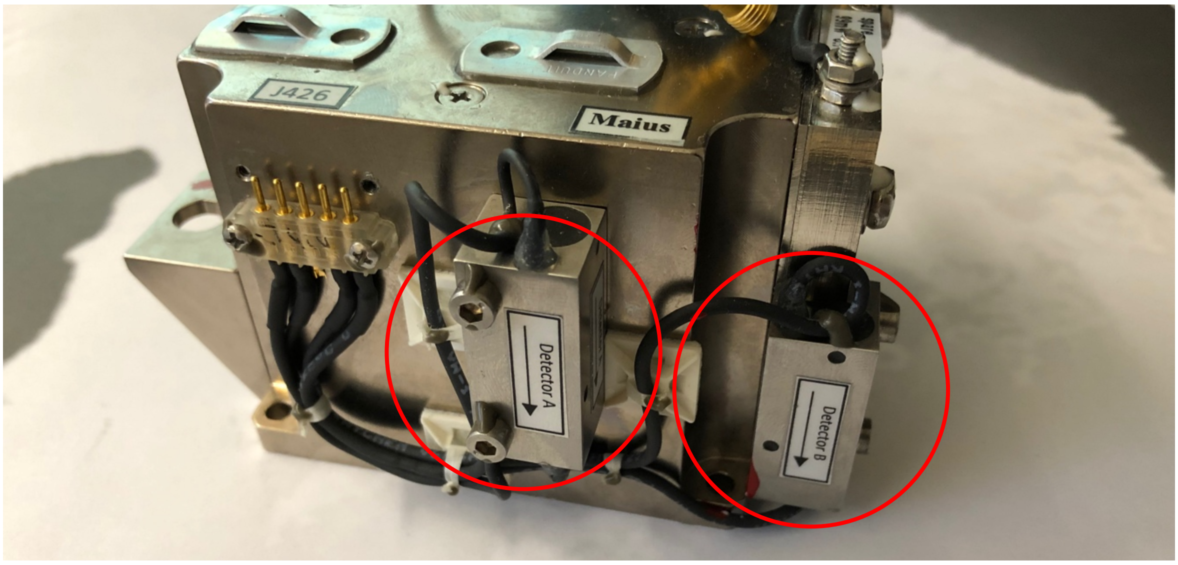


Figure 7: Position of the G-Switches at the Housing

The baro switch is on a plate in two slots and bolted with hexagon nuts. The chamber in which the baro switch is located is sealed by silicone and a plate, as shown as in Figure 8. A vacuum is generated via a hose adapter using a vacuum pump to test the baro switch. The baro switch is activated as soon as the payload falls below the altitude of 4570m.

Figure 8: Integrated Barometric Switch

A rubber mat is used to seal the housing, which is clamped between the housing and the bulkhead with the four connecting bolts. Silicone is also used to sealing the chamber.

The electronics of the beacon tracking unit consists of a circuit board and the associated cabling. The cabling is feed through via a 15-pole HD D-Sub connector as shown in Figure 9.

Figure 9: Left: 15-Pole HD-D-Sub Connector; Right Camera Plug Bracket

Finally, the camera plug bracket for the camera plug is attached to the outside of the beacon tracking unit by two bolts. The bracket is designed as an angle with a through hole for the camera plug. It is a milled aluminium part and can be seen in Figure 9.

3.1.3 Packaging

The packaging is defined by the external dimensions of the current beacon tracking unit and is 80mm x 80mm x 65mm shown in the green box in Figure 10 below. The packaging can be extended to 95mm x 90mm x 80mm as shown in the brown zone. The position of the Mounting holes is predefined by M4 in a square configuration symmetrical to the current B-Box and cannot be changed, the distance is 72mm x 72mm. The position of the G-switches, HD-D-Sub connector and the camera bracket should remain if possible. The red zone shows the position of the attachments.

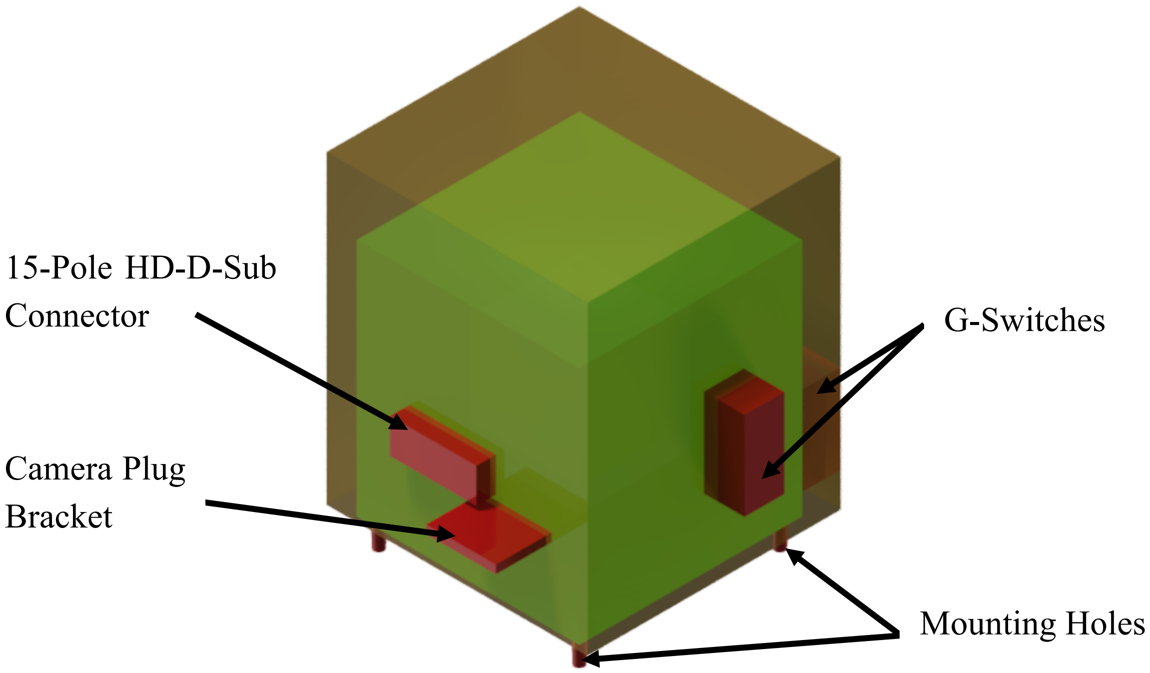


Figure 10: Packaging and Attachments

3.2 Weak Point Analysis

The analysis of weak points is based on the experience of mechanical and electrical colleagues. They have practical experience with the beacon tracking unit during normal operation as well as during a campaign. Furthermore, the results of the product analysis are evaluated. The central weak points are described in the following and the development focuses for the following chapter are defined.

3.2.1 Beacon Signal

The Beacon Transmitter only sends a signal to determine the direction and approximate range, no exact position of the payload is determined.

3.2.2 Beacon Range and Transmission Time

The range of the beacon transmitter is limited to 10km under optimal conditions. There are also problems with the transmission time at low temperatures which are related to the continuous transmission and the power supply through the primary cell.

3.2.3 Barometric Switch Sealing

The sealing of the baro switch is realized by a rubber mat under the housing and silicone at the mounting of the baro switch as the arrows in the Figure 11 show. Due to the large distance between the bolts and the design of the housing underside, a complete sealing cannot be guaranteed. This leads to leaks and thus to problems during the function test.

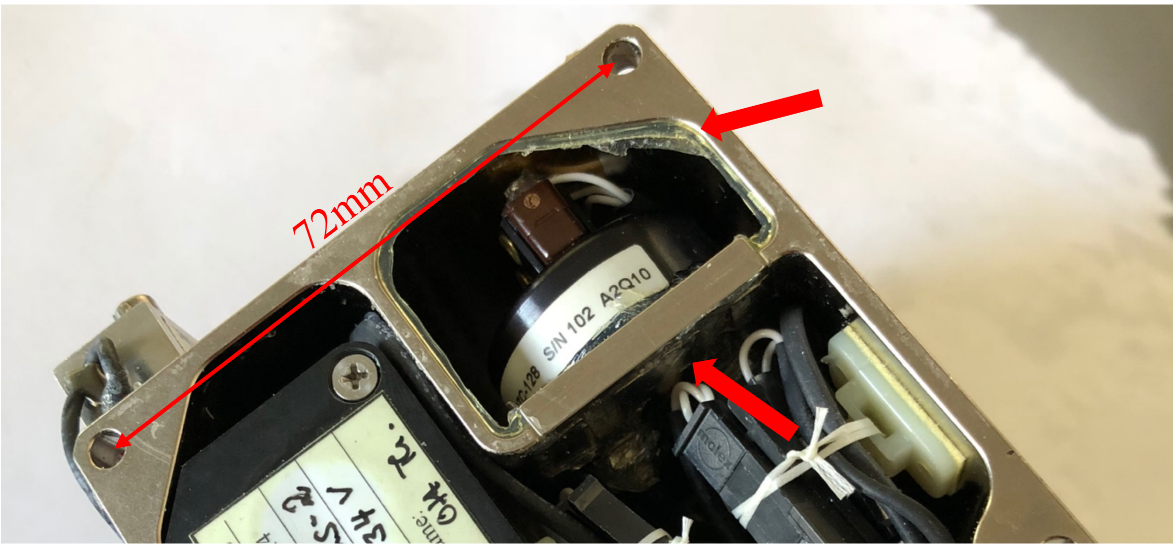


Figure 11: Problem Areas of the Sealing

3.2.4 Battery Replacement

Primary cell batteries cannot be charged, for this reason, the battery must be completely replaced, and the housing must be removed because there is no other way to access the battery. The problem is the exchange on campaign shortly before the start, because all system tests are finished, and a faulty assembly or disassembly can lead to large delays.

3.2.5 Camera Plug Mounting

The camera plug holder is attached to the outside of the beacon housing. The mounting of the plug to the bracket is very time consuming due to the limited space. The plug must be held from below by a open-end wrench and tightened from above with the appropriate torque.

3.2.6 Assembly and Disassembly

The assembly and disassembly of the beacon tracking unit is generally very time consuming due to many handles and small space requirements. In case of wrong order or inattention, electrical cables can be damaged. To illustrate the situation, the Figure 12 shows the beacon tracking unit in its installed state.

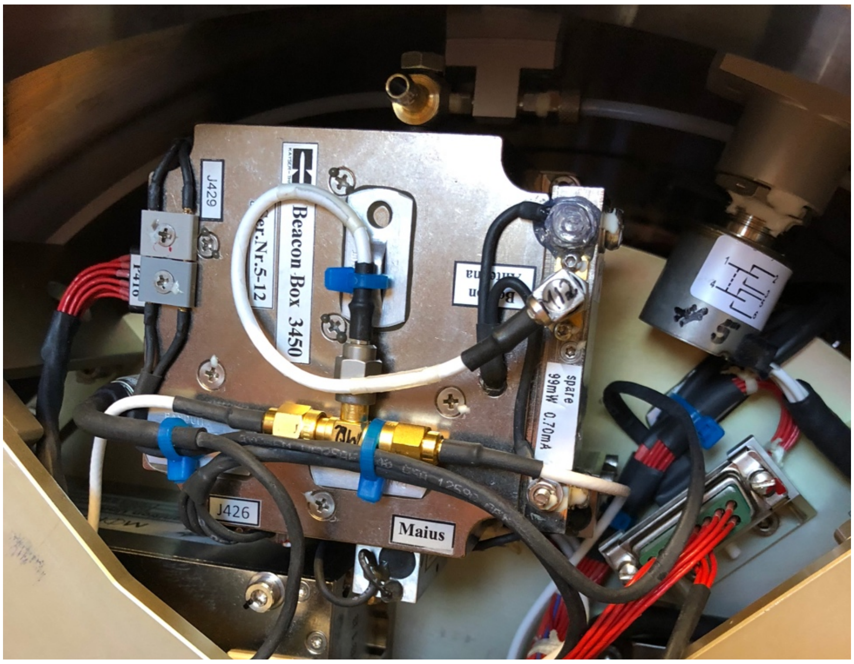


Figure 12: Integrated Beacon Box

3.2.7 Manufacturing

The housing of the beacon tracking unit is milled from a solid block of aluminium it is almost completely milled out, which leads to a very large machining volume and thus to many process steps during production. In addition, each side of the box must be machined, which can only be achieved with many clamping operations or modern multi-axis-controlled machines. Figure 13 shows the CAD model of the housing.

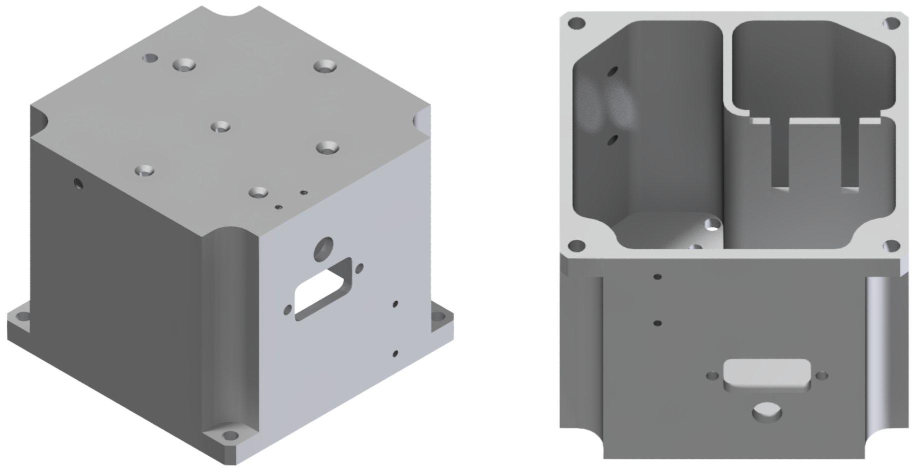


Figure 13: Overview of the Beacon Tracking Unit Housing

3.3 Development Focus

From the evaluation of the results of the product analysis and weak point analysis the development focuses are defined. These serve as the basis for the next work conception and design.

The Development Focus effort first on the design of the housing because it offers the largest customization options and is the main component of the design. The conversion of the tracking system follows next. Since the beacon system no longer meets the desired requirements. The next issue that will be addressed deals with the sealing of the baro switch, which proved to be one of the main problems in the beacon tracking unit. Then follows the optimization of the power supply. The next step is then to improve ease of installation in a very limited space. Redefining assembly and positioning of the components follows next. This also affects ease of installation. The final aim is to reduce manufacturing costs.

The following provides a short summary of the development priorities:

- Design of the housing
- Modification of the tracking system
- Sealing of the baro switch
- Optimization of energy supply
- Assembly friendliness
- Positioning and mounting of the components
- More cost-effective production

4 Conception

During the conception phase, various solutions are worked out on the basis of the development focus. Different methods are used to ensure that the results are unbiased, and a variety of different solutions are generated. In the first step, various solutions are sought without their evaluation and feasibility.

4.1 Mind Mapping

In the first step, all solutions to the various development priorities are plotted with the help of a mind map. All thoughts and ideas are received without consideration of feasibility. The results are shown in Figure 14. The aim is to generate as many solutions / variations as possible. Afterwards, these are examined more closely and prepared for the creation of the concepts.

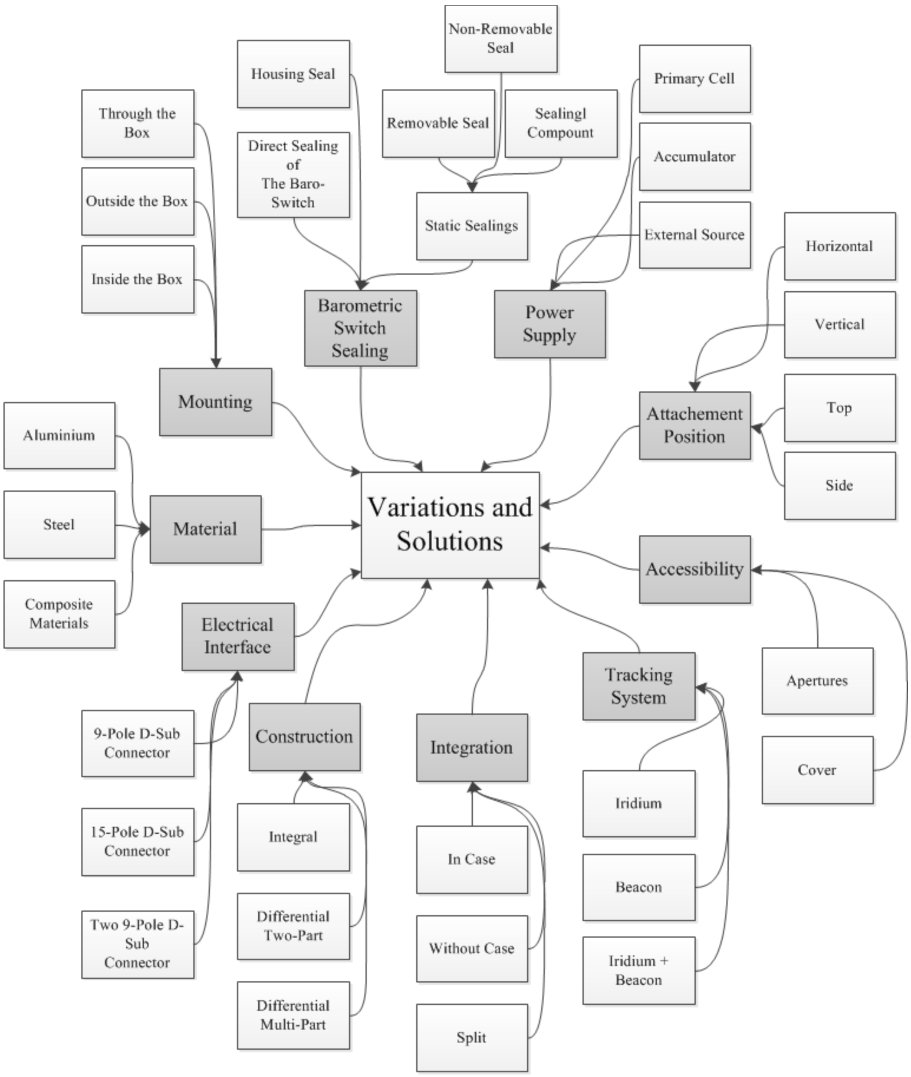


Figure 14: Mind Map with different Variations and Solutions

4.2 Creation of Partial Solutions

In the next step, the results from the mind mapping are examined in more detail and worked out. All ideas are considered, even if at first glance they do not seem to be effective.

Construction

There are three possibilities for the construction, an integral construction from one part as in the already existing housing. In addition, there is the possibility of a differential construction, whereby a further differentiation is made between a two-part or multi-part division of the components. All three solutions offer advantages and disadvantages but can be implemented without restrictions. The Figure 15 shows the three variants.

Figure 15: Representation of the construction from left to right: integral, two-part, multi-part

Tracking System

The tracking system is the central component for fulfilling the main function. Here it is possible to stay with the currently used beacon or to integrate the new iridium system. A third possibility is the combination of the two systems. Both tracking systems are shown in Figure 16.

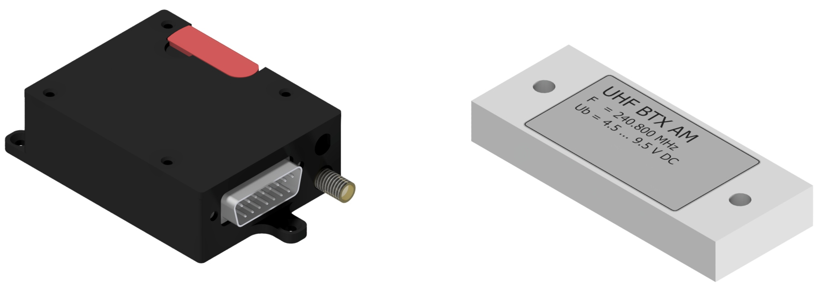


Figure 16: Left: Iridium transmitter, Right: Beacon transmitter

Barometric Switch Sealing

For the sealing, a variety of sealing options come into consideration, whereby a distinction is made between a case sealing and a direct sealing for the baro switch. Only removable seals are suitable for both variants. A non-detachable seal, for example by welding, is not possible due to the replaceability of the component in the case of a defect. For the housing seal, for example, there is the option of a flat seal adapted to the contour or a seal with a sealing compound such as silicone. For the direct sealing of the baro switch, an O-ring is used, which ensures quick and easy replacement.

Attachment Positions

For the positioning of the attachments, especially the connectors, accessibility is essential to make the assembly as easy as possible. Positioning is possible on all four sides as well as from above. The exact positioning of the connectors is not considered in the concept phase yet, this follows in the construction of the selected concept in the next chapter.

Power Supply

The energy source can be realized either as a primary cell or as an accumulator. An alternative would be the power supply via an external source, more precisely via an existing source in the ERS. It must be checked whether the source is sufficient for the additional consumers. The first two possibilities can be implemented without restrictions, but the primary cell does not offer a big advantage over the accumulator, which is the reason why it is not favored. The three variants are shown in Figure 17.

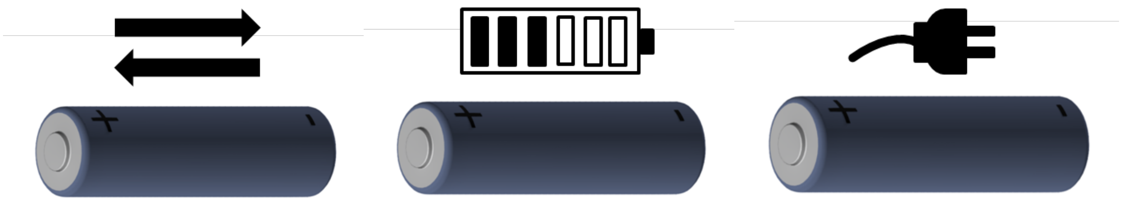


Figure 17: Power Supply Variations from Left to Right: Primary Cell, Accumulator, External Source

Mounting

The Mounting is the attachment of the housing to the existing M4 threaded holes. The first possibility is a bolt connection on the outside of the housing. Another possibility is a bolt connection on the inside of the housing. The last possibility is a through hole through the housing. With the bolt connection on the inside of the housing must be considered that it not match with all construction methods. The other variants can be implemented without restrictions. The different options are shown in the next figure.

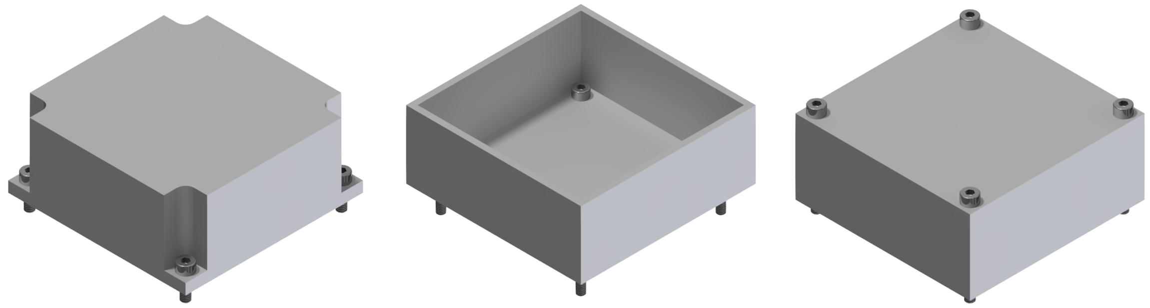


Figure 18: Attachment Options from Left to Right: Outside the Housing, Inside the Housing, Through the Housing

Integration

This determines how the components are integrated into the housing. The first possibility is to integrate all components in the ERS. Another variant would be to divide the integration one part of the components is fastened in the box and another on or at the sides. The last variant would be an integration without housing on the existing bulkhead, thus the main part of the construction is eliminated. Why this variant is not considered further and is only listed for completeness.

Electrical Interface

The electrical interface of the tracking unit, this is realized by a standard D-Sub. Only the number of pins is varied and is between 9 and 18. This gives the following possibilities a 9 pole D-Sub, a 15 pole D-Sub or two 9 pole D-Sub.

Material

An aviation aluminum alloy has established itself. The relation between costs, mass and manufacturability dominates there. Steel and composite materials were available as alternatives. The problem there is either too much mass or more complex production and the associated higher costs.

4.3 Concept Creation

After the development of the partial solutions, all results were listed in a morphological box, which is shown in Table 1. There the most important variation features are listed and graphically represented. In order to ensure that there are no conflicts between individual solution variants, a compatibility matrix was created which is shown in Table 2.

The compatibility matrix shows that almost all combinations are possible. The different variants of a variation feature are not compatible with each other. There are also problems with the bolt connection from the inside of the housing in combination with an integral construction, because otherwise the box would have to be open to get to the bolts. A further point is the component integration without box whereby all three construction methods would be omitted and thus the central component of the work. The last problem is between a differential multi-part design and sealing with a flat sealing or sealing compound as these solutions are too complex for several parts. The compatibility matrix is shown in Table 2 where the critical areas are represented by a black dot.

Table 1: Morphological Box

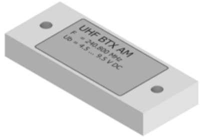
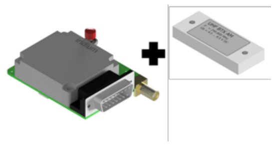
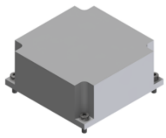
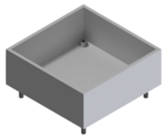
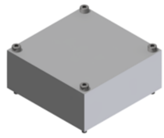
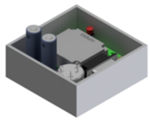
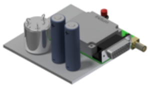
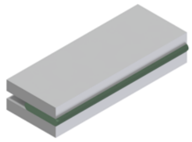
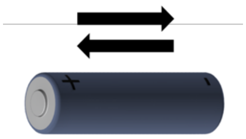
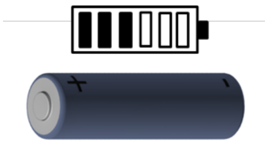
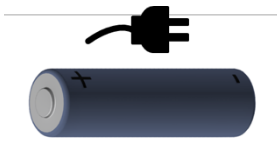
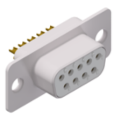
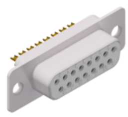
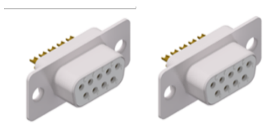
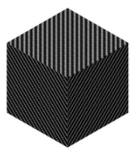
design features	Variation I	Variation II	Variation III
Construction	 Integral	 Differential: two-part	 Differential: multi-part
Tracking system	 Iridium (GPS)	 Beacon (Radio)	 Iridium + Beacon
Mounting	 Outside the housing	 Inside the housing	 Through the housing
Integration	 All inside	 All outside	 mixed
Baro Switch Sealing	 O-Ring (part)	 Flat sealing (Housing)	 Sealing compound
Power supply	 Primary Cell	 Accumulator	 External source
Electrical Interface	 D-Sub 9 pole	 D-Sub 15 pole	 2 x D-Sub 9 pole
Material	 Aluminum	 Steel	 Composite

Table 2: Compatibility Matrix

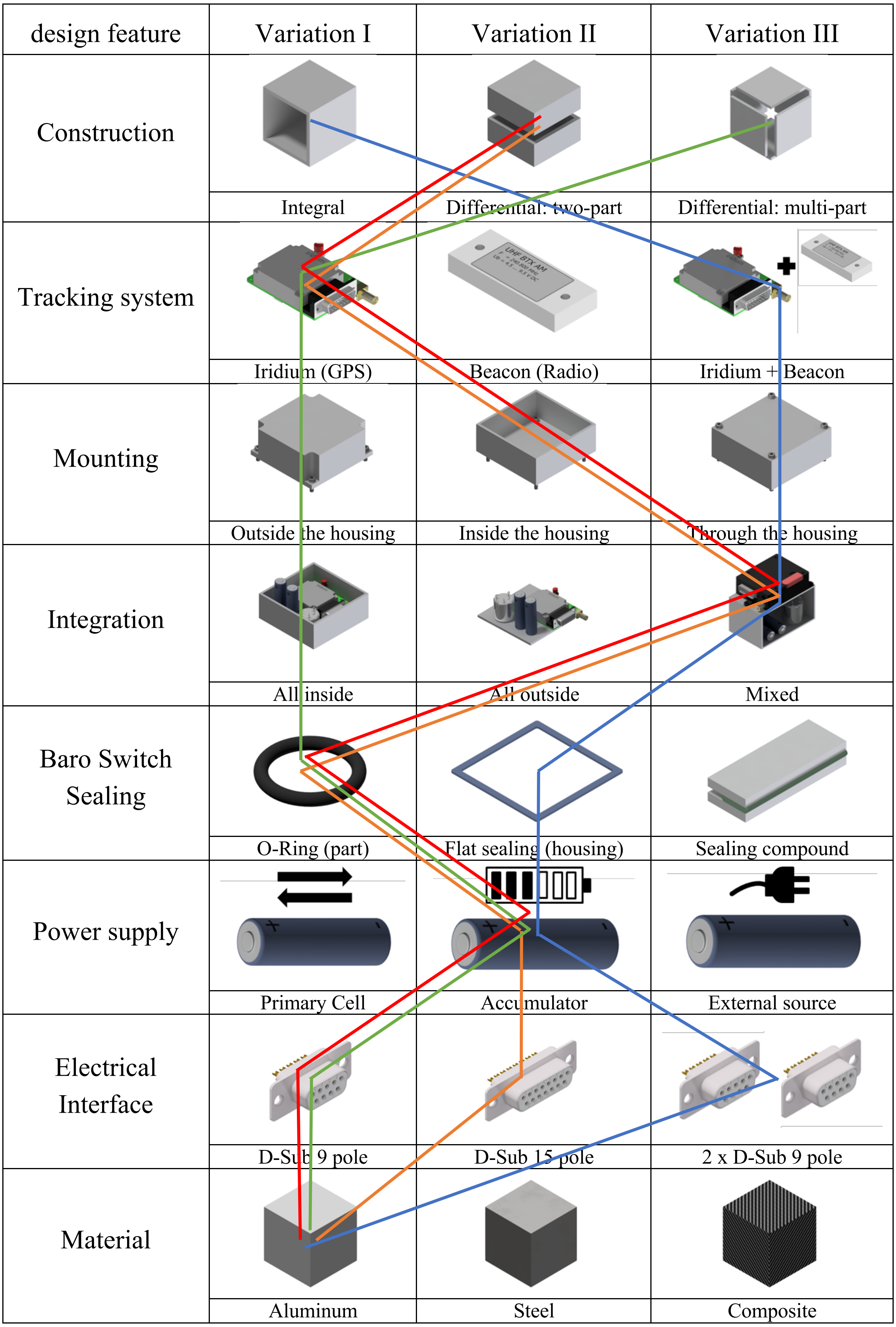
Compatibility matrix	Construction: Integral	Construction: Differential: two-part	Construction: Differential: multi-part	Tracking system: Iridium (GPS)	Tracking system: Beacon (Radio)	Tracking system: Iridium + Beacon	Attachment: Outside the box	Attachment: Inside the box	Attachment: trough the box	Part integration: In case	Part integration: Without case	Part integration: Split	Sealing: O-Ring (part)	Sealing: Flat seal (case)	Sealing: compound	Power supply: Primary cell	Power supply: Accumulator	Power supply: External source	Electrical connection: D-Sub 9 pole	Electrical connection: D-Sub 15 pole	Electrical connection: 2 x D-Sub 9 pole	Material: Aluminium	Material: Steel	Material: Composite
Construction: Integral		●	●	○	○	○	○	●	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Construction: Differential: two-part			●	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Construction: Differential: multi-part				○	○	○	○	○	○	○	●	○	○	●	●	○	○	○	○	○	○	○	○	○
Tracking system: Iridium (GPS)					●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Tracking system: Beacon (Radio)						●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Tracking system: Iridium + Beacon							○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Attachment: Outside the box								●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Attachment: Inside the box									●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Attachment: trough the box										○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Part integration: In case											●	●	○	○	○	○	○	○	○	○	○	○	○	○
Part integration: Without case												●	○	○	○	○	○	○	○	○	○	○	○	○
Part integration: Split													○	○	○	○	○	○	○	○	○	○	○	○
Sealing: O-Ring (part)														●	●	○	○	○	○	○	○	○	○	○
Sealing: Flat seal (case)															●	○	○	○	○	○	○	○	○	○
Sealing: compound																○	○	○	○	○	○	○	○	○
Power supply: Primary cell																	●	●	○	○	○	○	○	○
Power supply: Accumulator																		●	○	○	○	○	○	○
Power supply: External source																			○	○	○	○	○	○
Electrical connection: D-Sub 9 pole																				●	●	○	○	○
Electrical connection: D-Sub 15 pole																					●	○	○	○
Electrical connection: 2 x D-Sub 9 pole																						○	○	○
Material: Aluminium																							●	●
Material: Steel																								●
Material: Composite																								

● : incompatible
○ : compatible

The information in the compatibility matrix can now be used to create concepts. Special care has to be taken to ensure that all variants of the construction are taken into account because it is the central component of the tracking unit. The different concept paths can be seen in Table 3. A total of four different concepts were created, which are characterized by the four different paths in the morphological box. The concepts are marked as follows:

- Green: Concept I
- Orange: Concept II
- Green: Concept III
- Red: Concept IV

Table 3: Different Concept Developments



design feature	Variation I	Variation II	Variation III
Construction	Integral	Differential: two-part	Differential: multi-part
Tracking system	Iridium (GPS)	Beacon (Radio)	Iridium + Beacon
Mounting	Outside the housing	Inside the housing	Through the housing
Integration	All inside	All outside	Mixed
Baro Switch Sealing	O-Ring (part)	Flat sealing (housing)	Sealing compound
Power supply	Primary Cell	Accumulator	External source
Electrical Interface	D-Sub 9 pole	D-Sub 15 pole	2 x D-Sub 9 pole
Material	Aluminum	Steel	Composite

4.4 Concept Presentation

In the following, the individual concepts are presented and described in order to evaluate them objectively against each other. The individual implementation of the most important function is dealt with and explained.

4.4.1 Concept I

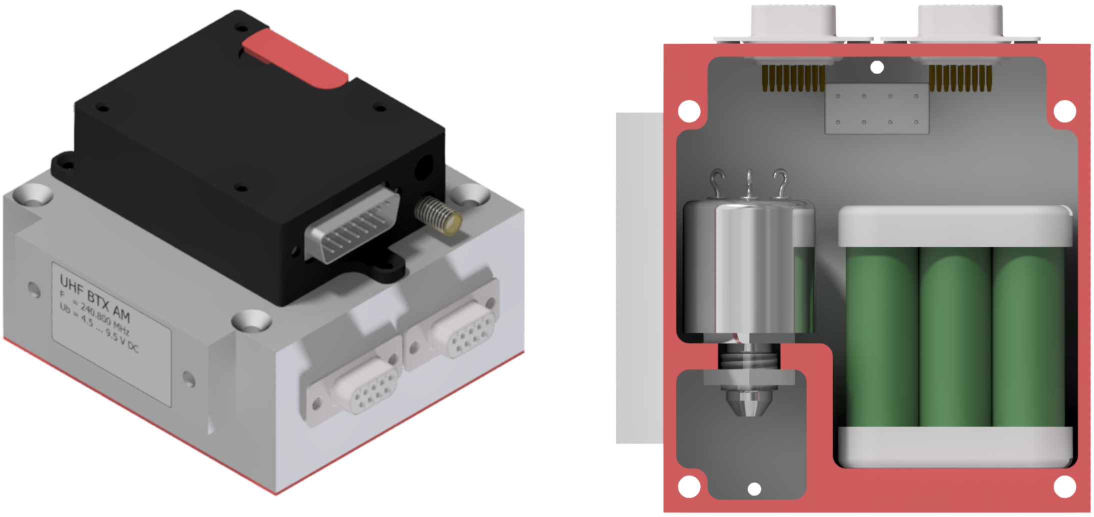


Figure 19: Overview of Concept I

Concept I is an integral construction in which the box is fixed from the outside with the use of through-holes. The component integration was split between the top of the housing and the inside. The Iridium system remains in the purchased condition and is screwed to the top. An accumulator located in the inside is used as the power supply. The baro switch is sealed by a flat sealing located between the housing and the bulkhead. The baro switch is pushed into a slot and then clamped with a nut. For the feedthrough of the electronics two 9 pole D-Sub connectors are used. An aluminium alloy is used as the material. No additional components are required to fasten the components.

Concept I has the following dimensions 65mm x 90mm x 82mm. A total of 16 connecting elements are required for assembly. The

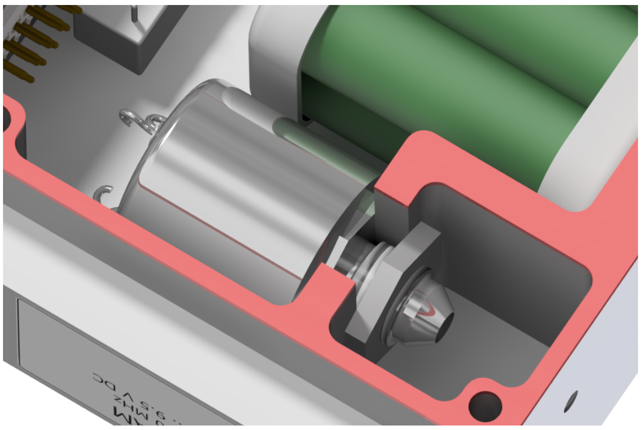


Figure 20: Integration of the Baro Switch

production is carried out through various processing steps, the majority of which are milling, drilling and thread cutting. To estimate the manufacturing costs, the number of components processing steps and processing surfaces of the component were estimated, whereby a high number of steps is equivalent to higher costs. The estimation is shown in the Table 4, the overview drawing used for the estimation is shown in Appendix A1.

Table 4: Cost Estimation for Concept I

Concept I									
Part	Number of processing Surfaces	Processing Steps							Total
		Milling to Size	Pocket Milling	Connector Cut-Out	Slot Milling	Drilling	Lowering	Thread Cutting	
Housing	6	6	2	2	1	16	4	12	49

4.4.2 Concept II

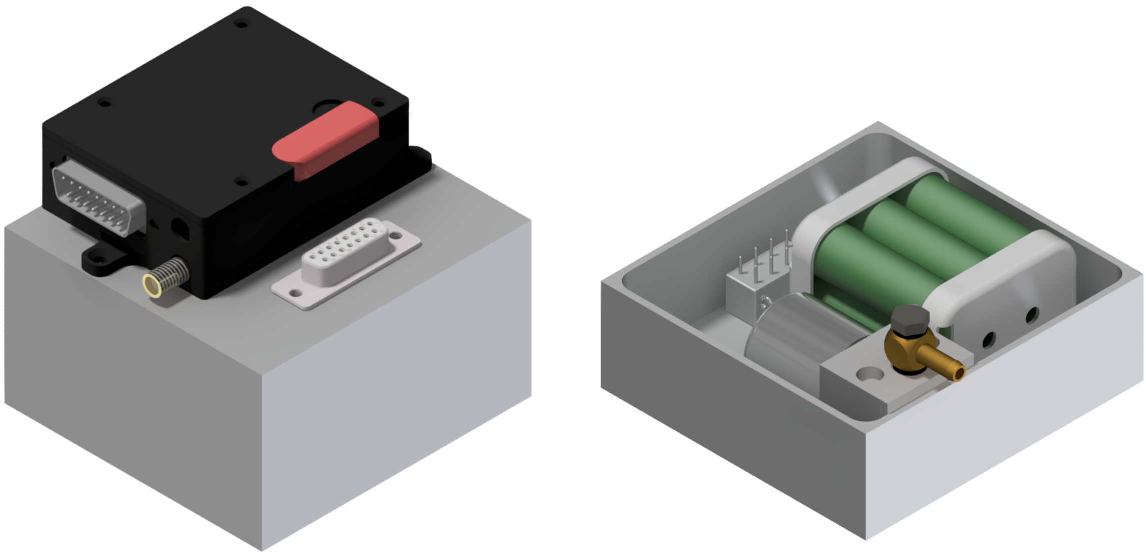


Figure 21: Overview of Concept II

In concept II, the housing was divided into two parts. The housing is fastened from the inside of the lower housing part. The Iridium system also remains in the purchased condition and is attached to the upper part of the case. The battery is attached to the housing by two brackets. An O-ring is used to seal the baro switch, the baro is screwed into a block which is in turn fastened to the housing as shown in Figure 22. A 15-pole D-Sub connector is used for the feedthrough of the cabling. As in the first concept, an aluminium alloy is used as the material. For the fastening of the components additional parts are needed as already mentioned above.

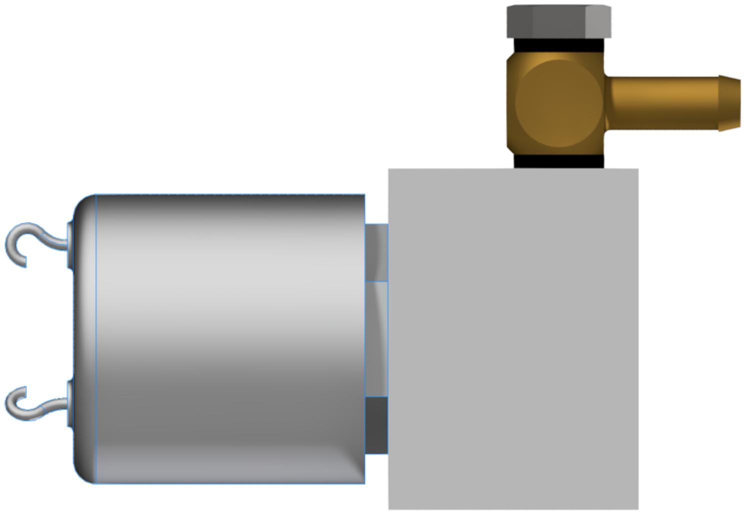


Figure 22: Baro Switch and Bracket

Concept II has the following dimensions 90mm x 86mm x 75mm. 23 connecting elements are required for assembly. The costs were estimated exactly as in concept I, only that the machining areas and machining steps for all required components were estimated and then summed up. The result is shown in the following table. The overview drawing used for this purpose can be found in Appendix A2.

Table 5: Cost Estimation of Concept II

Concept II									
Part	Number of processing Surfaces	Processing Steps							Total
		Milling to Size	Pocket Milling	Connector Cut-Out	Slot Milling	Drilling	Lowering	Thread Cutting	
Housing Upper Part	2	6	1	0	0	14	4	10	37
Housing Top Part	3	6	1	1	1	13	4	5	34
Baro-Bracket	2	6	0	0	0	4	3	2	17
Battery-Bracket	2	2	0	0	0	4	0	0	8
Total									96

4.4.3 Concept III

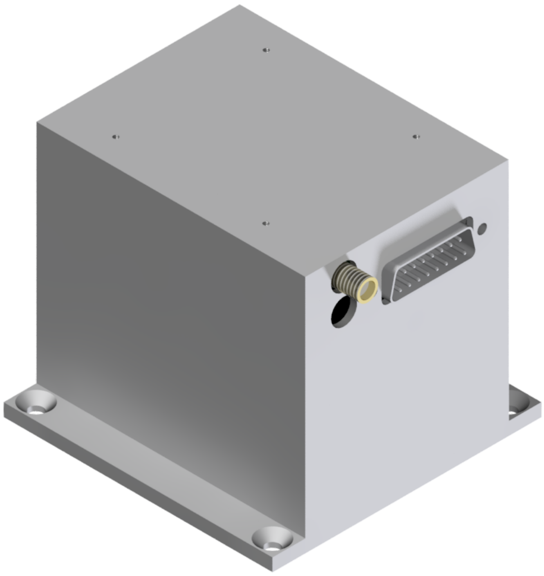


Figure 23: Overview of Concept III

Concept III is a differential build and consists of several components. The box is attached to the outside as shown in the Figure 24 above. The Iridium system is removed from the supplied housing, then only the electronics of the Iridium system are installed, thus reducing the installation space. The baro switch is installed as in Concept II, but no additional component is necessary, instead it is screwed directly into a side part and sealed via an O-ring. The power supply is realized by an accumulator and screwed between the side parts. A 9-pole standard D-Sub connector is used for the feedthrough of the electronics.

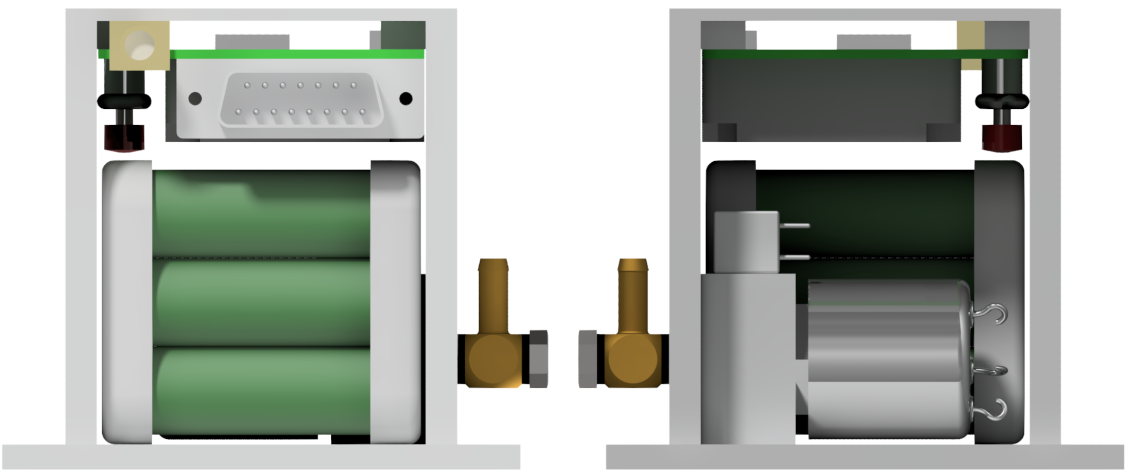


Figure 24: Sideview of Concept III

The dimensions of Concept III are 82mm x 62mm x 73mm. 38 connecting elements are required for assembly. The cost estimate is shown in Table 6, the overview drawing used for it is shown in Appendix A3.

Table 6: Cost Estimation for Concept III

Concept III									
Part	Number of processing Surfaces	Processing Steps							Total
		Milling to Size	Pocket Milling	Connector Cut-Out	Slot Milling	Drilling	Lowering	Thread Cutting	
Bottom Plate	2	4	0	0	0	10	8	0	24
Top	2	5	1	0	0	10	6	4	28
Back	1	4	0	1	0	8	6	2	22
Front	1	4	0	1	0	10	6	0	22
Side Plate	5	4	0	0	0	14	2	12	37
Side Plate Baro	6	5	1	0	0	16	1	16	45
Total									178

4.4.4 Concept IV

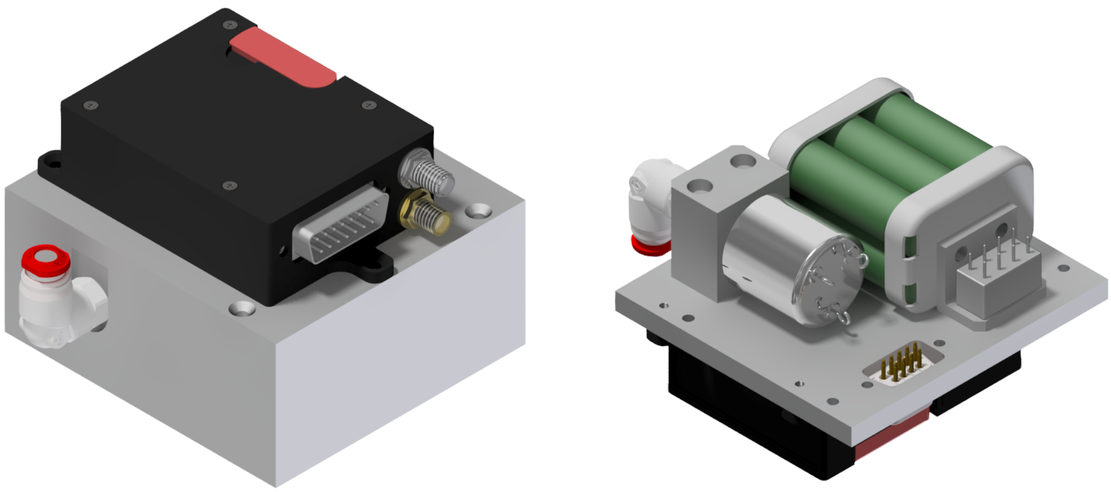


Figure 25: Overview of Concept IV

Concept IV consists of a two-piece housing. The big difference to concept II is that all components are integrated into the cover, so the electronics can be removed without having to remove the complete housing. The Iridium system is located on the outside and is screwed into the supplied housing. The battery and baro switch are fixed on the underside of the cover. The housing is screwed to the bulkhead from the inside. The baro switch is sealed by an O-ring just like in Concept II and screwed over a baro bracket as shown in Figure 22. The energy source is an accumulator that is attached to a bracket. The electronics are feedthrough via a 9-pole standard D-Sub connector.

The dimensions of Concept IV are 89mm x 82mm x 65mm. A total of 21 connecting elements are used for assembly. The estimate of the costs is shown in Table 7, the overview drawing required for this is shown in Appendix A4.

Table 7: Cost Estimation for Concept IV

Concept IV									
Part	Number of processing Surfaces	Processing Steps							Total
		Milling to Size	Pocket Milling	Connector Cut-Out	Slot Milling	Drilling	Lowering	Thread Cutting	
Housing	3	6	1	0	1	8	4	4	27
Cover	1	4	0	1	0	15	8	7	36
Baro-Bracket	3	6	0	0	0	4	3	2	18
Battery-Bracket	2	2	0	0	0	4	0	0	8
Total									89

4.5 Concept Evaluation

The evaluation attempted to achieve as objective an assessment of the concepts as possible. In the first step, the evaluation criteria were defined and described. The criteria and their descriptions are shown in Table 8. A high number of points is preferred.

Table 8: Evaluation Criteria

Points	1	2	3	4
Costs	Number of Parts, processing surfaces, -steps > 150	Number of Parts, processing surfaces, -steps > 100 <= 150	Number of Parts, processing surfaces, -steps > 50 <= 100	Number of Parts, processing surfaces, -steps <= 50
Space [cm^3]	>= 600	>= 500 < 600	>= 400 < 500	< 400
Mountability	Number of connecting elements > 30	Number of connecting elements <= 30 > 20	Number of connecting elements <= 20 > 10	Number of connecting elements <= 10
Accessibility	Complete removal of the box necessary	Restricted access to components	Access to all built-in components	Quick and easy access to the components
Tightness	No complete sealing, complex implementation	Possibilities of leaks, complex implementation	Complete sealing, complex implementation	Complete sealing, simple implementation

The concepts are evaluated against each other in a weighted point evaluation. First of all, the priority is determined, paying special attention to the costs, but also to the mountability, space and accessibility. In the next step, the characteristics of the concepts are determined, and the simple score is awarded. Finally, the points are multiplied by the priority and the total number of points is calculated. The complete evaluation is shown in Table 9.

Table 9: Evaluation of the Concepts

Evaluation Criteria	Space		Mountability		Costs		Tightness		Accessibility	
Priority	20		20		25		15		20	
Concept I	500 cm^3		16		49		-		--	
Concept II	581 cm^3		23		96		++		-	
Concept III	371 cm^3		38		178		++		-	
Concept IV	480 cm^3		21		89		++		++	
Points	Points	Priority	Points	Priority	Points	Priority	Points	Priority	Points	Priority
Concept I	2	40	3	60	4	100	2	30	1	20
Concept II	2	40	2	40	2	50	4	60	2	40
Concept III	4	80	1	20	1	25	4	60	2	40
Concept IV	3	60	2	40	3	75	4	60	4	80

Concepts	Concept I	Concept II	Concept III	Concept IV
Total Points	250	230	225	315

The results of the evaluation are very clear. Concept III was evaluated the worst, concept I and II are in the midfield. Concept IV was evaluated the best, which will be worked out in the following chapter.

5 Construction

In the following chapter, the most important steps of the elaboration are briefly described. Afterwards, the Tracking Unit and its components are presented. Finally, drawings are to be generated for the individual components so that the tracking unit can be manufactured.

5.1 Construction Procedure

In the first step, the component arrangement is reconsidered and checked for possible collisions. The beacon tracking unit in CAD is replaced with the new concept and checked for collisions in the assembly. Figure 26 shows, that there is a collision between the hose adapter and the lift-off switch in the current component arrangement.

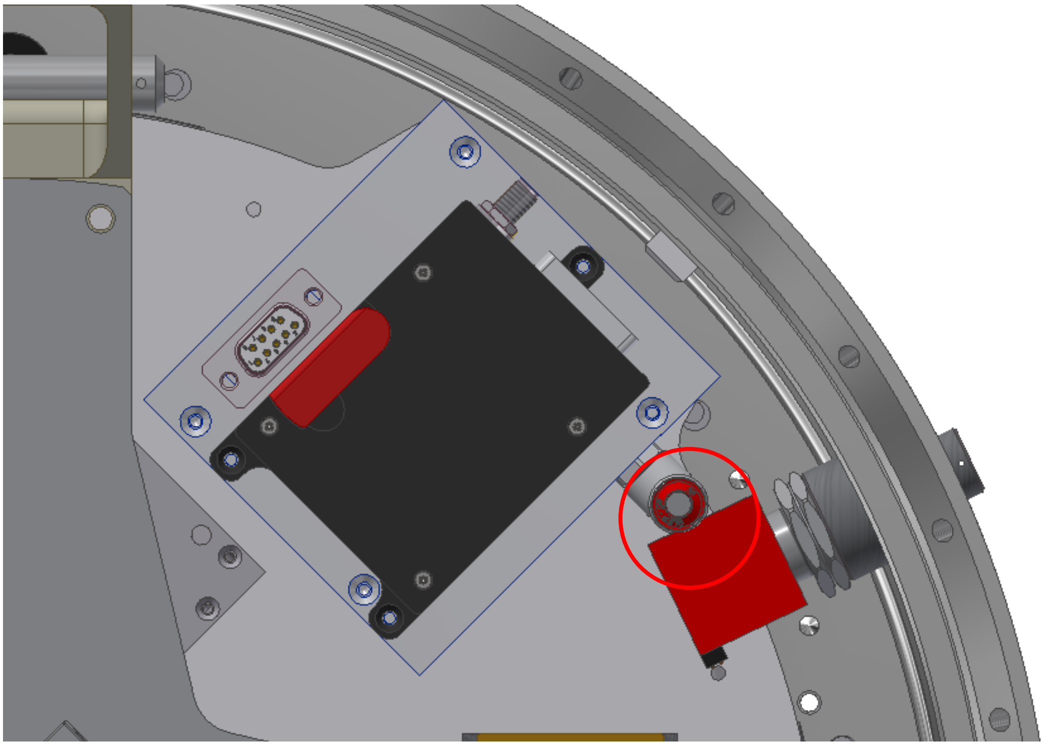


Figure 26: Collision between Hose Adapter and Lift-Off Switch

Collision can be prevented by simply rearranging the components. The battery is replaced with the baro switch on the cover. Figure 27 shows the new positioning.

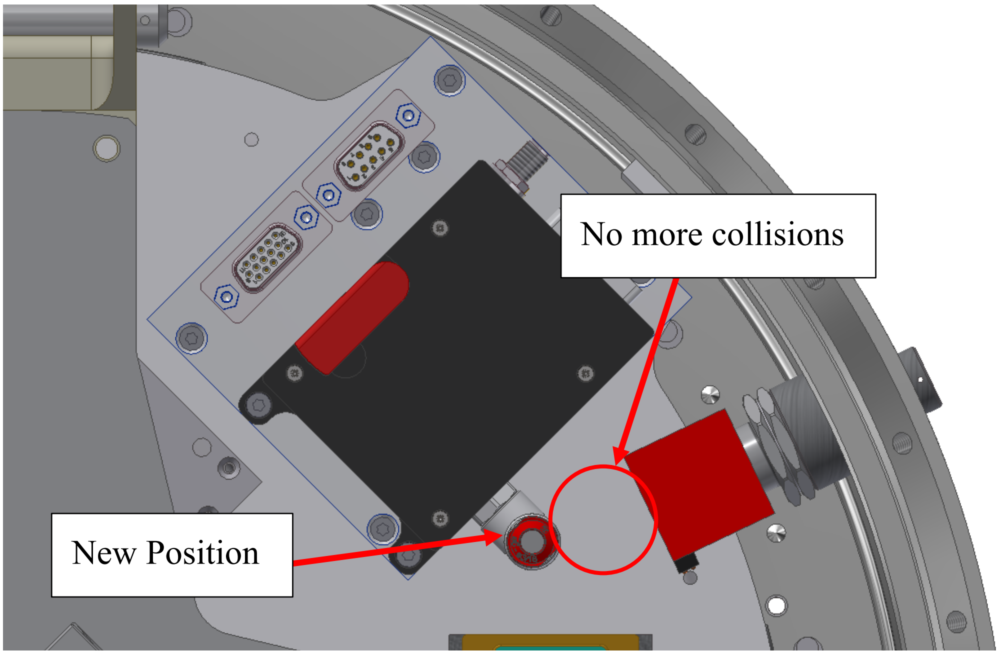


Figure 27: Repositioned Components

Next, the G-switches and their wiring are positioned and attached to the new system. The position of the G-switches should be in the same position as on the old B-Box. The new positions were determined using the installation space model by overlaying both models. In Figure 28 the red area shows the old position of the G-switches in grey, the new position can be seen.

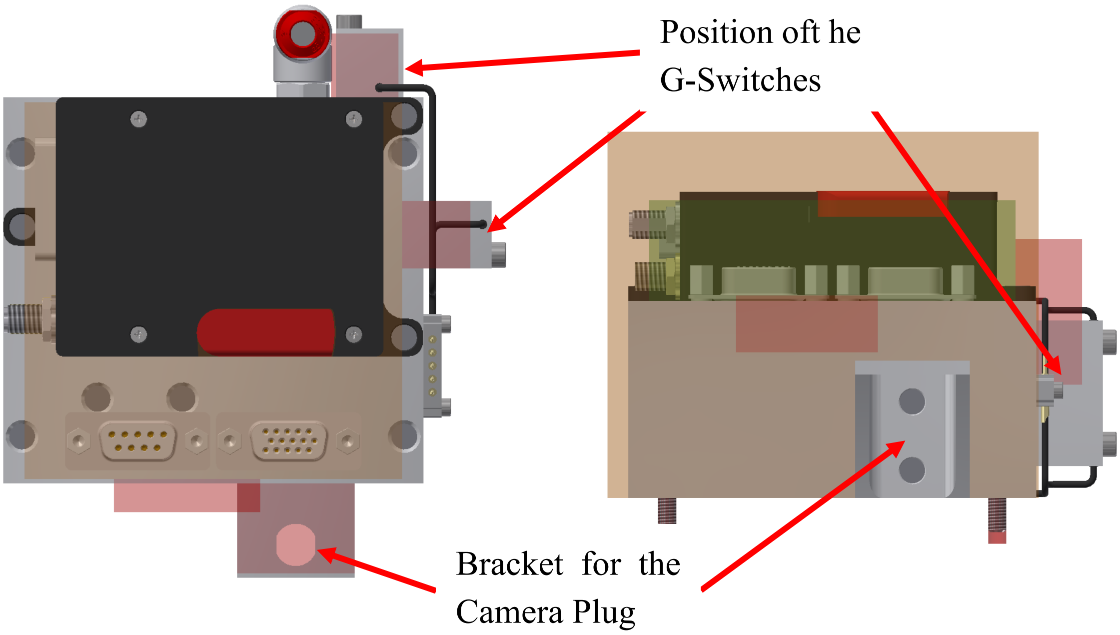


Figure 28: Overlay of the two Models

As shown in Figure 28 on the left, the position of the G-switches has hardly changed. The red and grey areas cover each other to a large extent. Only the height of a G-switch has changed as can be seen on the right side of Figure 28. Changing the height has no effect on the function of the G-switches. The G-switches are each fixed to the housing with two M3 cylinder head screws.

The wiring of the switches is attached to the outside of the box as in the old box and ends in a 5-pole plug, which is attached to the housing with two M2 cylinder head screws. In addition, the threads for the mating connector are located on the housing, which is not shown in the following figure. Figure 29 shows the G-switches and the wiring to the housing.

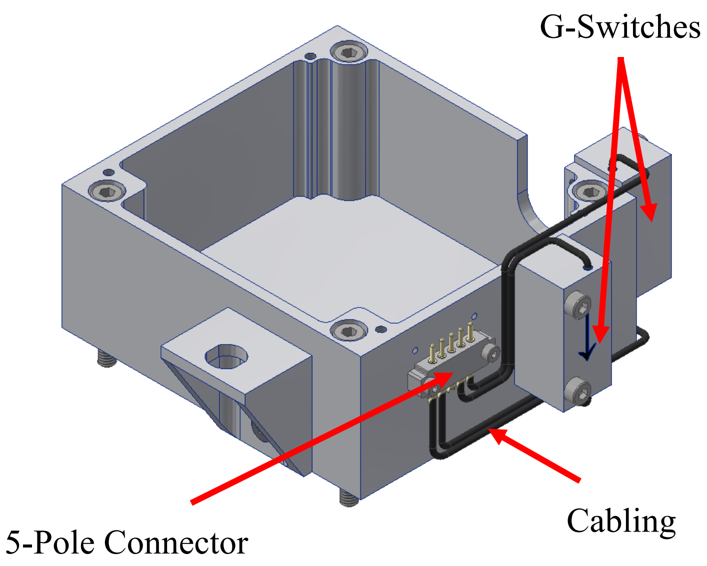


Figure 29: Position of the G-Switches and the Wiring

The next step is to attach the bracket for the camera plug to the housing. The position is very important for retrofitting the system, because the cabling in the ERS system exists and cannot be adapted. As with the G-switches, a overlap with the installation space model is used for this, which can be seen in Figure 28 The position can be taken exactly so that no problems with the wiring can occur. The bracket is attached to the housing with two M3 countersunk screws

The next step is to install a 15-pole HD D-Sub connector, which is necessary and serves as an interface to the other systems in the ERS. The position cannot be determined here as before using only the installation space model. This is used as a rough orientation but for the exact determination the wiring tree is checked in the real

ERS, which is shown in Figure 30. The connector P416 is important here, the position of the box is shown with a dashed blue line.

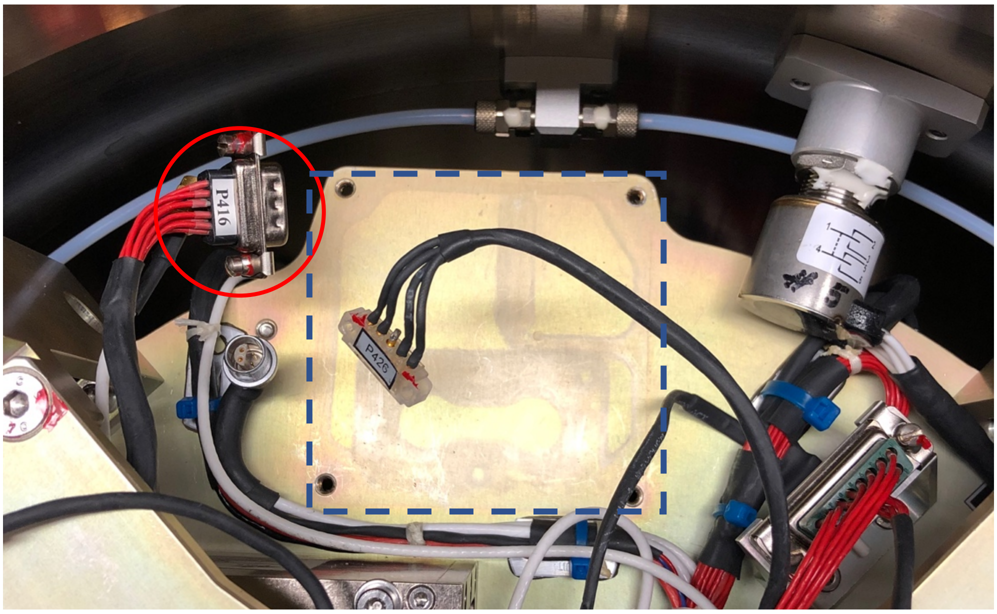


Figure 30: Wiring of the ERS

The position is slightly changed due to the available length. The connector is no longer attached to the side, but to the top of the cover. This improves accessibility and simplifies assembly and disassembly. Figure 31 shows the new and old position of the D-Sub connector. The connector is attached to the cover of the box with two spacer bolts.

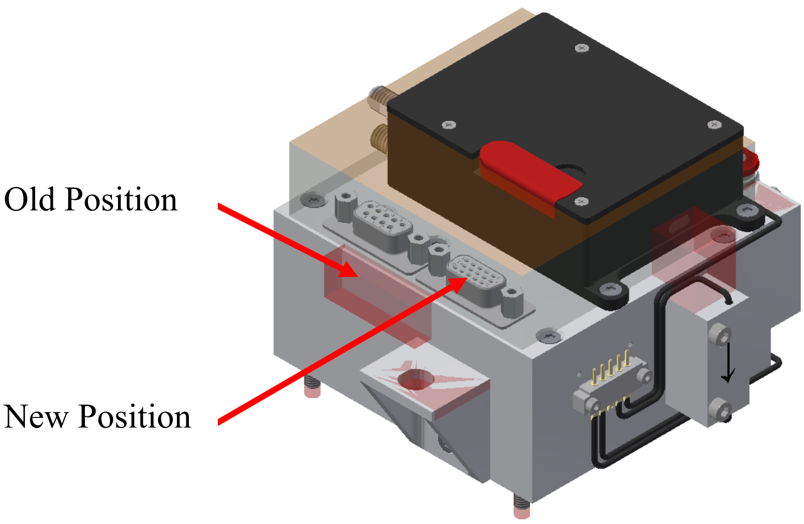


Figure 31: Old and New Position of the D-Sub Connector

In the last step, the components required for the iridium are integrated. This is an amplifier and a coupler. The amplifier is placed on the free side of the case which can be easily implemented. The coupler is placed between the iridium and the cover. This results in mounting difficulties with the D-Sub connectors and fixing screws to the housing. Figure 32 shows the problem.

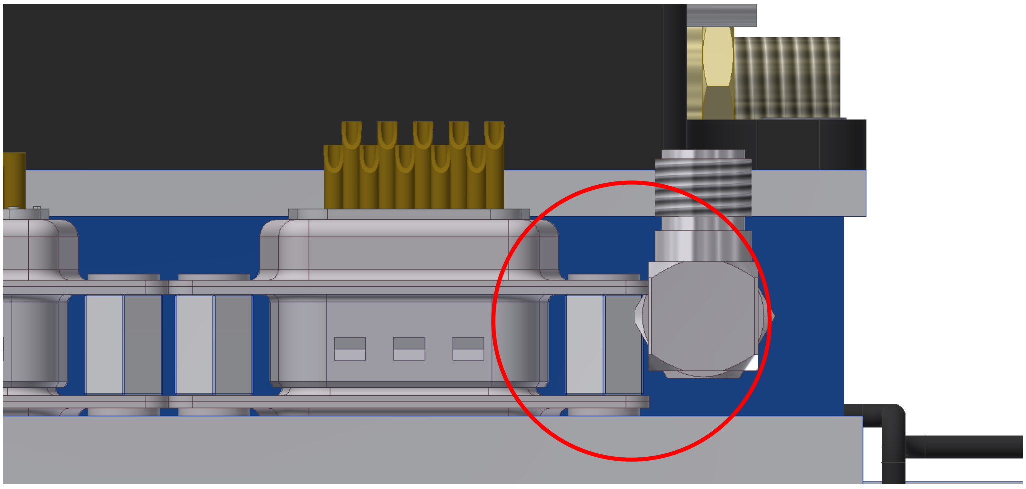


Figure 32: Collision between D-Sub and Coupler

To ensure accessibility, spacer bolts are used to create enough space to attach the D-Sub connectors and antenna cables to the coupler. In addition, the cover can be screwed to the housing again without further problems. For mounting the iridium, an adapter plate is required between the coupler and the iridium. Figure 33 shows the final placement of the components. All necessary components of the tracking unit are now placed.

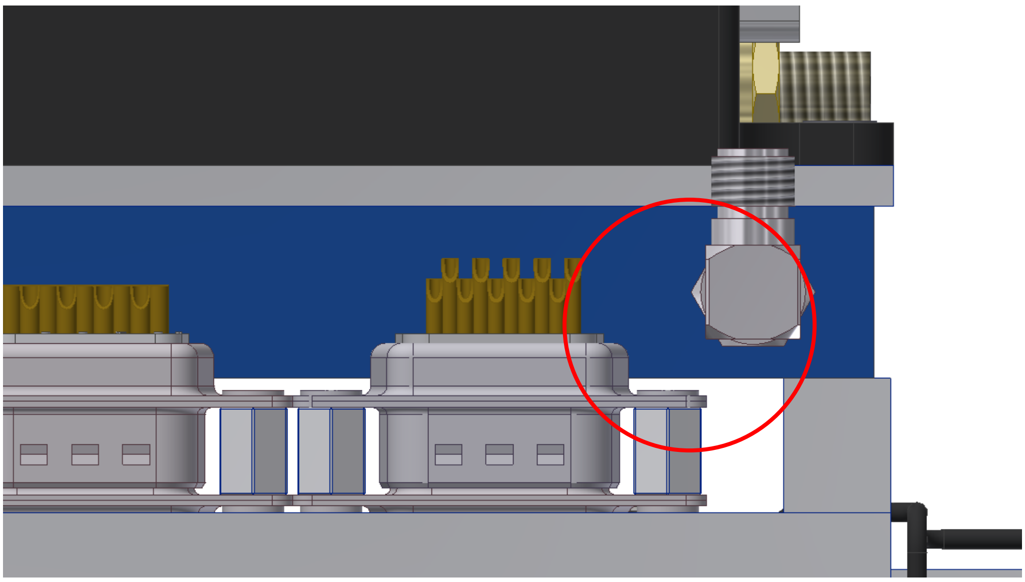


Figure 33: Position of the Coupler and Adapter Plate

5.2 Presentation of the Tracking Unit

The Tracking Unit consists of two assemblies, the housing and the cover. The housing provides the connection to the bulkhead and is used to attach the G-switches, camera plug bracket and amplifier. This offers the advantage that the housing only has to be mounted once. In addition, the components are positioned so that the attachments can be taken directly from an old BB. This ensures that the new tracking unit can be retrofitted without any problems.

The cover is the core of the construction. All functionally relevant components are attached to the cover. By simply removing the connecting screws between cover and housing and disconnecting the plugs, the cover can remove together with the electronics. This offers the advantage that technical problems of a component can be solved quickly and easily. The plug connections are oriented upwards to improve accessibility and thus further simplify assembly.

The locating function is implemented via an iridium system. This is located on the cover. A coupler and an amplifier are required to send GPS and Iridium signals via a pair of antennas. The advantages of iridium compared to the old beacon are listed in the chapter Fundamentals.

The baro switch with hose adapter is designed as a closed in itself sealed system. It is attached to the housing via an adapter. It is sealed by two O-rings on the baro switch and on the hose adapter. This ensures that the system is leak-proof and that there are no problems during the function test.

An accumulator is used as power supply which can be charged via the 9-pole D-Sub connector or via a umbilical connector. This means that a complicated removal as in the old system is no longer necessary.

5.3 Description of the individual Parts

5.3.1 Housing

The housing is an integral component made of EN AW 7075, the aluminium alloy was selected because the company has a lot of experience and it is not a strength-relevant component. The following components are also made of EN AW 7075. The housing has been designed to be as simple as possible to keep manufacturing costs as low as possible.

The height was increased by 6mm after a first 3D print prototype to ensure enough space for the wiring. Figure 34 shows the Prototyp.

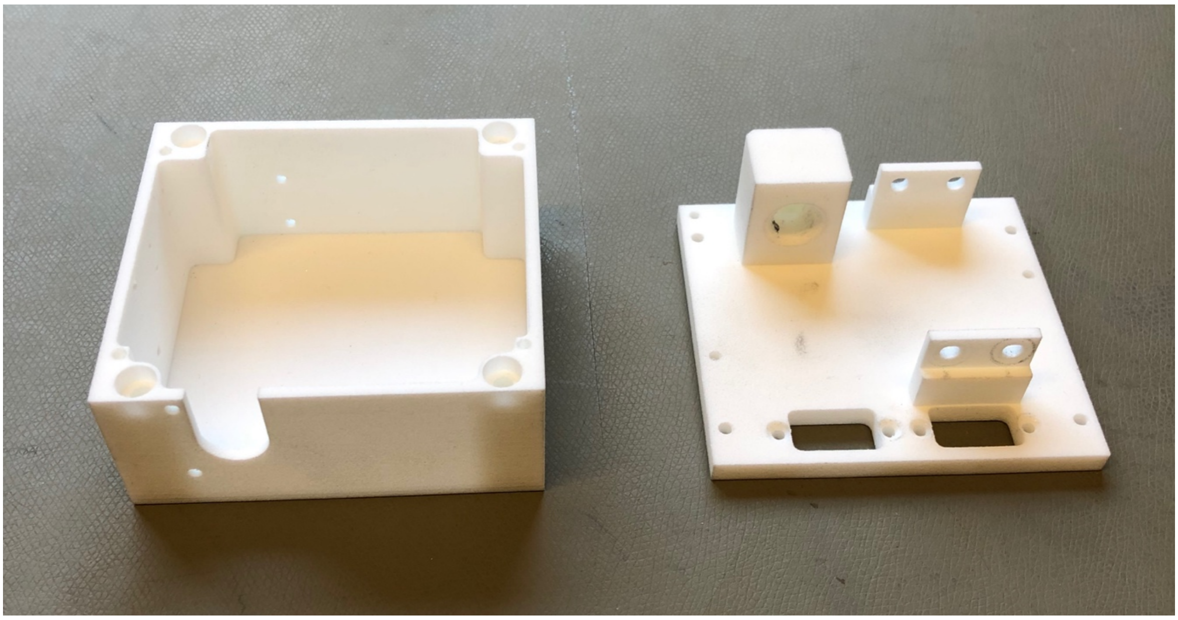


Figure 34: Prototyp

The drawings can be found in Appendix A5. Figure 35 shows the housing.

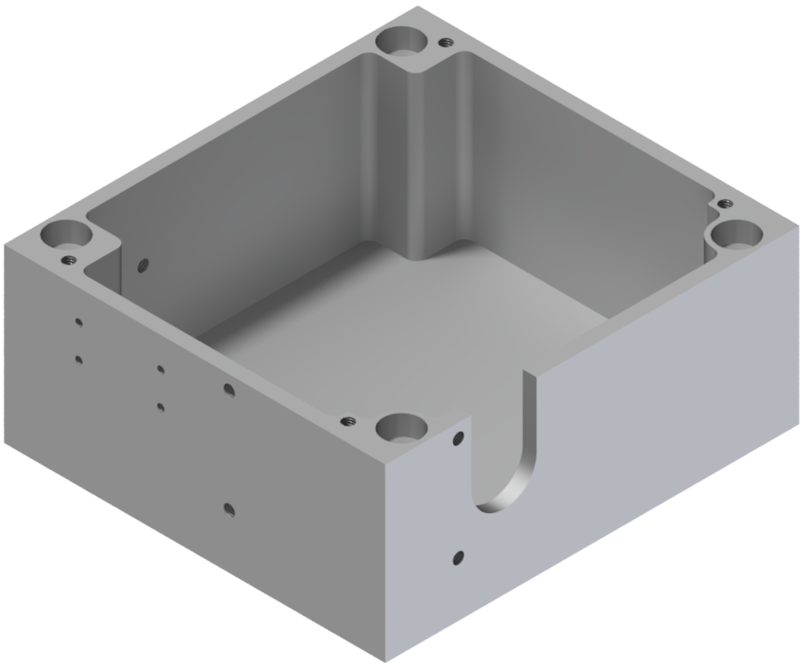


Figure 35: Housing of the Tracking Unit

5.3.2 Cover

The cover was initially designed as a simple plate on which the various components are screwed together. An integral construction method was preferred in order to save costs. This not only saves costs, but also has the advantage that fewer connecting elements are required, making assembly easier. The distance between the battery brackets is set to the upper limit due to the battery tolerance to ensure that the batteries fit properly. Figure 36 shows the cover, the drawings are in Appendix A6.

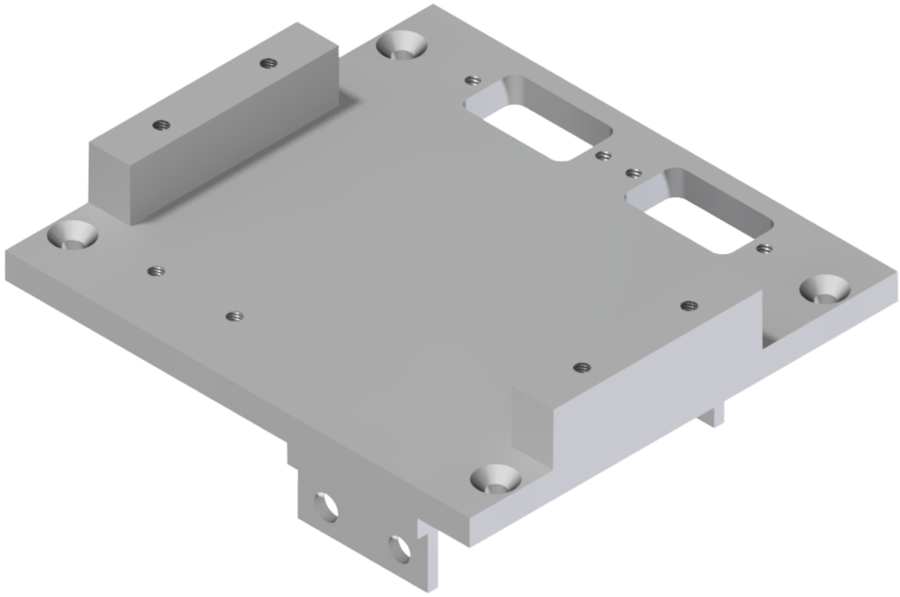


Figure 36: Cover of the Tracking Unit

5.3.3 Baro-Bracket

The baro bracket was developed on the basis of existing systems that have already been successfully flown. The connecting hole for the baro switch and the countersink for the O-ring seal were adopted. The chamfers are required because of the rounding in the housing. Figure 37 shows the baro switch, the corresponding drawings are in Appendix A7.

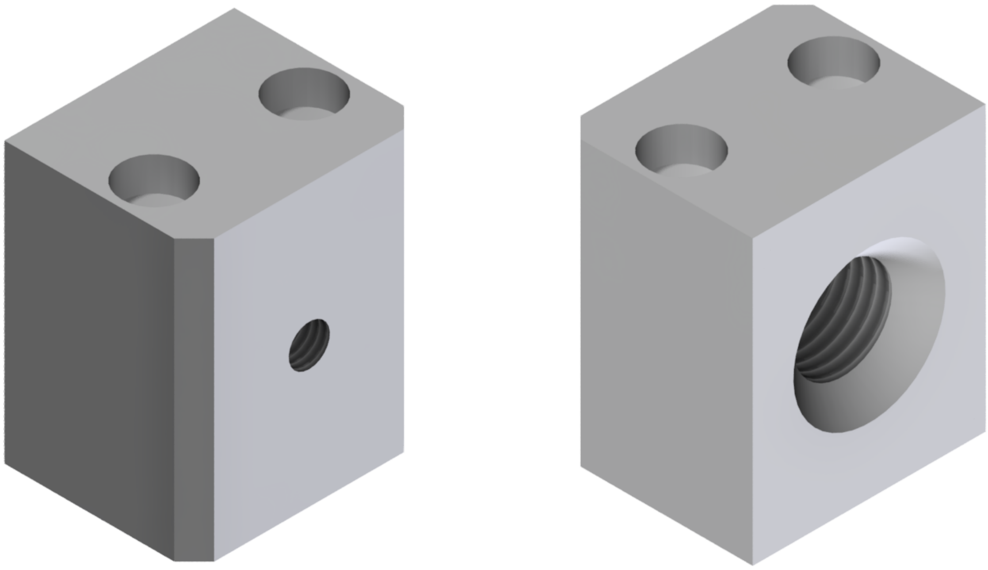


Figure 37: Baro-Bracket

5.3.4 Adapter-Plate

The adapter plate is designed to be as simple and light as possible. Figure 38 shows the adapter plate, the drawings are shown in Appendix A8.

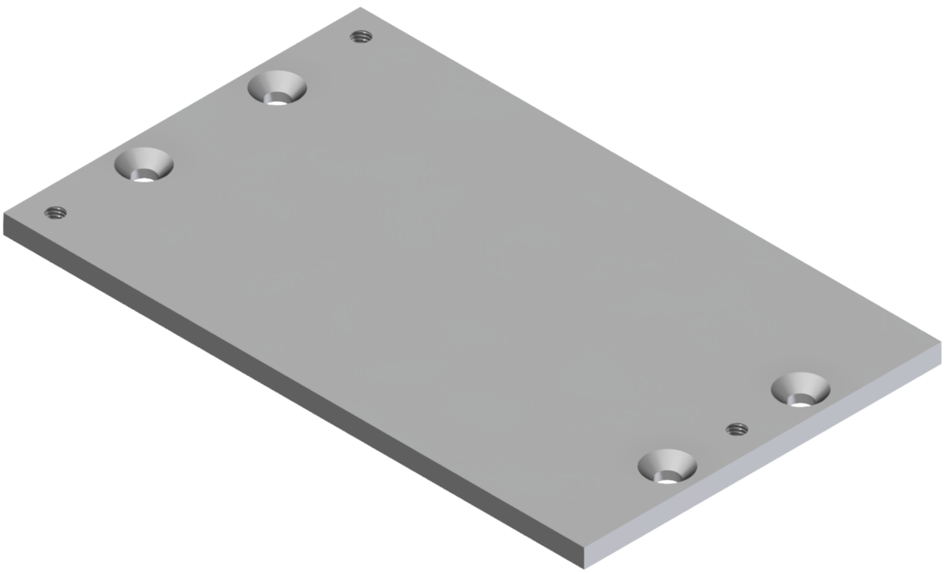


Figure 38: Adapter Plate

6 Tests

6.1 Integration Test

In the integration test, it was determined whether the new Iridium tracking unit could be integrated into an existing ERS. The new Iridium tracking unit was installed step by step and connected to the existing connectors.

6.1.1 Experimental Set-Up

The basis is an existing ERS where the old beacon tracking unit is expanded. The new Iridium tracking unit is equipped with all attachments and cabling. Figure 39 shows the installation space in the ERS and the new tracking unit.

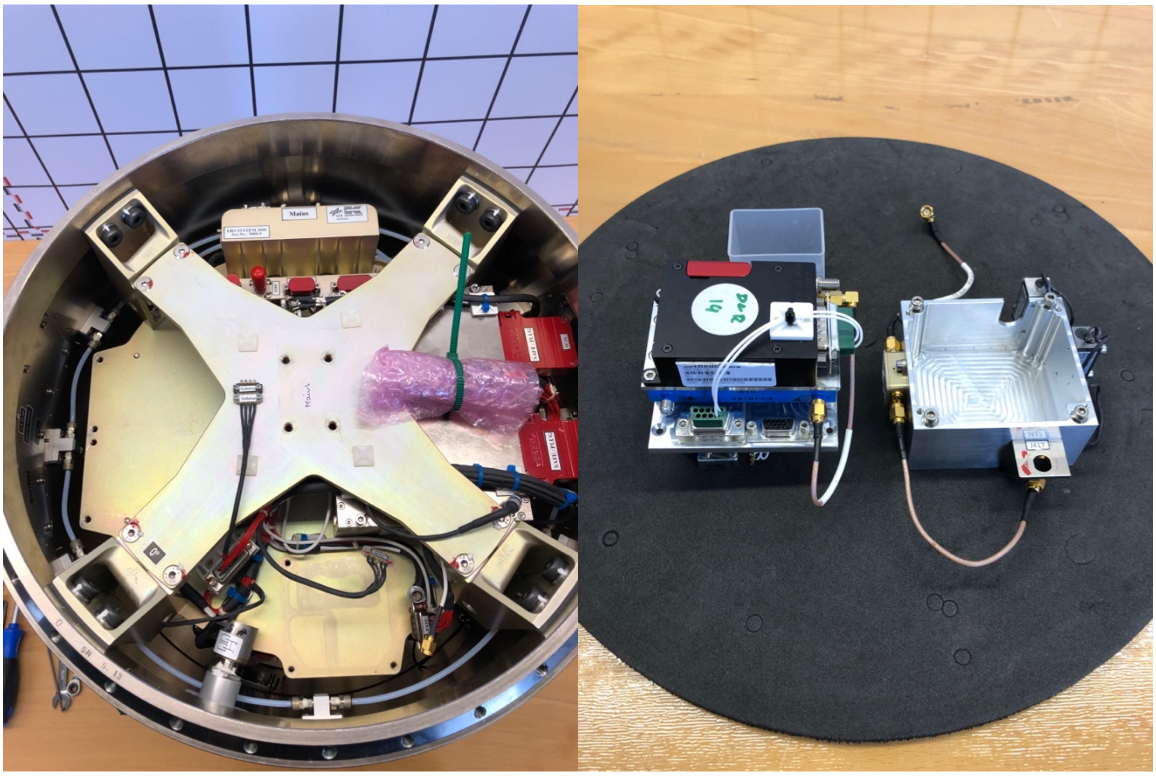


Figure 39: Left: Installation Space in the ERS; Right: Iridium Tracking Unit

6.1.2 Experiment Execution

At the beginning the housing of the Iridium tracking unit was installed, the g-switches were connected, and the camera cable was fixed in the bracket. The housing is attached to the bulkhead with four M4 cylinder head bolts. The integrated housing is shown in Figure 40.

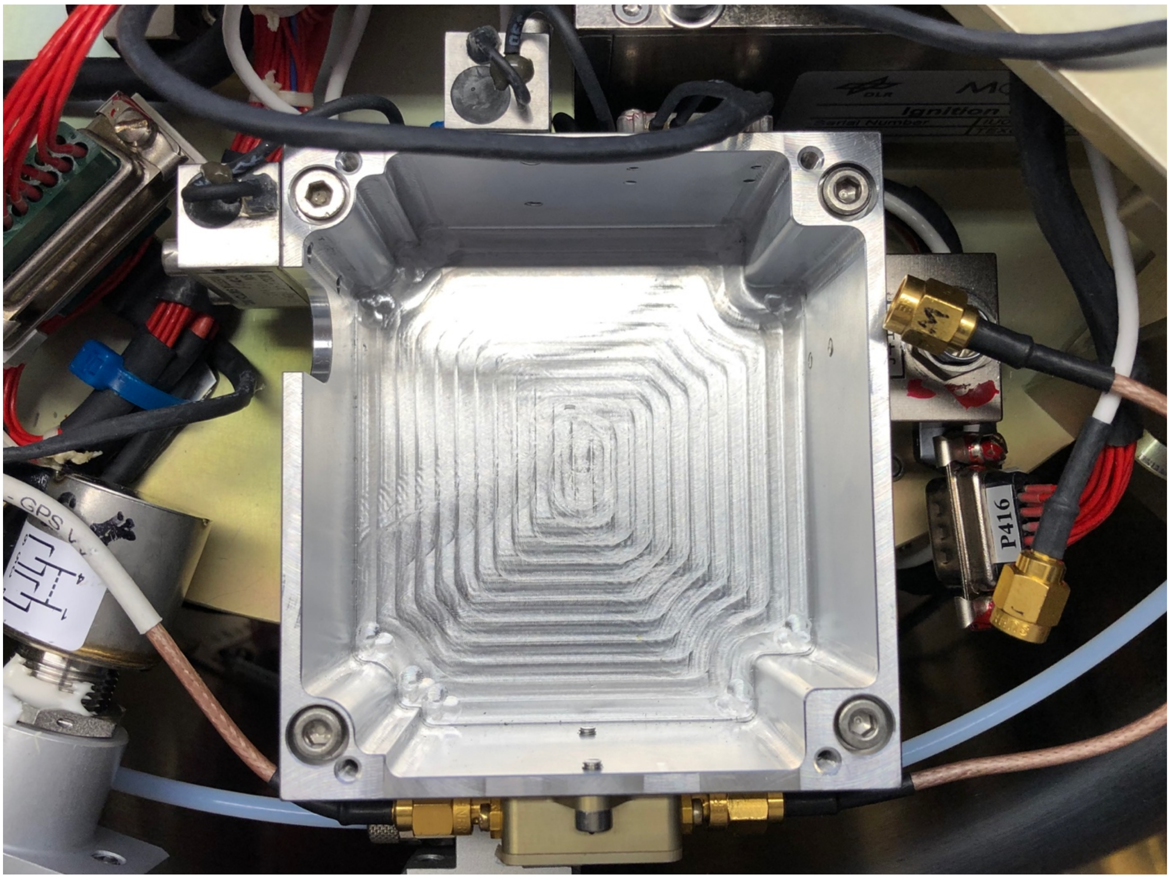


Figure 40: Integrated Housing of the Tracking Unit

The next step was to insert the cover with the electronics and fasten it with four countersunk bolts. Then the camera plug and the 15-pole HD D-Sub connector were screwed together. Finally, the antenna cable from the coupler to the amplifier and from the amplifier to the iridium was attached. Figure 41 shows the integrated Iridium tracking unit.

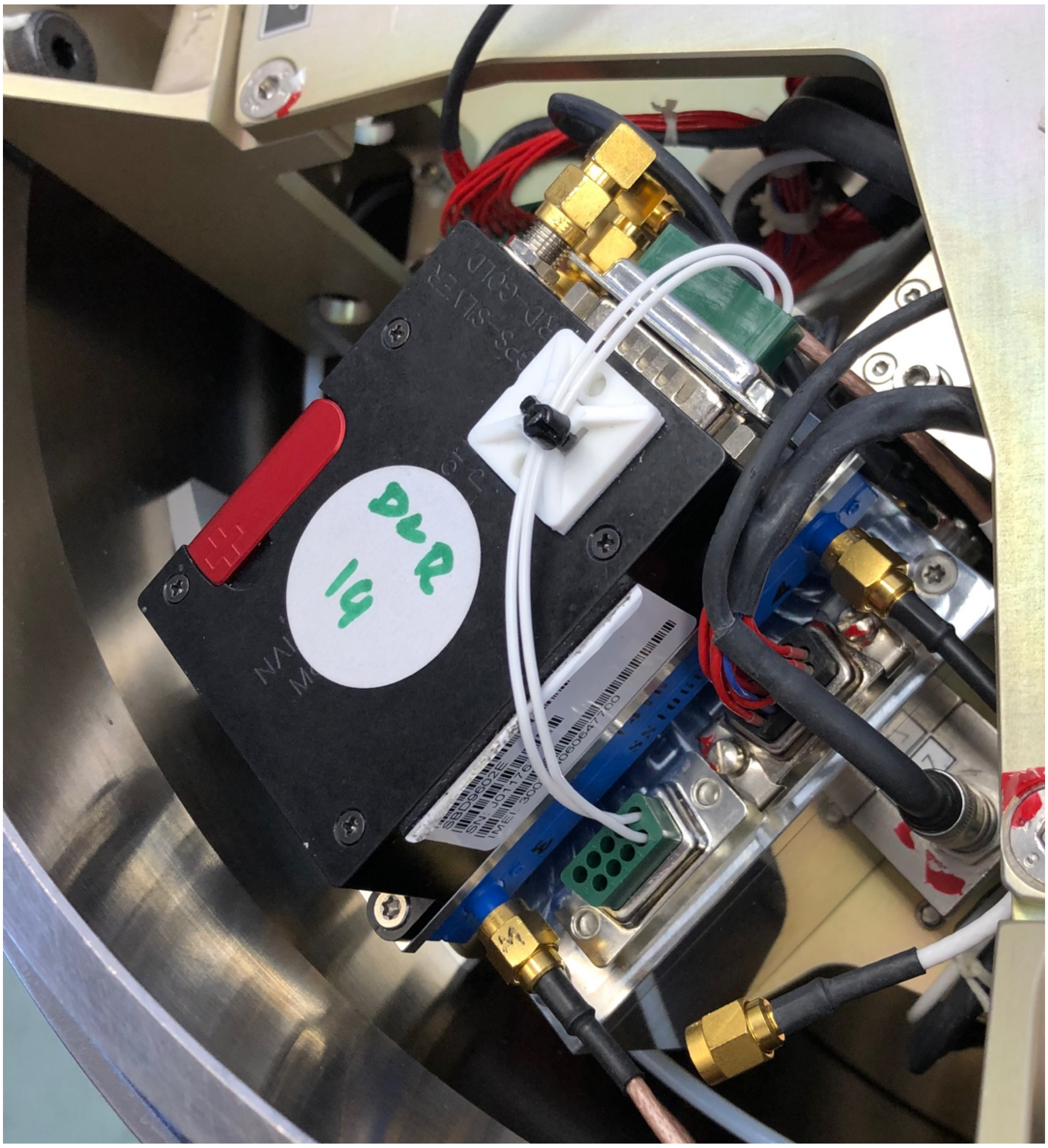


Figure 41: Integrated Iridium Tracking Unit

6.1.3 Result and Evaluation

The integration in the existing ERS was successfully completed all components could be connected and fastened without major problems. The division into cover with electronics and housing with attachments works perfectly. The tracking unit can be removed quickly and easily by simply removing the connecting bolts and antenna cable. Only the space on the side of the g-switches is very tight and offers even more improvement potential.

6.2 Function Test

In the function test, the first step was to test the activation via the baro switch and then the transmission function of the Iridium transmitter.

6.2.1 Experimental Set-Up

For the test, a test battery was connected to the tracking unit and two test antennas. To activate the baro switch, a vacuum pump was used which is connected to the baro switch via a hose. Figure 42 shows the experimental setup.

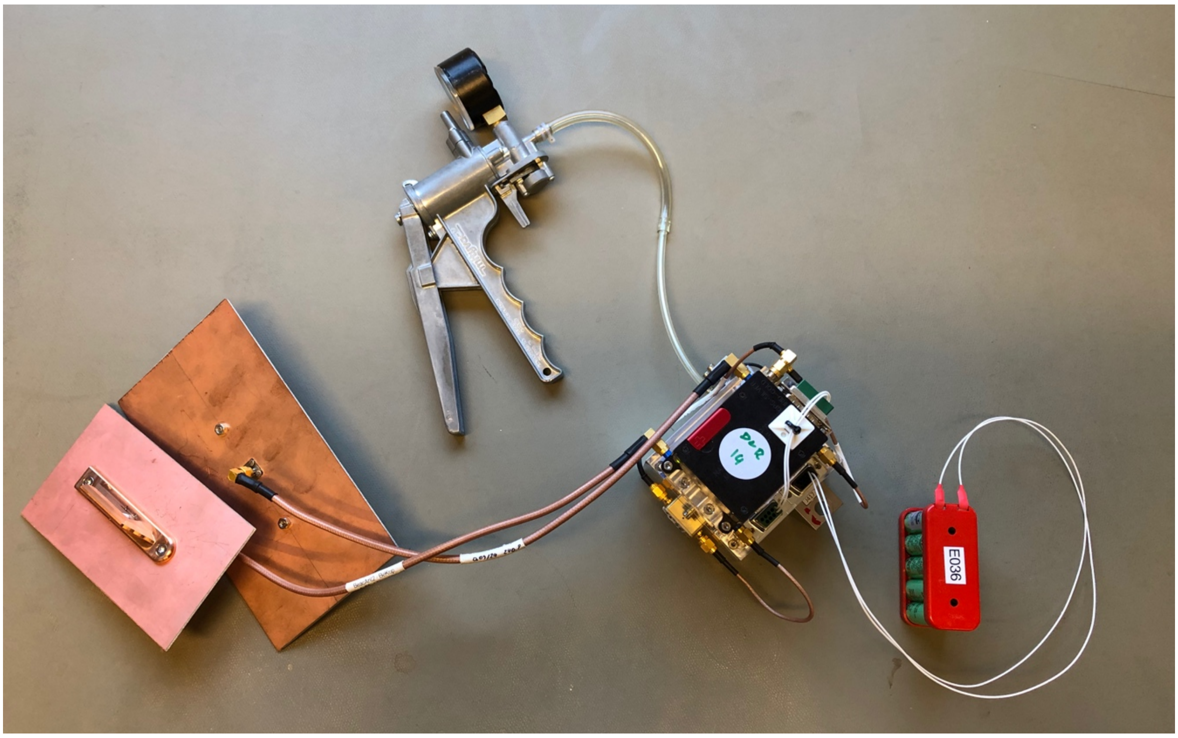


Figure 42: Experimental Set-Up

6.2.2 Experiment Execution

The first step was to test the activation of the Iridium tracking unit via the baro switch. The vacuum pump was used to simulate an air pressure above the baro switch and the system was deactivated. The pressure was then released when the required air pressure was reached, and the system was activated. Figure 43 shows the deactivated tracking unit on the left and the activated tracking unit on the right after falling below the required air pressure, visible by the green LED.

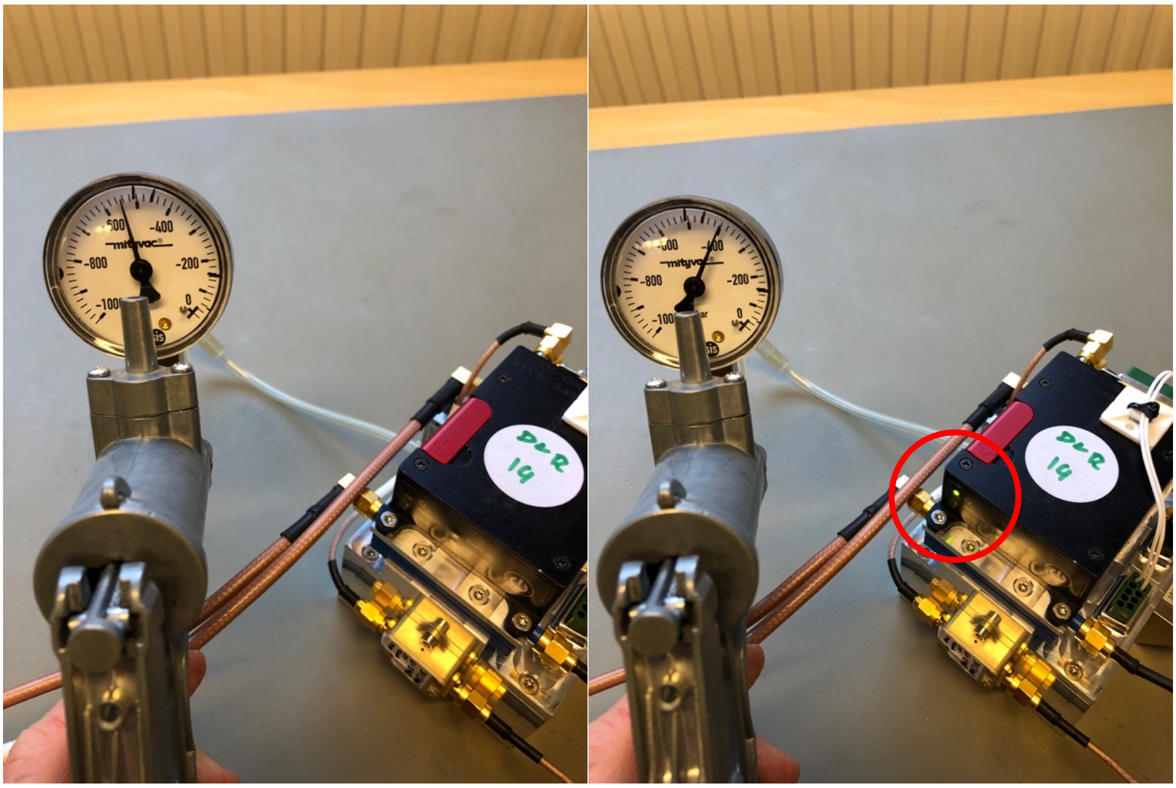


Figure 43: Left: Deaktivated Tracking Unit; Right: Aktivated Tracking Unit

After the successful activation of the tracking unit the Iridium transmitter was tested. For this purpose, the tracking unit with the test antenna was set up outside. The Iridium transmitter has connected to GPS and Iridium without further problems and has sent the current position. Figure 44 shows the Iridium Tracking Unit the green LED shows the successful connection to the Iridium and GPS as well as the send status.

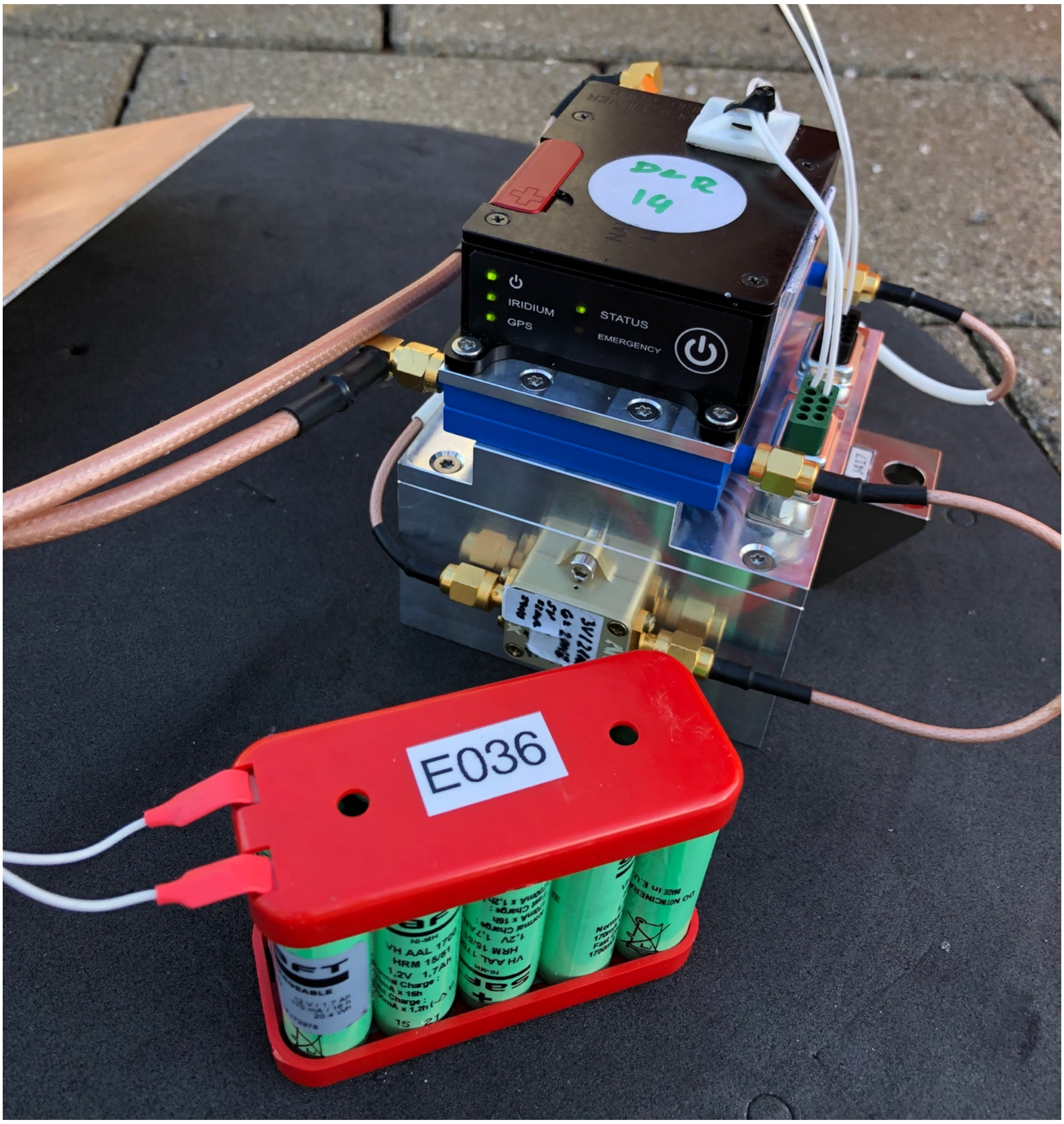


Figure 44: Successfully connected Tracking Unit

6.2.3 Result and Evaluation

The function test was carried out successfully. The activation via the baro switch worked perfectly. Problems with the sealing as in the old system did not arise. The transmission attempt of the Iridium transmitter also worked without further restrictions. The transmitter connected to GPS and Iridium immediately after activation and sent the current position. The tracking data can be found in Appendix A10.

7 Comparison and Conclusion

In the following, both systems will be compared, and function, mass and costs will be discussed. This determines whether the new Iridium tracking unit meets the requirements.

At the beginning the main function is compared, in the beacon tracking unit a signal is sent via the beacon transmitter, thus the direction and the approximate distance can be determined. In the Iridium tracking unit, the exact position is transmitted via the Iridium transmitter with the help of coordinates. The function of the Iridium tracking unit has improved significantly without any limitations.

The power supply has been implemented in the Iridium tracking unit with a rechargeable accumulator. The beacon tracking unit is equipped with a non-rechargeable primary cell. The new accumulator improves the handling with the tracking unit and the complicated replacement of the primary cell is no longer necessary.

The sealing of the baro switch is necessary for the function test to activate the baro switch. In the old beacon tracking unit, the sealing was done with a rubber mat and silicone, this led to problems with the tightness and thus to problems with the function test. In the Iridium tracking unit, the baro switch is sealed by an o-ring that is screwed into a bracket. This means that the baro system is self-contained and there are no problems with the sealing.

The costs of the systems were determined on the basis of the components to be manufactured. For this purpose, an offer was obtained. The beacon tracking unit is with 420€ approx. 45% cheaper than the new Iridium tracking unit, which is with 755€ clearly above the beacon tracking unit. The exact costs for the beacon tracking unit cannot be determined because it is purchased with the entire ERS from OHB. The beacon tracking unit is not listed as a single item. Information on surcharges is also unknown. Therefore, costs are not considered to be a crucial factor in the comparison.

The assembly and disassembly in the Iridium tracking unit has improved significantly. Due to the division into cover and housing, the entire electronics can only be removed by simply removing the bolts. The attachments are located on the housing and only have to be mounted once in the ERS. The beacon tracking unit always had to be completely assembled and disassembled, which is very time-consuming. The new tracking unit has significantly improved in terms of assembly / disassembly. The results are summarized in Table 10.

The mass of both systems was determined in the fully equipped condition the results of the measurement are shown in Figure 45. It can be seen that the Iridium tracking unit is much heavier. The reason for the higher weight is mainly due to iridium transmitter and the coupler.

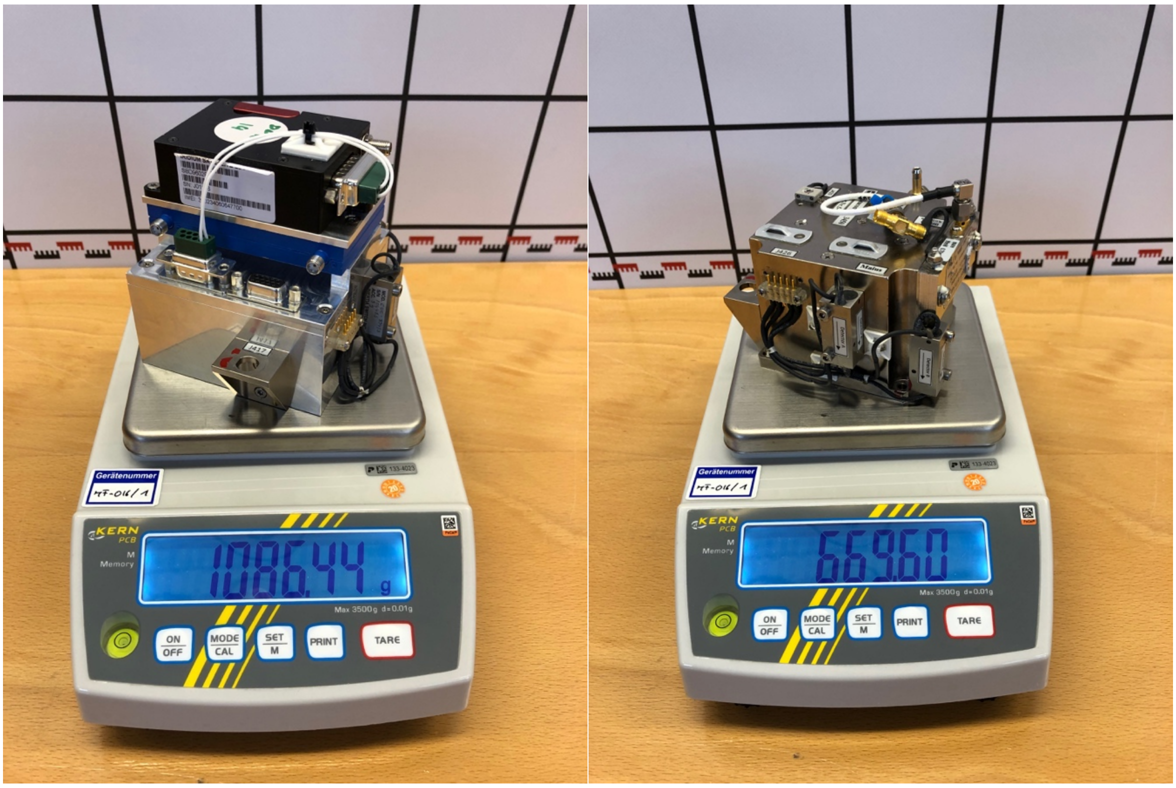


Figure 45: Left: Mass Beacon Tracking Unit; Right: Mass Iridium Tracking Unit

The comparison of the two systems has shown advantages and disadvantages for both systems. However, the significantly better functionality of the Iridium tracking unit outweighs its disadvantages. In terms of mass, the new tracking unit offers even more potential for improvement. The weak points of the beacon tracking unit have largely been improved especially the tracking function, power supply and the assembly and disassembly. The higher costs in terms of manufacturing costs are offset by the significantly better functionality. The results are summarized in Table 10.

Table 10: Comparison of the Beacon and Iridium Tracking Unit

	Beacon Tracking Unit	Iridium Tracking Unit
Tracking Function	-	+
Power Supply	-	+
Baro Switch Sealing	-	+
Mass	670g	1086g
Costs	420€	755€
Assembly / Disassembly	-	+

8 Summary and Outlook

8.1 Summary

The work begins with a close look at the beacon tracking unit. The functions of the beacon tracking unit have been determined for this purpose. The individual components were examined in more detail and the weaknesses identified. The packaging for the new Iridium tracking unit and the development focus were determined.

After analyzing the beacon tracking unit, a mindmap was used to determine possible variations. These were then examined in more detail and elaborated. With the help of a morphological box, four concepts were developed, presented in more detail and then evaluated.

The favoured concept was then developed. The individual components and parts were placed and modified. The Iridium tracking Unit was manufactured after the production drawings had been created.

After production, the Iridium tracking unit was completely assembled and cabled, then the tracking unit was tested. In the first test, the tracking unit was integrated into an existing ERS. The test was successful and there were no problems during assembly and disassembly. Next, the function of the Iridium tracking unit was tested, activation via the baro switch and position determination via the Iridium transmitter worked without any further problems.

Finally, the beacon tracking unit and the Iridium tracking unit were compared. Special attention was paid to functionality, costs, mass and assembly / disassembly. The Iridium tracking unit was particularly convincing due to its significantly improved functionality. The mass still offers improvement potential. The costs have increased but the advantages of the Iridium Tracking Unit outweigh the costs significantly.

8.2 Outlook

In order to fly the Iridium tracking unit in a sounding rocket further tests have to be made, especially a vibration test and a complete function test in the installed condition is necessary. Another task is to place the antennas in an existing ERS or a other payload structure. In addition, the programme adjustment in the ERS must be completed. The Iridium Tracking Unit offers great advantages compared to the beacon tracking unit but has to be tested extensively until it can be used as a standard part in projects.

9 References

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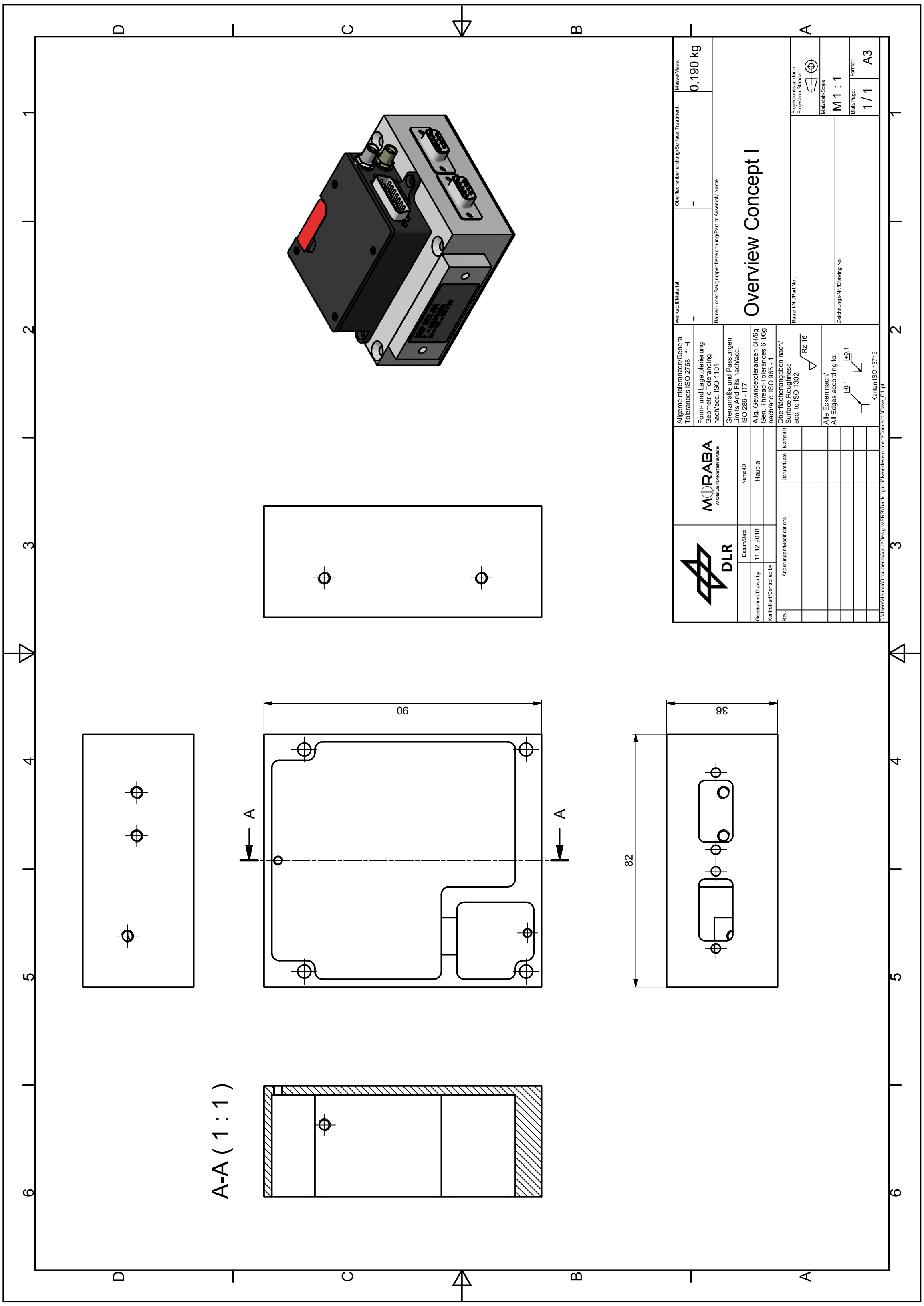
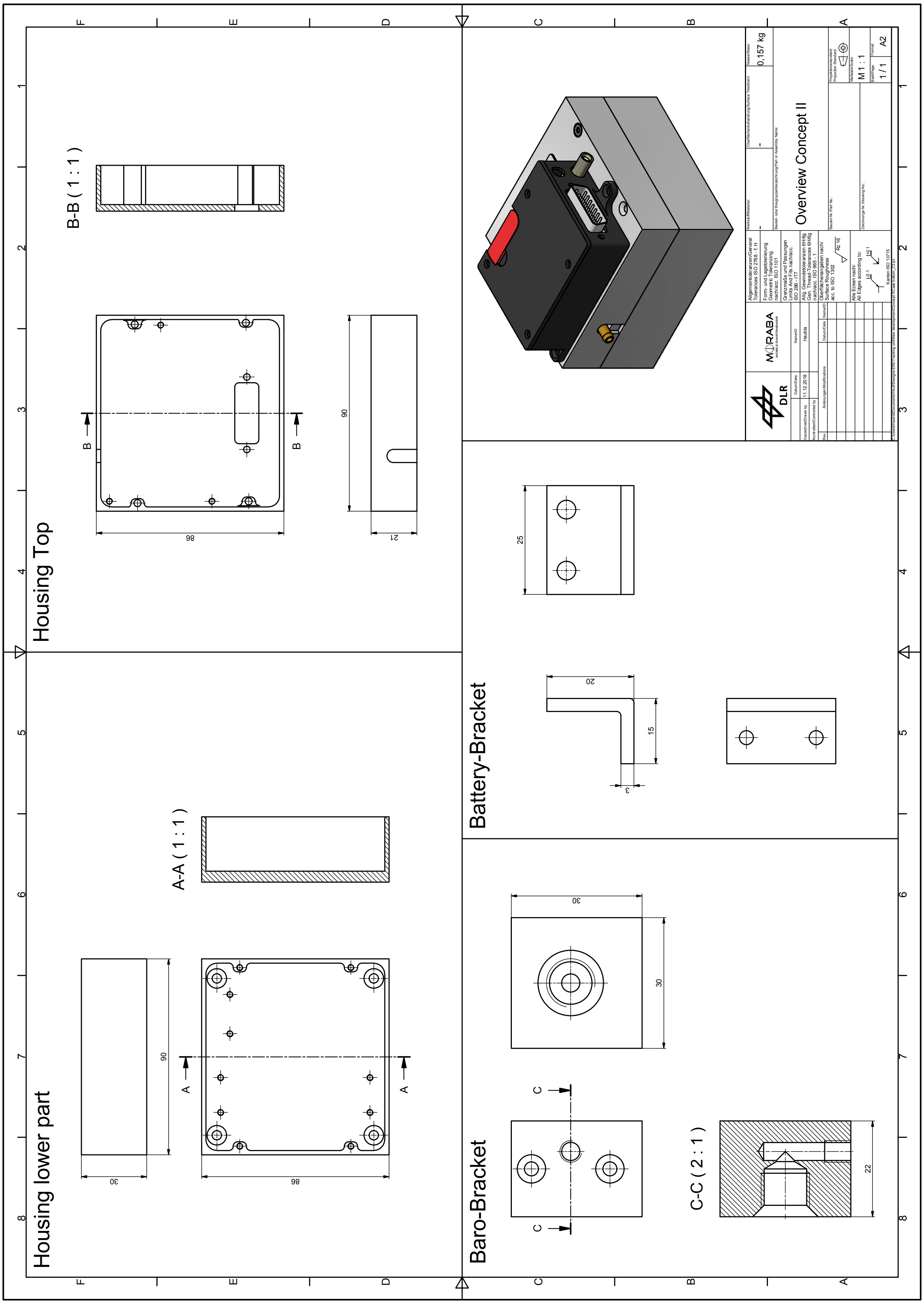
10 Appendix

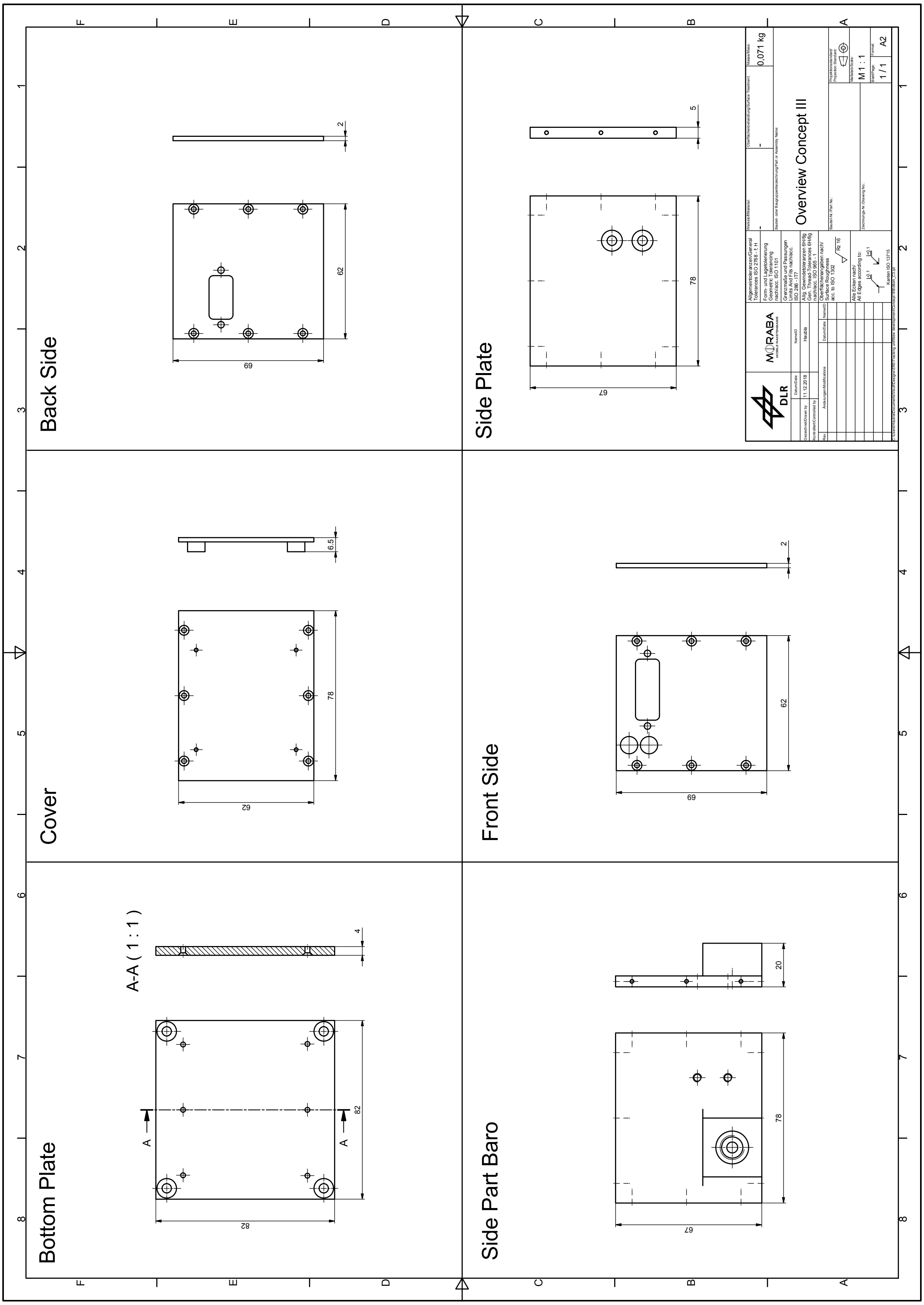
A1 Overview Drawing Concept I



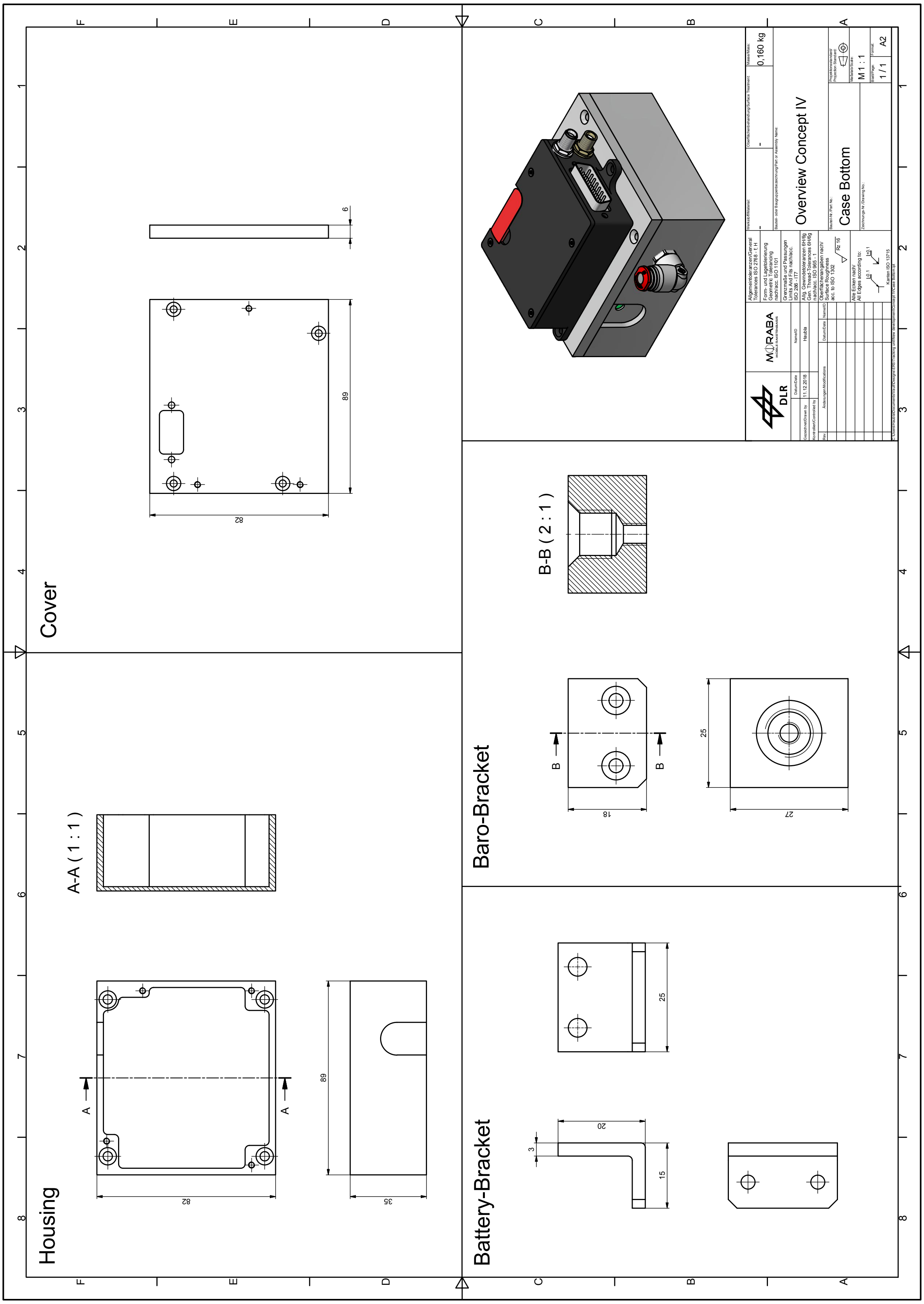
A2 Overview Drawing Concept II



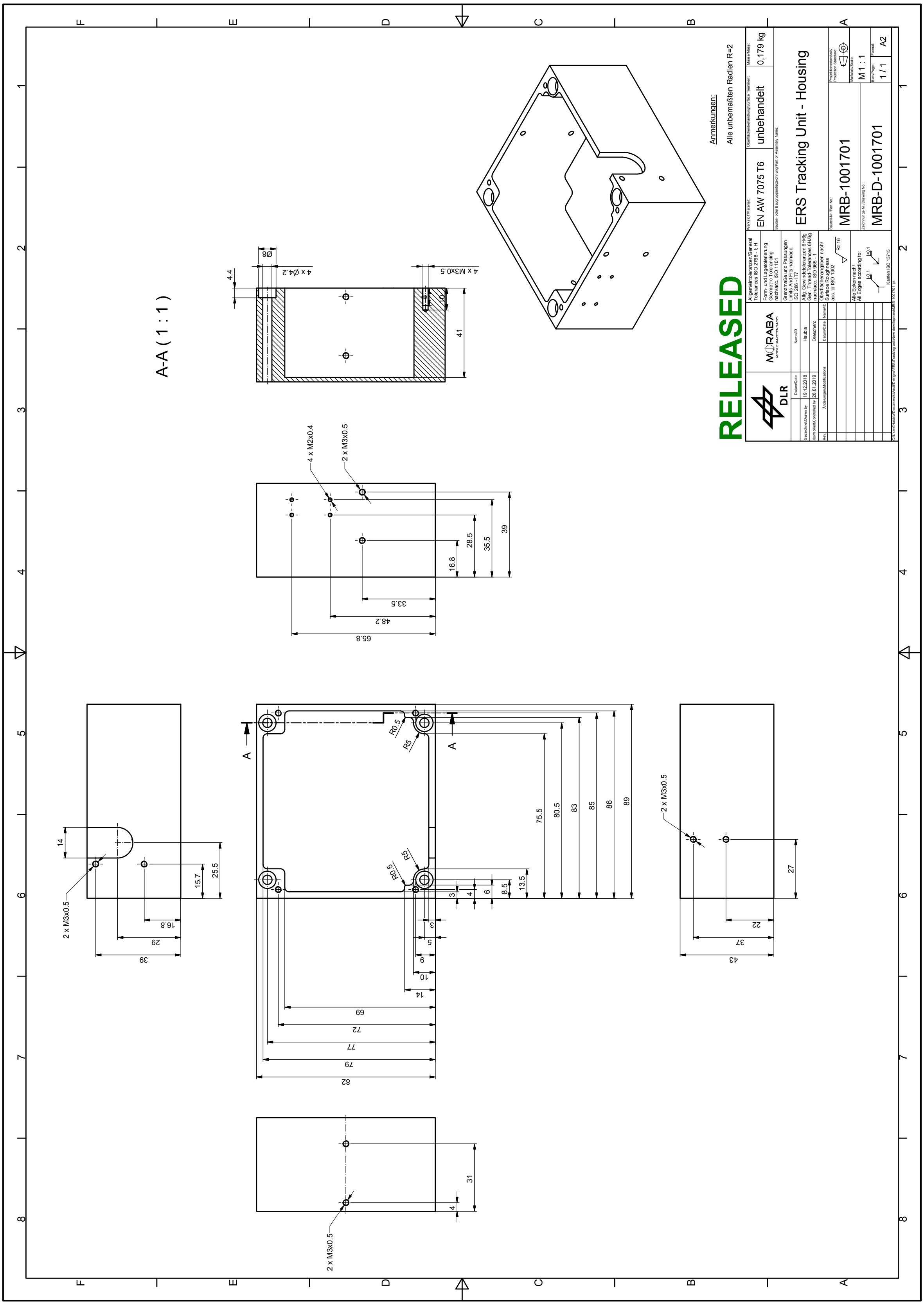
A3 Overview Drawing Concept III



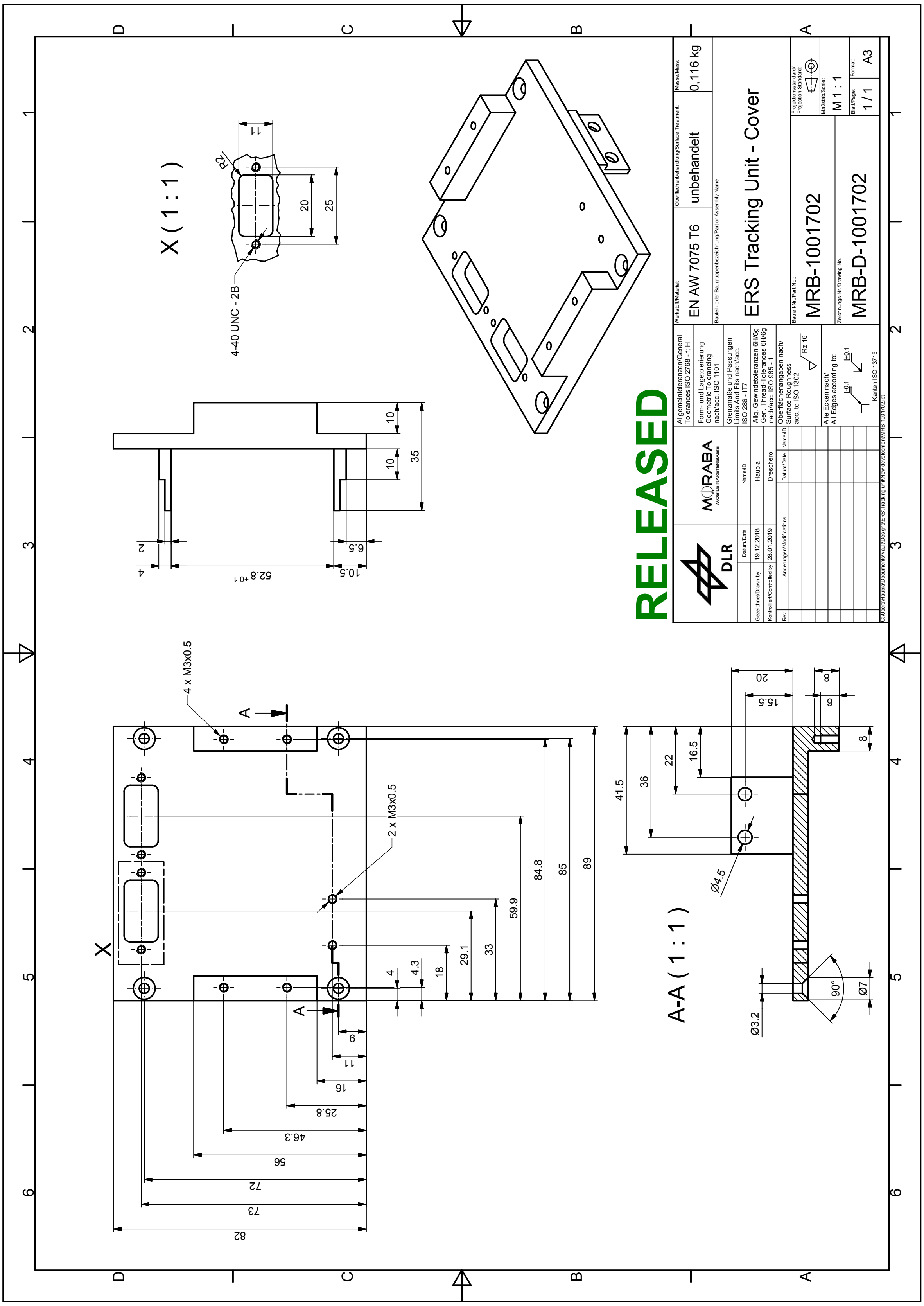
A4 Overview Drawing Concept IV



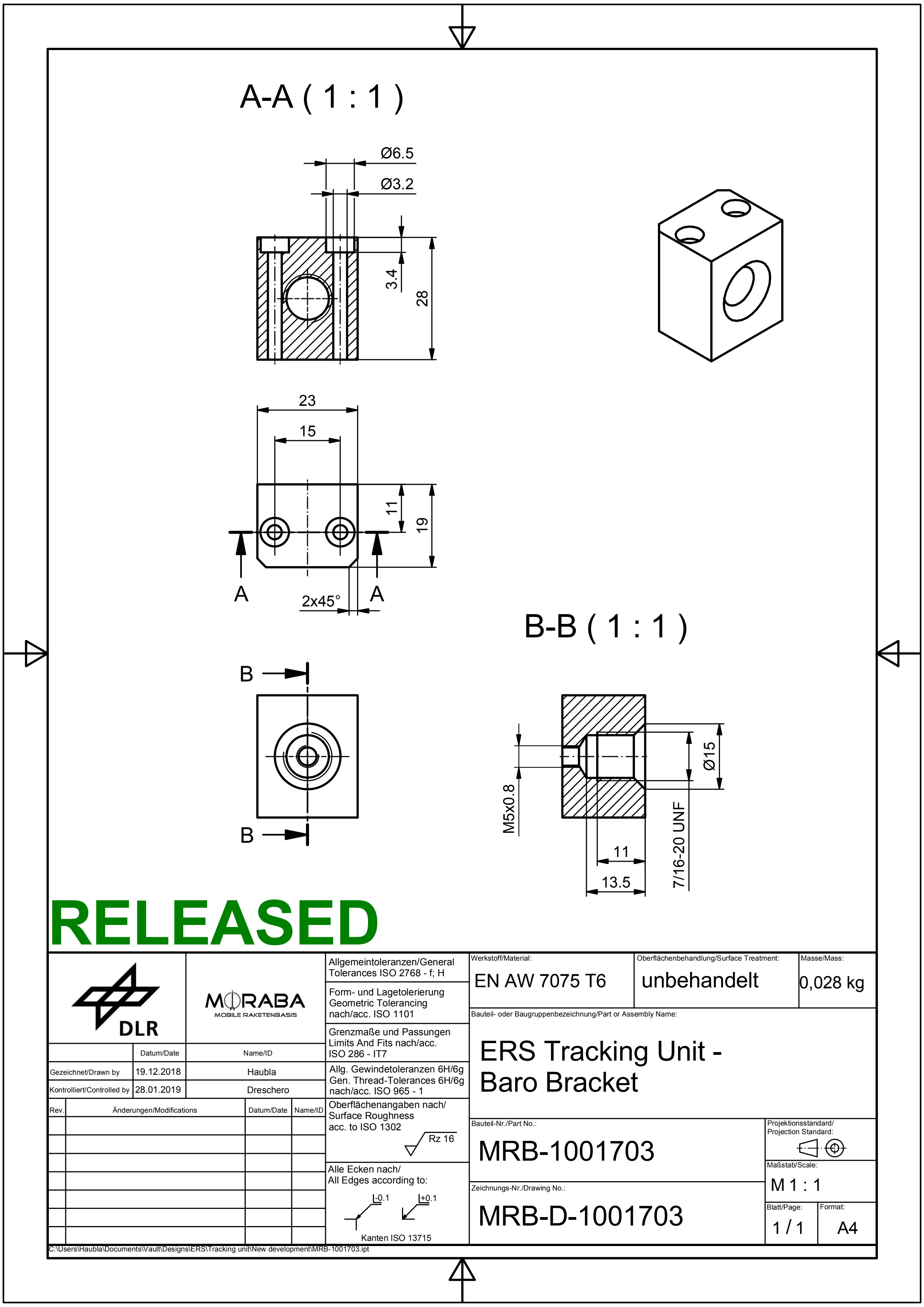
A5 Drawing: Housing



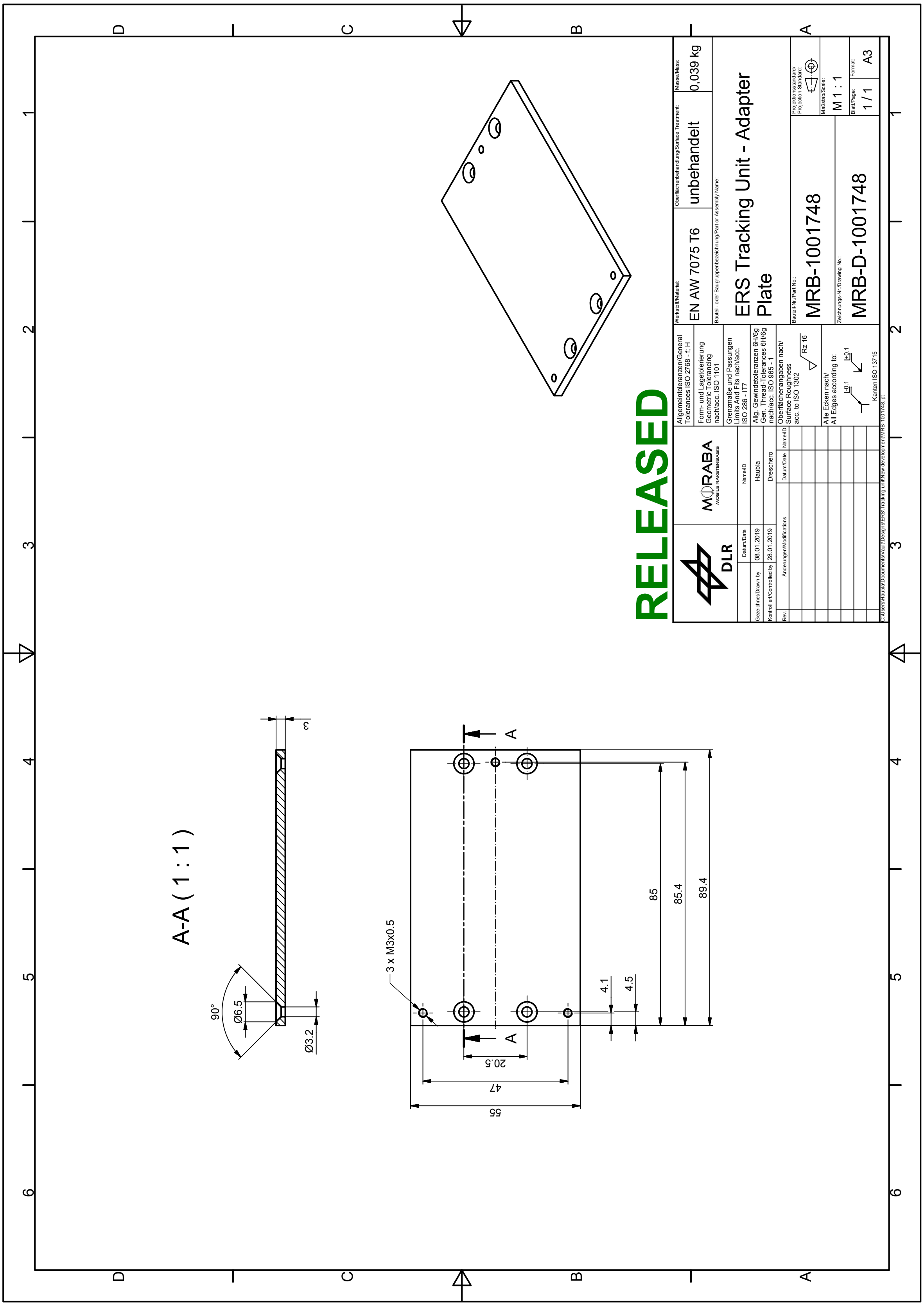
A6 Drawing: Cover



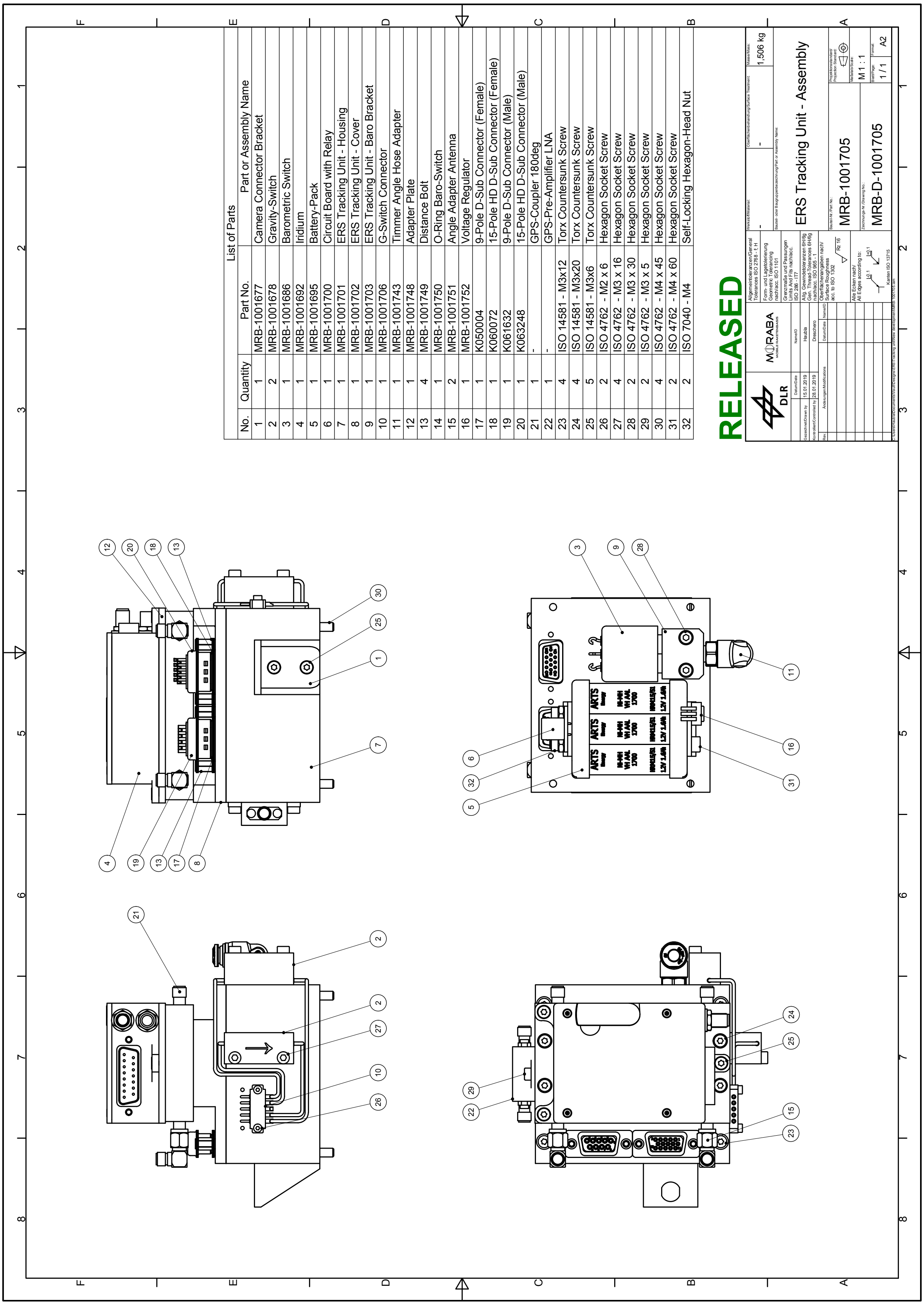
A7 Drawing: Baro-Bracket



A8 Drawing: Adapter-Plate



A9 Drawing: Tracking Unit Assembly



List of Parts

No.	Quantity	Part No.	Part or Assembly Name
1	1	MRB-1001677	Camera Connector Bracket
2	2	MRB-1001678	Gravity-Switch
3	1	MRB-1001686	Barometric Switch
4	1	MRB-1001692	Iridium
5	1	MRB-1001695	Battery-Pack
6	1	MRB-1001700	Circuit Board with Relay
7	1	MRB-1001701	ERS Tracking Unit - Housing
8	1	MRB-1001702	ERS Tracking Unit - Cover
9	1	MRB-1001703	ERS Tracking Unit - Baro Bracket
10	1	MRB-1001706	G-Switch Connector
11	1	MRB-1001743	Timmer Angle Hose Adapter
12	1	MRB-1001748	Adapter Plate
13	4	MRB-1001749	Distance Bolt
14	1	MRB-1001750	O-Ring Baro-Switch
15	2	MRB-1001751	Angle Adapter Antenna
16	1	MRB-1001752	Voltage Regulator
17	1	K050004	9-Pole D-Sub Connector (Female)
18	1	K060072	15-Pole HD D-Sub Connector (Female)
19	1	K061632	9-Pole D-Sub Connector (Male)
20	1	K063248	15-Pole HD D-Sub Connector (Male)
21	1	-	GPS-Coupler 180deg
22	1	-	GPS-Pre-Amplifier LNA
23	4	ISO 14581 - M3x12	Torx Countersunk Screw
24	4	ISO 14581 - M3x20	Torx Countersunk Screw
25	5	ISO 14581 - M3x6	Torx Countersunk Screw
26	2	ISO 4762 - M2 x 6	Hexagon Socket Screw
27	4	ISO 4762 - M3 x 16	Hexagon Socket Screw
28	2	ISO 4762 - M3 x 30	Hexagon Socket Screw
29	2	ISO 4762 - M3 x 5	Hexagon Socket Screw
30	4	ISO 4762 - M4 x 45	Hexagon Socket Screw
31	2	ISO 4762 - M4 x 60	Hexagon Socket Screw
32	2	ISO 7040 - M4	Self-Locking Hexagon-Head Nut

A10 Tracking Data from the Iridium Transmitter