**NEWSLETTER**
June 2023

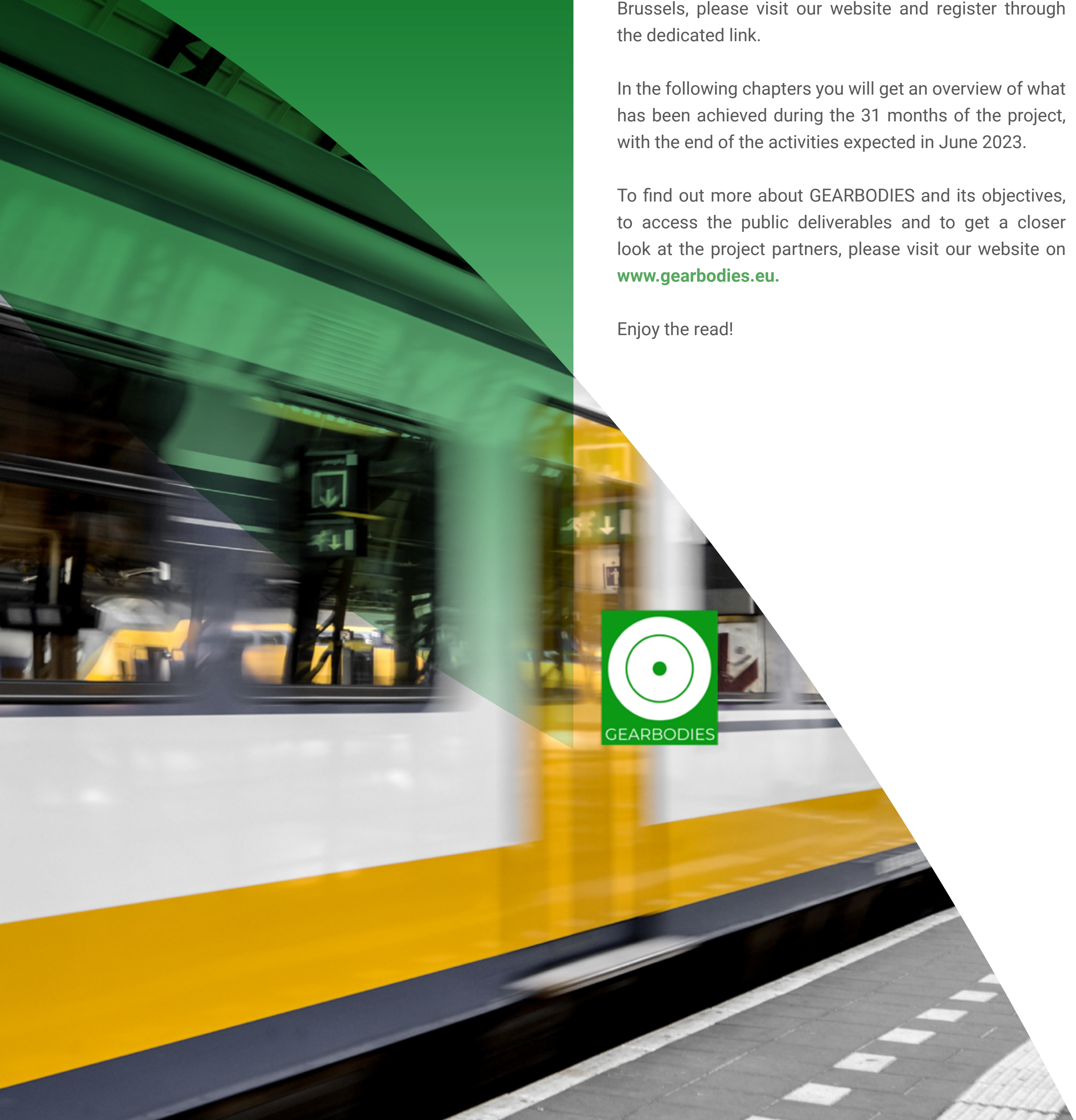
# GEARBODIES

## Innovative Technologies for Inspecting Carbodies and for Development of Running Gear

GEARBODIES

CONTENT





# FOREWORD

Dear Reader,
In this final newsletter before reaching the end of the GEARBODIES (Innovative Technologies for Inspecting Carbodies and for Development of Running Gear) project, you will learn more about what the project partners have achieved. The best way to get a closer look at the project achievements though will be to attend the GEARBODIES final conference that will take place on the 21st June in Brussels. Therefore if you want to learn more about the project and you still have the opportunity to join us in Brussels, please visit our website and register through the dedicated link.

In the following chapters you will get an overview of what has been achieved during the 31 months of the project, with the end of the activities expected in June 2023.

To find out more about GEARBODIES and its objectives, to access the public deliverables and to get a closer look at the project partners, please visit our website on **www.gearbodies.eu.**

Enjoy the read!

# Project scope & structure

**The GEARBODIES project works towards the development of cost-efficient and reliable trains by contributing with specific innovations towards the Technology Demonstrators (TD) of Innovation Programme 1 (IP1) within Shift2Rail, through two dedicated work streams:**

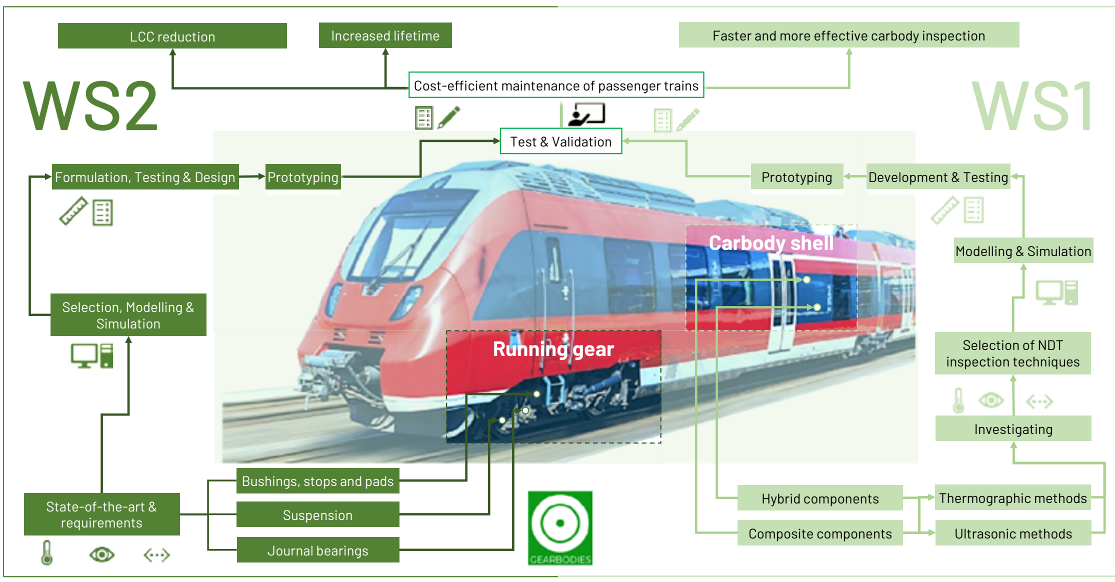
- Work Stream 1 (WS1): Inspection methods for innovative new carbodies that use lightweight composite materials (TD1.3) which aims to develop effective, affordable and automated solutions for non-destructive inspection of such vehicles;
- Work Stream 2 (WS2): Innovative approaches for developing running gear components (TD1.4) which aims to employ innovative approaches, tools and methods for developing novel concept designs of running gear components with extended lifetime, and low LCC, whilst maintaining or reducing current levels of reliability, noise emissions, and track damage.

In addition, the GEARBODIES consortium worked together with Shift2Rail members to allow for correlating and/or implementing their innovations into the final TDs, namely: TD1.3 "Carbody Shell Demonstrator" for WS1 and TD 1.4 "Running Gear Demonstrator" for WS2, contributing thus to the overall Shift2Rail IP1 strategy.

The two Work Streams of GEARBODIES actively contribute to improving the efficiency, safety and competitiveness of the European railway sector by supporting the implementation and exploitation of innovative materials and practices, with profound impacts on the cost-efficiency and reliability of the sector, as well as on its energy consumption and infrastructure maintenance. Inspection time is significantly reduced, while the use of new materials and systems enables an increase in the lifetime of components and lower maintenance costs.

The common element of WS1 and WS2 is the contribution towards the improvement of rolling stock maintenance processes through 1) the use of highly automated non-destructive testing (NDT) techniques for the inspection of composite carbody shells (WS1), and 2) the development of running gear components with enhanced performance (WS2).

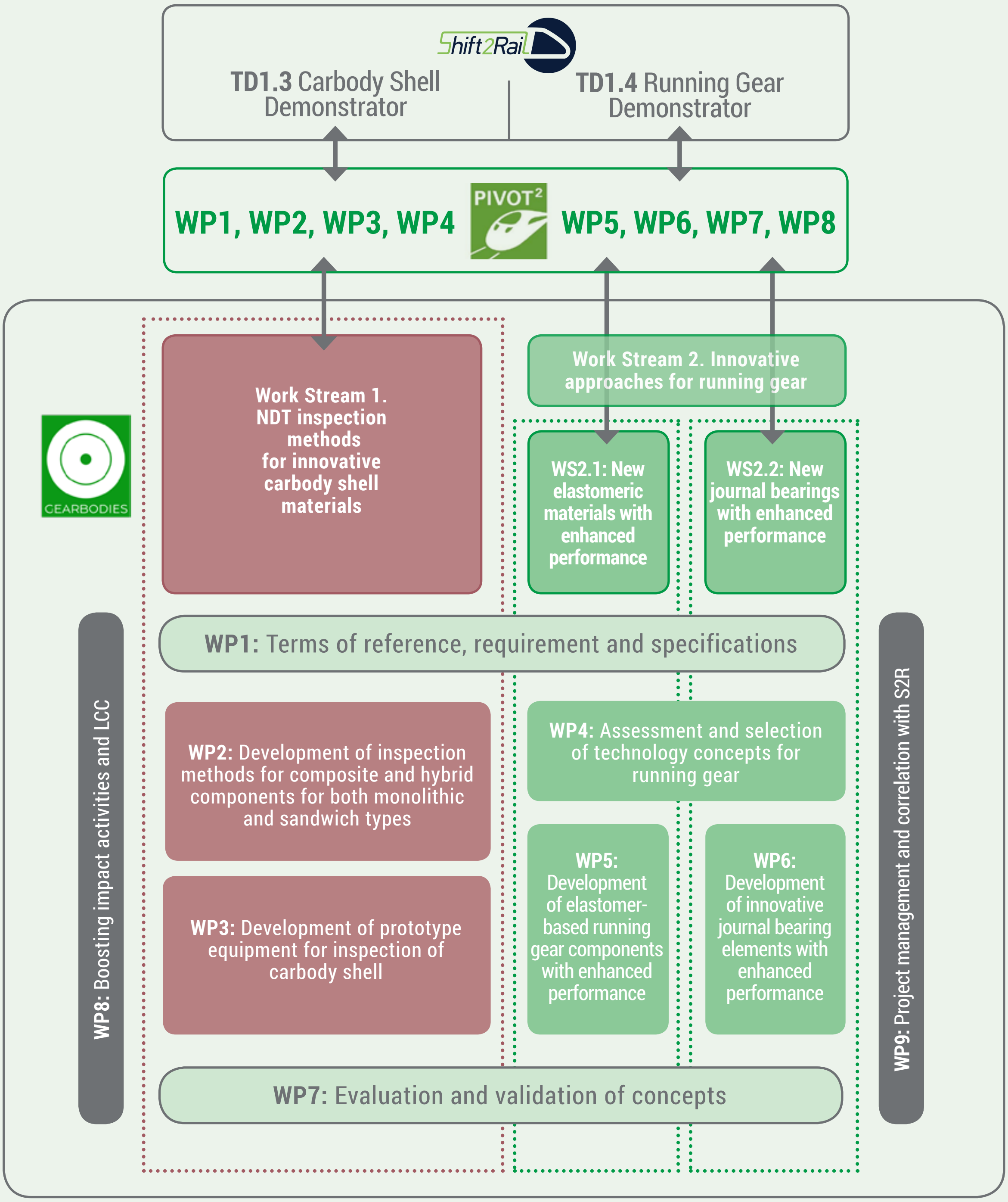
**FIGURE 1**
Overview of GEARBODIES concept



**GEARBODIES** has been structured in 3 functional Work Streams (WS1, WS2.1 and WS2.2). WS1 focuses on the development of an automate platform prototype for inspecting composite carbody shells utilising NDT techniques such as thermography and ultrasonic testing. To facilitate the work, WS2 has been divided into 2 different Work Streams, each one centred on specific elements of the running gear: WS2.1 works on innovations related to elastomer-based components, while WS2.2 focuses on innovations for journal bearings. The three WSs are contributing towards two cross-cutting WPs (WP1 and WP7), which help to harmonise the results and provide coherence to the project developments. Finally, two transversal WPs (WP8 and WP9) complete the structure of the project. WP8 comprises a set of activities to increase the impact of the project and to perform the LCC assessment. WP9 provides the project management and ensures the relationship with Shift2Rail.

The figure below illustrates how the project is organised:

**FIGURE 2**
GEARBODIES project structure



# WS1 NDT inspection methods for innovative carbody shell materials

The main objective of WS1 was to develop a prototype Non-Destructive Testing (NDT) inspection platform that would be capable of inspecting railway composite carbodies, using techniques such as infrared thermography (IRT) (performed by CERTH) and ultrasonic testing (UT) (performed by DASEL). Functional and operational requirements for the Modular Prototype Platform (MPP) (performed by AKKODIS) and the NDT methods, were set under WP1.

Following the work that has been presented in GEARBODIES Newsletter #1, that showed the theoretical application of IRT and UT techniques on composite rail components, through modelling and simulation, the later part of WP2 aimed to test, under lab conditions, certain NDT techniques. For this purpose, monolithic carbon fibre samples (20mm thickness) and sandwich samples were manufactured (performed by AIMEN), consisting of carbon fibre skins and PET foam core (40mm overall thickness). The samples were manufactured with subsurface artificial Teflon defects that were placed at various depths, in order to simulate delaminations and disbonds that can be caused to the side walls of the carbody from rail track ballast impact damage or other induced loads during operation of the train. These samples were designed to replicate composite carbody components according to input from the rails industry and have been used to test the capabilities of the IRT and UT techniques in detecting damage.

The IRT techniques that were used included: 1) optical lockin, 2) optical step heating, 3) pulsed thermography and 4) eddy current heating. The experiments have shown that optical lockin and step heating using halogen lamps were the most efficient techniques, being also simple to integrate onto the MPP. In terms of UT, two techniques, i.e., air coupling using Lamb Waves and water coupled phased array, have been tested. Between the two samples, the monolithic has been the easiest to inspect with optical techniques, being able to detect defects at depths up to 10mm for IRT and up to 15mm for UT respectively as seen on Figure 3. On the contrary, for the sandwich sample, only defects located in the

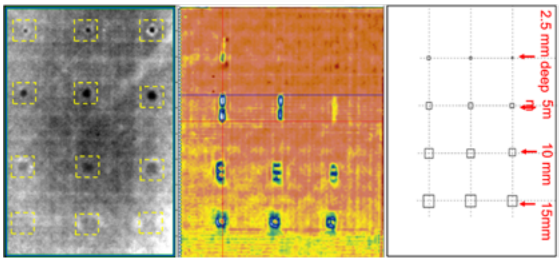



**FIGURE 3**
IRT (left) and UT (middle) images taken from the monolithic sample. Defects schematic shown on right.
* Defects on the IRT image are highlighted in yellow squares.

front skin, or disbonds between the front skin and the foam core were detected using both IRT and UT techniques. Thus, the inspection results have proven that the two NDT methods complement each other, with thermography being able to detect shallower defects while UT can detect deeper defects. The task of inspecting the full thickness of the type of sandwich composites used for carbody structures using only one-sided inspection remained a work in progress throughout the project as well as part of future research.

The next stage of WS1 included the manufacturing of a large sample that combines both monolithic and sandwich regions in order to replicate a larger area of a composite rail carbody. This sample was used during lab trials and was also incorporated into a mock-up section of a composite carbody. Under WP3 and WP7 the large sample was inspected at both under lab conditions as well as while incorporated into the carbody mock-up section, to compare the performance of the NDT techniques before and after their integration on the inspection platform. The lab results are shown in Figure 4.

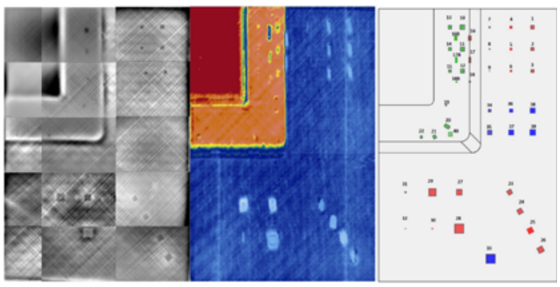


**FIGURE 4**
IRT (left) and UT (middle) images taken from the monolithic sample. Defects schematic shown on right.
* The IRT image is a collage of 15 acquisitions while the UT image are 2 separate acquisitions

The latter, presents on the left side a mosaic of the different image processed acquisitions taken from the inspection of the large sample with IRT (using optical step thermography) while the middle image shows the respective acquisitions using lamb wave ultrasonic testing. Once again similar results were acquired with the large sample with thermography performing better in detecting shallower defects and UT deeper ones respectively.

Within the concept of automating the inspection process of composite rail carbodies, the GEARBODIES project also focused on providing advanced data processing techniques and visualisation of the inspection results. In order to visualise the results provided by the MPP, an Image Fusion Software Tool was developed using advanced algorithms and techniques for combining the data together. Specifically, the software tool automates the assessment of the acquisitions from thermography and ultrasonic inspection methods and provides an accurate estimate of defect detection and localization using a reference processed image. The merging of the two inspections improves user confidence and software usability in terms of fault detection. It also requires proper design to handle different types of images, data and adjust the parameters according to the handler's needs. The tool offers the following functions:

- visualization of the train carbody to be inspected
- display of the coordinates for a specific selected point of interest where the user would like to call the results of the acquisitions
- display of the ultrasonic and thermography results for a point of interest
- provide dimensions of the identified defects
- updating or switching the inspection image to a new point
- printing the thermography and ultrasonic results on a specific selected point
- zoom in/out of the merged image

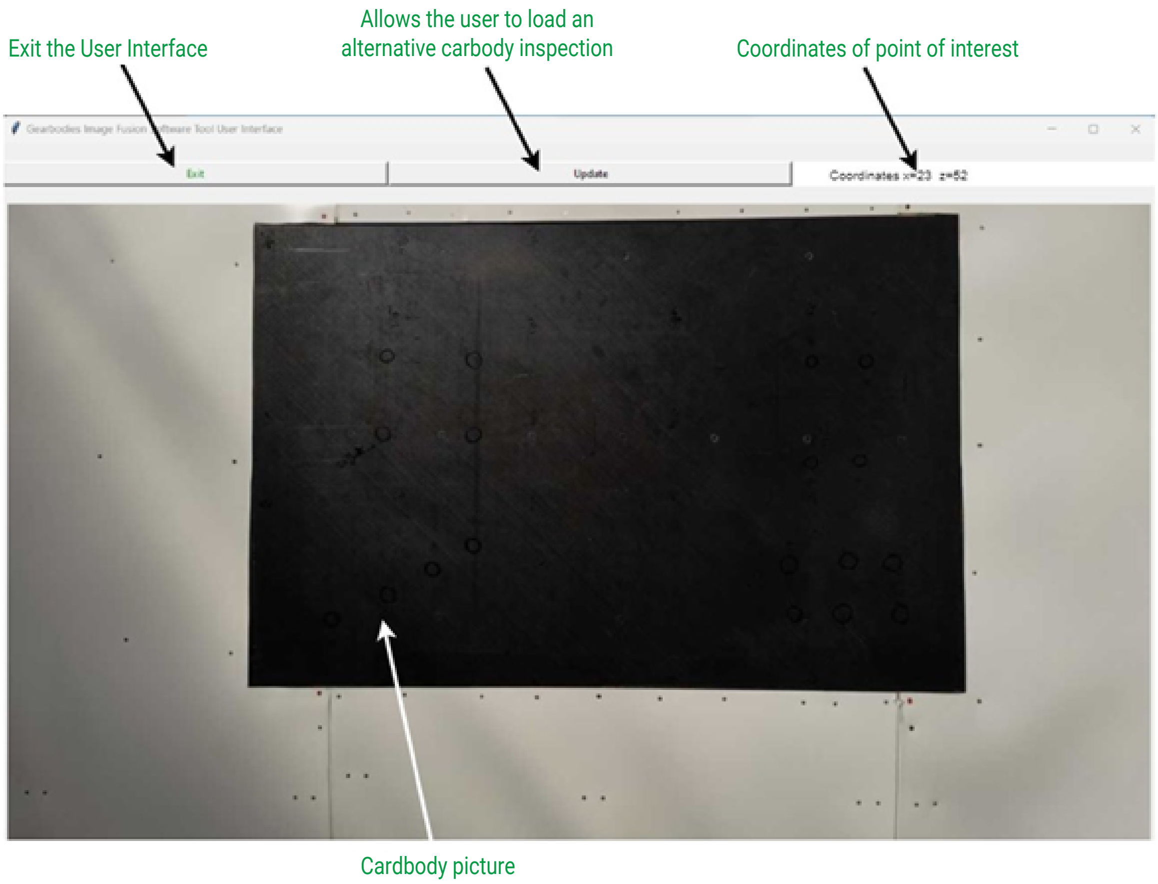



**FIGURE 5** Interface of image fusion tool

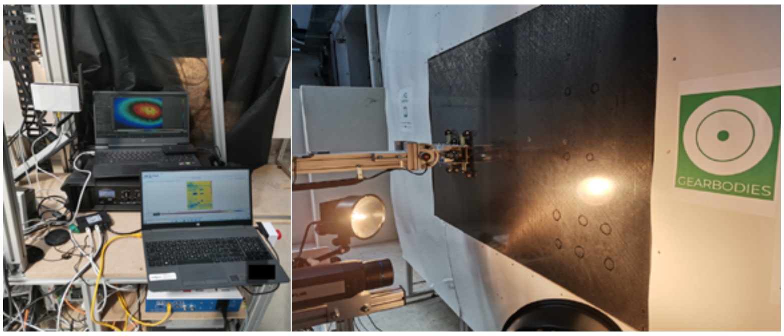



**FIGURE 6**
Mobile prototype inspection platform during inspection by UT and IRT systems

During the last phase of the GEARBODIES project, the final integration and validation took place, where the two NDT systems were combined together onto the inspection platform and further functional testing took place. In 2021 the initial concept of a robotised platform concept was studied, while an advanced design has been performed in 2022, to validate the design, ensuring its ability to integrate the two inspection methods, with the aim of creating a modular and multifunctional system as possible.

The physical implementation of the MPP started with the wheelbase using railway cartwheels for better positioning alongside the carbody. Industrial-grade linear axles have been tested and installed on the MPP while EtherCat communication have been integrated together with high-level a robotic framework Robot Operating Software (ROS2), to ensure proper and precise manual controls over the different MPP actuators, wheels and linear axles.

To validate both the MPP and the NDT techniques, a mock-up structure replicating a section of composite rail carbody was designed and built in AKKODIS' facility. The structure consisted of the large composite sample incorporated in the centre of the panel as well as PVC sheets that would reproduce the general curvature of a standard carbody. The composite sample have been used for actual acquisitions and further testing of the inspection equipment while the curved part has served for validation purposes of the usability of the MPP for a full carbody inspection.

Once the MPP and mock-up were finalized, the hardware integration of both NDT systems was conducted at AKKODIS facility, with help of DASEL and CERTH. The software integration is still to be improved to allow full autonomous inspection scenario of the whole carbody. However, movements of the ultrasonic and thermography acquisitions systems in any direction relative to the carbody mock-up as well as processing of the inspection results files and detection of defects have been achieved.

Integration, functionality and validation tests were carried out by CERTH, DASEL and AKKODIS at the end of May 2023 at AKKODIS' facility near Lyon, France, where the MPP and mock-up were built. These tests demonstrated and validated the usability of both NDT techniques for carbodies made of composites. The next steps would be to work with the railway industry to assess the kind and size of defects that can be a problem for carbodies integrity, improving the detection of the machine learning algorithms and the inspection methods to allow detection of deeper defects in the composite components.

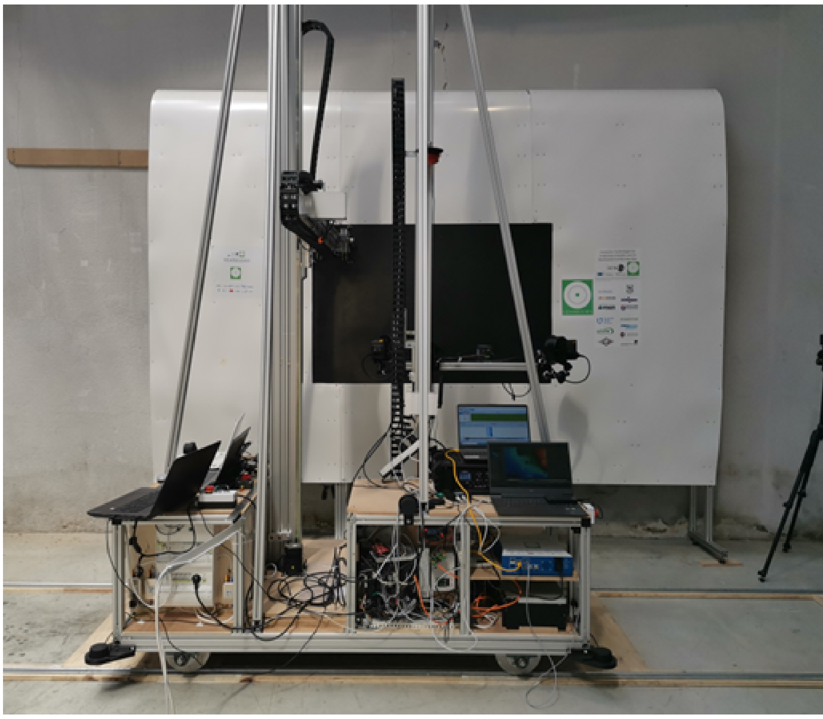


**FIGURE 7**
Mobile prototype inspection platform

# WS2.1 New elastomeric materials with enhanced performance

The methodological approach initially proposed for WS2.1 is shown in Figure 2 and comprises four main phases which are bound to one another for the success of the project. The first objective was to select elastomeric components of interest to prototype and evaluate including the new technologies developed in GEARBODIES project to increase lifetime. With this aim, during the first phase, corresponding to WP1, the the terms of reference of existing and emerging technologies for elastomer-based running gear components were analysed, as well as the definition of specifications of the innovative technologies. Based on this study, a first list of candidate components was ellaborated. In a second phase, in activities corresponding to WP4, a methodology based on the Analytic hierarchy process (AHP) was used for the final selection of two elastomer-based running gear components along with specification of loads and investigation of dynamic impact through multi-body simulation (MBS): ***Conical Spring in primary suspension*** Figure 8(a) and ***Bushing in the swingarm*** Figure 8(b) were the final selected components. The third phase corresponding to WP5 is dedicated to the development of technologies al lab scale leading to running gear components with enhanced LCC and lifetime. Two key experimental approaches have been identified: nanotechnology solutions have been proposed to reformulate the elastomeric phases of the selected components enhancing durability as well as the adhesive in the interfase between elastomeric and metallic parts enhancing adhesion strength. Long term testing of elastomers and elastomer-metal interfaces are carried out to validate the performance and durability of the introduced technologies while feeding the information needed for upgrading the design concepts of the selected running gear components.

a)

Conical Spring in primary suspension

b)

Guiding bushes in swingarm

**FIGURE 8**
Pictures of commercial conical spring in primary suspension (a) and bush in the swingarm (b). Images taken from www.continental-industry.com

In the following, the design cases will be adapted considering the integration of the elastomers and new interfaces as well as elastomer and interface properties, redimesioning etc. Finally, in the fourth phase corresponding to WP7, prototypes of elastomer-based running gear components based on outcomes of WP5 will be manufactured (taking also into account potential refinement of final designs based on MBS results) and tested in laboratory at TRL4/5 to be evaluated and validated.

Several of the initially established goals corresponding to experimental work of WP5 have been already achieved. With the aim of produce elastomeric materials with enhanced mechanical properties, nanothechnology solutions have been including in lab scale developments. According to extensive literature, Carbon nanotubes (CNTs) have shown very important potential as filler for elastomeric composites due to their structural characteristics and their electrical and mechanical properties. A new generation of composite materials is arising since relatively low carbon nanotube loading (<10 wt.%) within polymeric matrices, are required for various applications. In GEARBODIES, the original elastomeric formulations of the elastomer corresponding to the two selected components were modified by increasing the amount of CNT in the case of the Conical Spring anb by substituting complementary amounts of Carbon Black by CNTs in the case of the bushing. Several tests were performed to evaluate key mechanical properties of the reinforced polymers obtained. Results are shown in Figure 9. Represented curves suggest that by adding only 3% of CNT in original formulations sustantial enhancements are obtained that might lead to increment in the durability of the components.

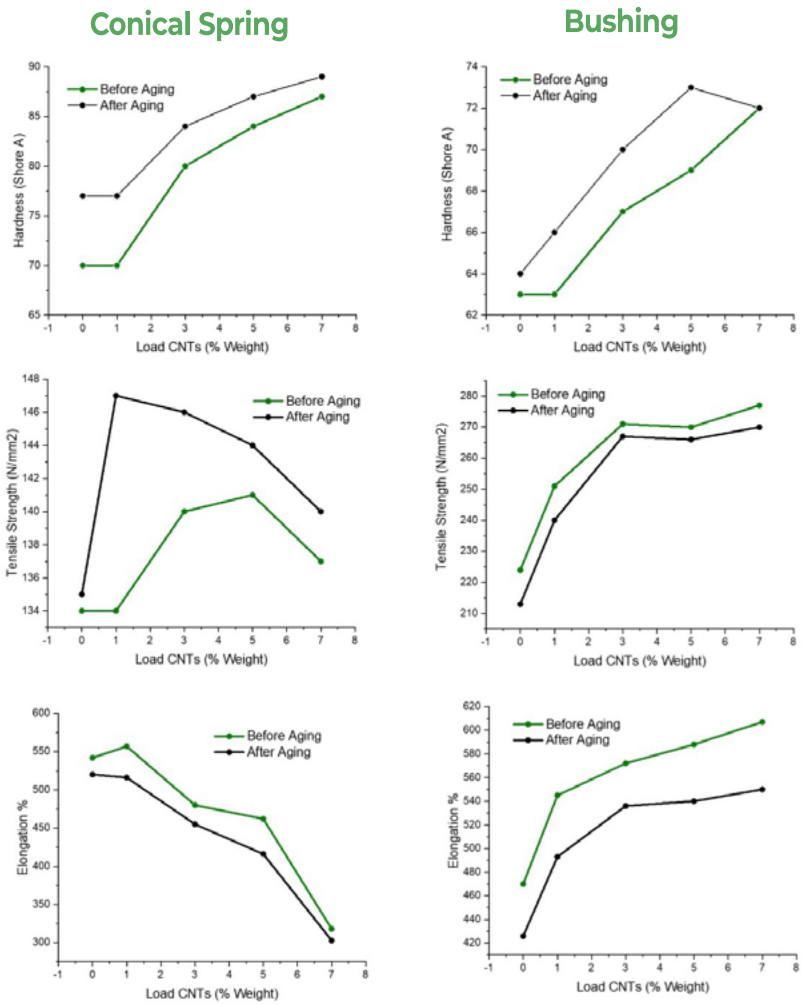
On the other hand, nanotechnology is also the main technology proposed to reinforced the interfase between elastomeric and metallic parts of components. Increasing amount of CNTs will be added to the adhesive using sonication techniques. Other experimental aproaches like plasma treatment or the use of a adhesives of different nature are as well proposed. Peel-off tests will be performed to evaluate the effect of the different techniques. Elastomer-metal specimens like those showed in Figure 10 are currently under preparation.

The manufacure of the two components selected at the beginning of the project (conical spring and the bushing) is being finished. They are being produced based on the findings of the previous work in this WS. Both components will be also tested to confirm the performance improvement expected from the test on the material samples.

The Life-Cycle related aspects concerning elastomeric components will be studied. Benefits in terms of lower-cost maintenance plans are expected following achievements concerning material improvements.

Finally, impact of WS2.1 findings on EN standards will be analysed. Some of the most important standards that can be considered are: EN 13913:2003 Railway applications: Rubber suspension components. Elastomer-based mechanical parts. This standard defines characteristics that elastomer-based mechanical parts shall achieve, together with applicable inspection and test methods to be carried out for verification, with respect to the following elements: elastomeric components; 2) elastomeric materials; 3) interfaces metal-elastomers. On the other hand, also the standard EN 13597 Railway applications – rubber suspension components – rubber diaphragms for pneumatic suspension springs might be studied.

**FIGURE 9**
Results corresponding to tests performed on elastomeric polymers with increasing amount of CNT



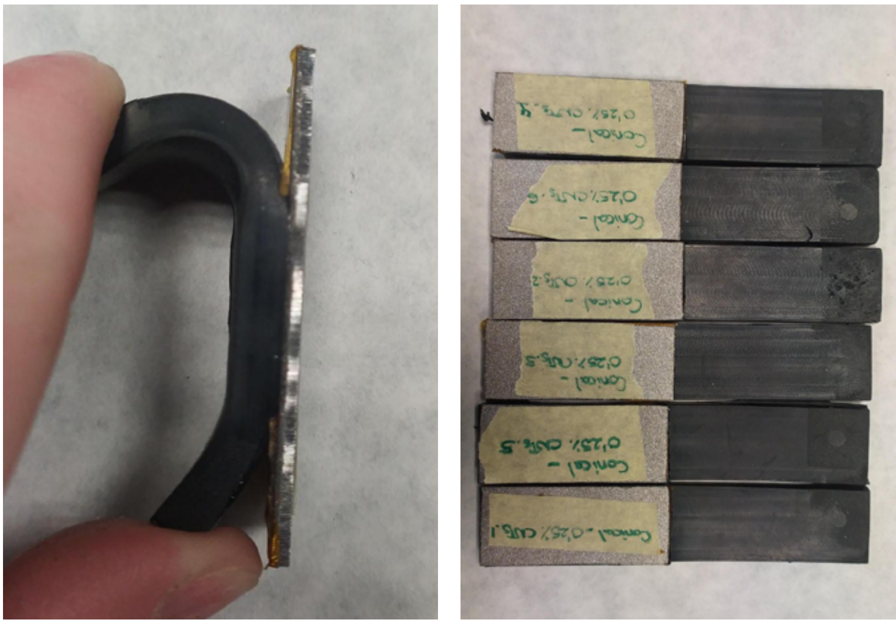



**FIGURE 10**
Metal-elastomer coupons to perform Peel-off tests

# WS2.2 New journal bearings with enhanced performance

Journal bearings, or axle-box bearings, are key drivers of the mileage-based overhauls prescribed by rolling stock maintenance plans. This is also true for High-Speed (HS) rolling stock, in which the wheelset configuration with the bearings in-board of the wheels is of high interest due to its aerodynamic and unsprung mass-related advantages. The first major overhaul, during which the running gear components require disassembly, often corresponds to the first maintenance interval of the bearing (indicatively up to 1.65 Mkm for some HS applications), with the other key components (wheels and axle, gearbox) not really needing the overhaul but experiencing it to avoid another similar overhaul after a relatively short period of time. Currently, the bearing maintenance interval is determined by the lubricant's lifetime. Perfect sealing and low mean operating temperature are the key factors for long lubricant lifetime.

GEARBODIES has developed and is validating Design Concepts (DCs) for journal bearings with extended lifetime to be used on high-speed trains. Two lifetime steps are targeted by extending today's maintenance interval (indicatively 1.65 Mkm):

- extra-long lifetime, corresponding to a maintenance interval of 3 Mkm (replacement at 6 Mkm), and
- ultra-long lifetime, corresponding to a maintenance interval of 5.5 Mkm (replacement at 11 Mkm, or approx. 25 years for an annual mileage of 450,000 km, SHIFT2RAIL SPD1 scenario).

**FIGURE 11**
Schaeffler's TwinTandem Ball Bearing

For extra-long lifetime, a concept has been developed and prototyped (Figure 11). The underlying idea is to minimise the frictional heat generated when rolling, thus curbing grease operating temperature and extending lifetime. The roller layout is entirely novel, and state-of-the-art materials and sealing concepts are used. The analysis of the GEARBODIES rig tests is under way.

Friction reduction has been studied for the more conventional tapered-roller layout, through geometrical refinements of the roller shape itself, of the roller-lip contact and of the cage, as shown in Figure 12. All of the proposed refinements have been shown to be promising through GEARBODIES simulations and, for the novel cage design, rig tests.

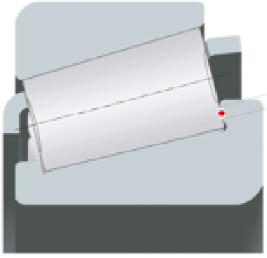


**FIGURE 12**
Roller-lip contact

Low friction is a key element for ultra-long lifetime too. However, novel materials are of interest. They can offer not only low friction, but also excellent ageing properties such as phase stability for rollers and rings, and little swelling or oxidation for the cage polymers.

High-Entropy Alloys (HEA) for the bearings' rolling components (rollers and rings) have been first screened via theoretical calculations and simulations in GEARBODIES. Fabricated samples of four selected alloys, some heat-treated, have been subjected to tests. All of the tested alloys performed generally better than the state-of-the-art steel taken as reference (Figure 13). Coating of a steel disc was successfully performed through Physical Vapour Deposition and the tests showed improvements in surface properties with respect to steel. Improved phase stability is also expected thanks to the "sluggish diffusion" effect of HEAs.

As to cage polymeric materials, the promising poly-ether-ether-ketone (PEEK) was subjected to several tests and compared with the widely used glass-reinforced polyamide PA66. Injection moulding was used to fabricate 120 samples of both materials. Some of them were subjected to accelerated auto-clave ageing for different durations in different lubricant environments (as it shown in Figure 14). Visual, mechanical, structural and tribological tests were then performed. PEEK showed interesting properties, such as lower absorption from the surrounding environment, and lower variations of key properties with ageing that encourage further research.

Another possibility to radically extend lifetime is changing the nature of the lubricant. Oil has been used in the past and is worthwhile revisiting in the light of technological progress. It promises low friction and, particularly in high-speed trains where oil-lubricated gearboxes are generally present, the opportunity to extend lubricant lifetime significantly by circulating it, filtering it and cooling it during operation. In GEARBODIES, a novel sealed-housing concept (Figure 15) was developed to progress in this direction.

The Life-Cycle related aspects of the above findings are currently under analysis. Benefits in terms of lower-cost maintenance plans are expected, whilst maintaining the same level of safety.

Implications on Standardisation and Regulation regard issues such as the inclusion in EN standards of balls as rollers, a specific ultrasonic testing methods and ring-marking provisions should the Twin-Tandem concept be introduced to market. For ultra-long lifetime, HEA could be allowed at least as a coating material, and, PEEK could be mentioned explicitly as a possible material. Also, the standard test-rig load cycle could be differentiated to match the operating scenarios (such as the SPD1 taken as reference) more accurately.

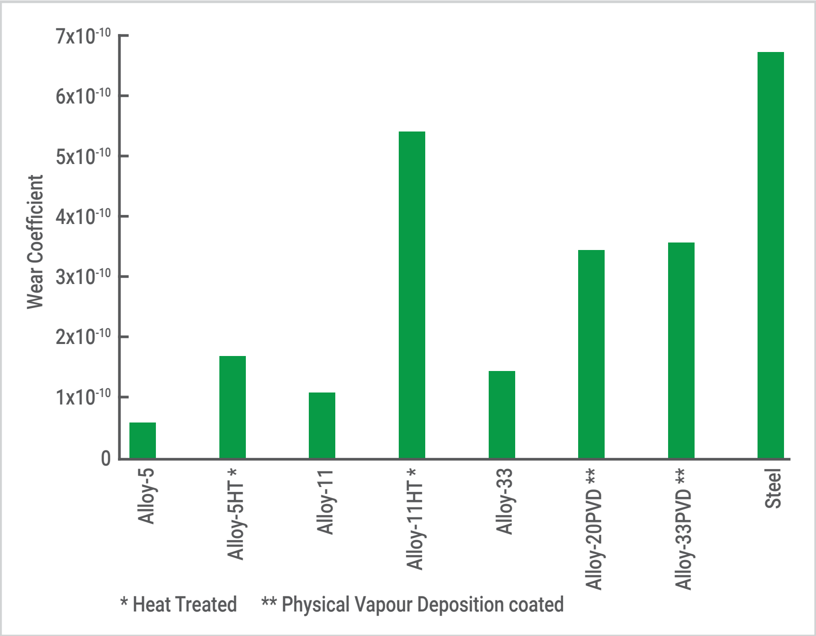



**FIGURE 13**
Wear coefficient of tested HEAs (along with value for benchmark steel)

**FIGURE 14**
SEM microscope pictures corresponding to the fractured areas of the PEEK samples aged at 140°C

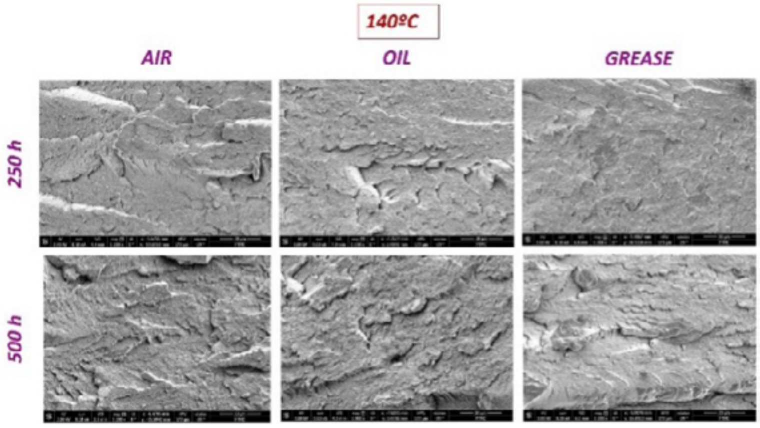
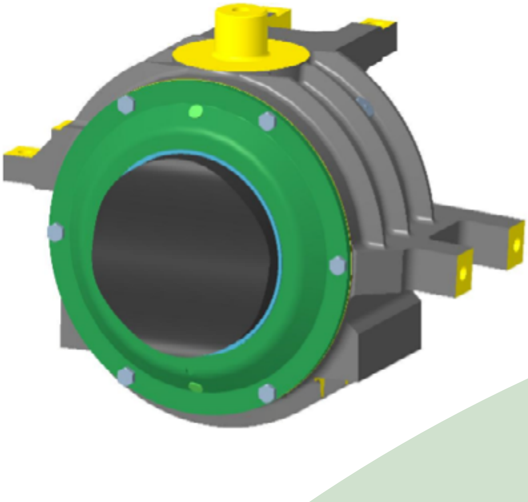



**FIGURE 15**
Sealed-housing concept drawing



# FACTS AND FIGURES

Budget
**2.4 million**

Duration
**31 months**

**13 Partners**
from 8 EU countries

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**01.12.2020**

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Coordinator
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