Polymeric composite materials have been increasingly applied owing to their low mass with simultaneous high strength and stiffness, and corrosion resistance. These advantages allow for application of composites as structural elements of aircraft skins, ship hulls, or modern car bodies. However, due to their complex internal structure, which consists of many layers of different materials – such as resin and carbon fibre, they also have disadvantages, including low resistance to impacts. A particularly serious problem is so-called low energy impact damage (in the case of aircraft it is caused by e.g. hailstorms, or runway debris), since it is barely visible on the impacted surface, whereas may cause remarkable internal damage. Despite this, such the impacted elements are often allowed to be further used, provided that they can continue to fulfil their function in spite of the damage existing inside. In order to check this, such elements are periodically inspected with use of non-destructive testing methods, such as ultrasonic testing (UT), by means of which it is possible to visualize the internal damage and to calculate its size and depth. However, one of the current needs concerning monitoring of structures' condition is development of a method of prediction when the existing damage will develop to cause a total destruction of the element. Such the information could help preventing failure and would allow for proper planning of repairs. The aim of the research project is to develop a method enabling prediction of the residual life of composite elements, which can be given for instance in a number of operating hours of the damaged element left to failure, based on scans obtained during UT and assessment of the structure's condition by means of computer simulations.

This aim is planned to be implemented in several stages. Firstly, two types of composite specimens will be manufactured – made of a carbon fibre and a glass fibre reinforced polymer, and they will be artificially damaged by means of various configurations of impactors. Then, the specimens will be tested using UT and X-ray computed tomography (XCT), as a reference method, since XCT enables exact visualisation of the internal form of elements. Afterwards, an algorithm for the purpose of detection and three dimensional (3D) reconstruction of damage from UT, using advanced image processing methods, will be developed. Then, accuracy of this reconstructed 3D damage will be verified by comparing it with the reconstructed damage from the reference XCT data, and the algorithm will be improved if the accuracy will not be high enough. The next step will be the development of an algorithm enabling damage classification, i.e. separation of damage into areas being cracks and delamination, since contours and arrangement of these two types of damage will be needed to prepare simulations. Later, a method will be developed that will enable conversion of the acquired damage characteristics to a CAD model, i.e. to the format by which geometric forms of new products are modelled by constructors. The obtained CAD model of damage will be exploited in further stages as the input data to structural simulations, which will be performed in order to predict damage development. In order to look broadly at the scientific problem undertaken in the project, the numerical analysis will be performed both for simulation and experimental data. Firstly, numerical analyses and predicting residual strength using compression after impact (CAI) tests will be performed based on prepared numerical models of composite specimens and simulations of impacts. Afterwards, the same types of analyses will be performed based on the experimental data, i.e. the real damage extracted from UT scans. Moreover, the laboratory CAI tests of the impacted specimens will be performed in order to verify the developed methodology. Having the above discussed numerical results of structural degradation for both the simulation and experimental data and the results of the laboratory CAI tests, they will be analysed and compared. Based on findings from the obtained results and comparative analysis, as well as taking into consideration the theoretical fundamentals of fracture mechanics of composite materials, a theoretical model describing the residual strength of composites with low velocity impact damage will be developed.

The effect of the project will be the new experimentally verified methodology of predicting the residual strength of composite structures based on UT scans and numerical simulations. A new approach based on reverse engineering will be developed, exploiting data extracted from ultrasonic scans of composite elements in order to create a CAD model of the element reflecting its current condition, including existing damage. The results obtained from numerical analysis will bring information about the estimated residual strength of the tested composite element, which will bring more information than the results obtained solely from UT.