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# REVERSE ENGINEERING OF COMPLEX SHAPED PARTS

*Modern automated design of complex shaped parts using CAD/CAM/CAE software faces the task of creating a virtual 3D-model of an existing physical object, without reference to the source documentary producer. This work is dedicated to the practical application of reversible designing of technology elements used in extreme downhill biking. Significant load leads to destruction of some parts of the equipment, but replacement of a unit is economically disadvantageous. Simulation of the idler lower pulley wheel of rear derailleur and creation of attachment to the protective helmet are described in the paper.*

*The aim of the present research is practical application of the knowledge, obtained in the classroom with computer 3D-design of complex shaped parts, using a modern technology of reverse engineering (modeling) by means of PowerSHAPE 2015 (Delcam Ltd, UK) and Autodesk Fusion 360 (USA) software.*

*The work will be presented to the international student competition Delcam 2016 and was awarded the second prize of the International 3D Modeling Competition 2016 at Pavel Sukhoi State Technical University of Gomel, Belarus.*

*Keywords: reverse engineering, hybrid modeling, Delcam, PowerSHAPE, Fusion 360, Autodesk, 3D-print.*

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# РЕВЕРСИВНЕ МОДЕЛЮВАННЯ СКЛАДНИХ ЗА ФОРМОЮ ДЕТАЛЕЙ

*Висвітлено хід реверсивного комп'ютерного моделювання (зворотного інжинірингу) складних за формою деталей із використанням сучасного CAD/CAM/CAE програмного забезпечення PowerSHAPE та Fusion 360 на прикладі зубчастого колеса компаньйоли та кріплення камери GoPro до захисного шолома. З'ясувалося, що зубчасте колесо зруйноване в процесі експлуатації, але запропонована заміна цілого блока економічно недоцільна. Задачу розв'язано із застосуванням технології реверсивного моделювання в програмі PowerSHAPE. Дублююче ідентичне зубчасте колесо використано для визначення вихідних параметрів форми і розмірів. У процесі проектування застосовано гібридне твердотільне й поверхневе моделювання. Кріплення камери до захисного шолома має оригінальну конструкцію. Реверсивним моделюванням визначено криволінійну форму поверхні стикування об'єктів та параметри сполучення. Проектування виконано в «хмарній» технології Autodesk Fusion 360. Обидві деталі виготовлено 3D-друкуванням.*

*Ключові слова: реверсивне моделювання, зворотний інжиніринг, гібридна технологія моделювання, Delcam, PowerSHAPE, Fusion 360, Autodesk, 3D-друк.*

**Introduction.** Present day automated design of complex shaped parts using CAD/CAM/CAE software faces the task of creating a virtual 3D-model of an existing physical object, without reference to the source documentary producer. A component part is measured and processed up to the manufacturing stage in the format suitable for the designer. This work is dedicated to the practical application of reversible engineering technology for elements used in extreme downhill biking. Significant load leads to destruction of some parts of the equipment, but replacement of a unit is economically disadvantageous. The paper describes the course of modeling the idler lower pulley wheel of rear derailleur, gear-change mechanism (see Fig. 1) and designing safety helmet added equipment mount.



**Figure 1 – Rear derailleur (left) and its idler lower pulley wheel (visualization)**

**Latest research sources and publications analysis.** In the absence of engineering drawings and in the presence of a sound or damaged part, when repair parts supply is impossible, there occurs the necessity to apply «reverse engineering» [1,2]. This term [3] is understood as a possibility of determining 3D parameters of a detail in the absence of the design documentation. It is possible to take measurements of the real dimensions (which has actually been done) or to use 3D scanner for obtaining a «point cloud» [1,2].

**Problem definition.** The study is aimed at the practical application of knowledge, obtained in the academic process, on computer 3D design of complex shape parts, using the present day reverse modeling technology by means of licensed CAD/CAM/CAE software PowerSHAPE 2015 sold by Delcam Ltd (UK) and Fusion 360 sold by Autodesk (USA).

**Basic materials and the results.** Nowadays, complicated high-curvature parts are prevalent as a basis for the parts design. Our choice of reverse engineering is explained by the fact that, though one of the idler lower pulley wheels was damaged, the rear derailleur has two identical tooth gear wheels (upper and lower ones), and the upper one (jockey) remained sound; therefore, there was an opportunity to determine the output parameters of the object's dimensions and shape. It should be noted, that we had to apply both solid modeling – two sections rotation (Fig. 2) and surface modeling – for designing curvilinear edges (Fig. 3). For surface modeling the specific command «smart surfacer» was applied. Finally, the surface part of the model was converted into a «solid body» and the integrated element was created by means of «Boolean combination process» (Fig. 4).
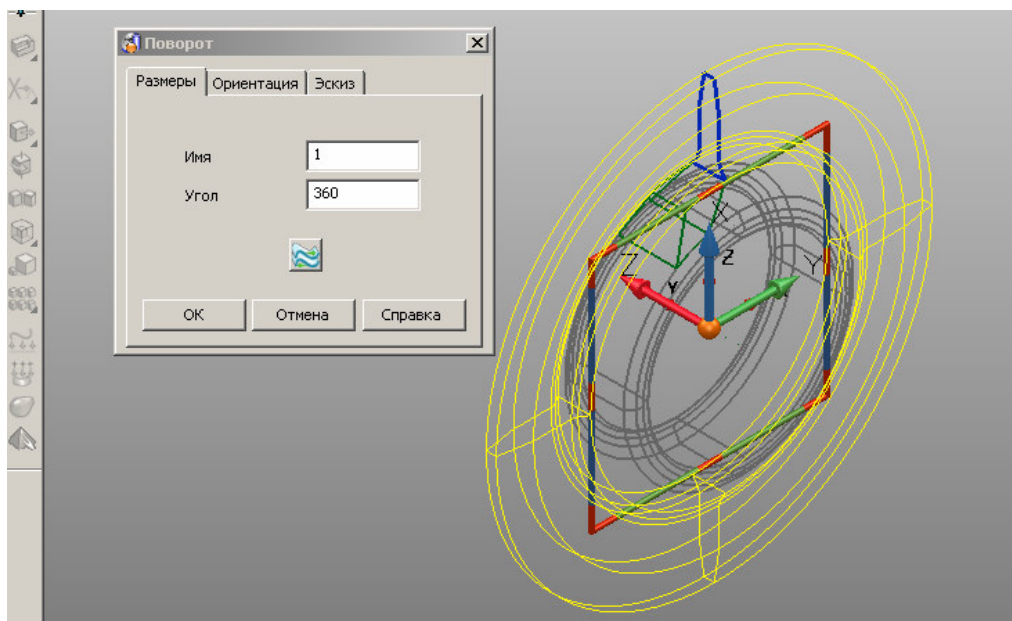
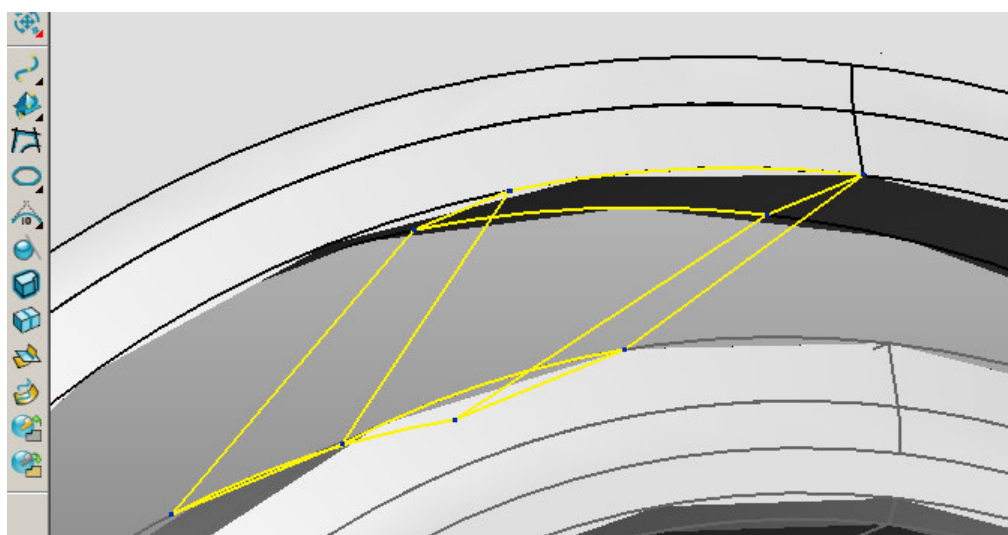**Figure 2 – Solid modeling by means of rotation**



**Figure 3 – 3D curves contours as basis for "smart" surface modeling**

Combined application of solid and surface (hybrid) modeling is one of important features of designing with PowerSHAPE. Meanwhile, there is a possibility of Tribrid modeling, patented concept of Delcam Ltd., if in addition to the above technologies, triangulation elements are used in one and the same design project. Tribrid modeling is a technology, including (according to the project designer's needs) not only surface and solid, but Triangle modeling additionally. Combined application of all the available modeling types (having significant differences in their bases) in one and the same program permits to avoid export-import operations on transferring data to unauthorized software, improves the performance quality. The above approach permits obtaining a product's concept by its physical model, not only by simple cloning. A wide range of functions, such as Boolean operations, facet video overlay, morphing and many other features permit obtaining a prototype of an object existing in reality, performing an object editing to improve its design and technological properties
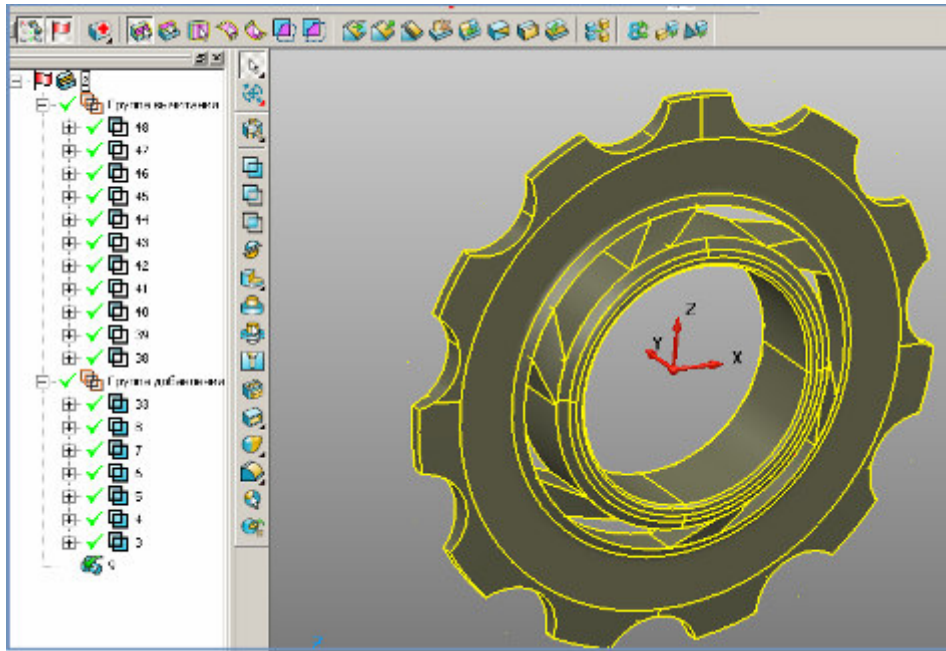
**Figure 4 – Complete solid model**

To manufacture the part, the operation of the solid element exportation into the triangle format of STL steriolithography was performed (the specialized Delcam Exchage software was applied). For 3D printing PLA plastic was used. The bicycle-type bearing, remained from the damaged part, was inserted into the tooth gear wheel (Fig. 5). The results of the printed tooth gear wheel's exploitation demonstrated that the part's wear was insignificant, the part performed its function successfully.



**Figure 5 – Tooth gear wheel: the original (left) and the printed part**

Delcam Ltd only permits home use of PowerSHAPE-e, a free version of PowerSHAPE-Pro, which can be used for design ideas assessment, training and research activities. However, file exportation (for instance, for manufacturing) is prohibited except for the «user fees». For designing the other part – safety helmet added equipment mount for a special GoPro camera, used to record race tracking video, another software, Fusion 360, was

used. Information for users: Fusion 360 is a project developed by Autodesk corporation, and Delcam has been its spin-off company since 2015.

Fusion 360 is an innovative software suite by Autodesk (USA) programmed as «cloudy» CAD/CAM/CAE instrument for engineering designing, aimed at small enterprises, engineers-inventors, etc. Autodesk Co (the world largest CAD/CAM/CAE technologies designer) presents Fusion 360 as a sort of a test platform, because that very approach is to be applied in the future versions of this company's flagship programs. In our case, the important factor, having prompted Fusion 360 application in reverse computer modeling, was a proposal made by the rightholders of the free software product use for students and their teachers for the 3-years term. The peculiar feature of the Fusion 360 «cloudy» structure is the possibility of working at a project both from a powerful graphic station and from a notebook, workpad and even smartphone, as all the «difficult» calculations, conversion operations, visualization are performed by the «cloudy» component available through Internet.

Various variants of universal added equipment mounts found in the Internet did not suit our particular case, because these variants used either a double-sided mounting tape or flexible mounts which were too huge or mounted in the wrong place, namely under the safety helmet's brim. Besides, to obtain a fixed joint, the lower surface of the part should duplicate the helmet's shape, fitting it tightly.

Safety helmet has a complicated shape, and it would be reasonable to apply reverse engineering of a 3D point cloud. The absence of such an option prompted to make use of a simple technique, namely: a fragment of expanded polystyrene was tightly pressed to the helmet in the place where a mount will be located. The obtained counterproof was scanned, and the bit map image was transferred to Fusion 360 software, where the picture was calibrated according to its real size (Fig.6). In PowerSHAPE the analogous command is absent.
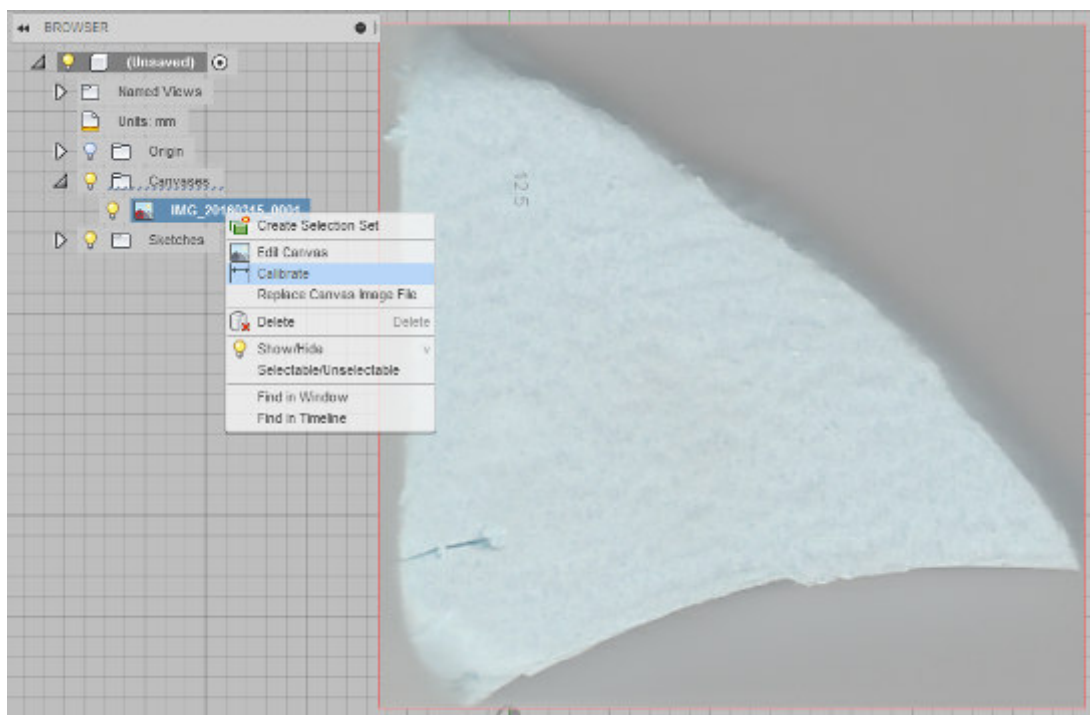


**Figure 6 – Counterproof image in the process of calibration**

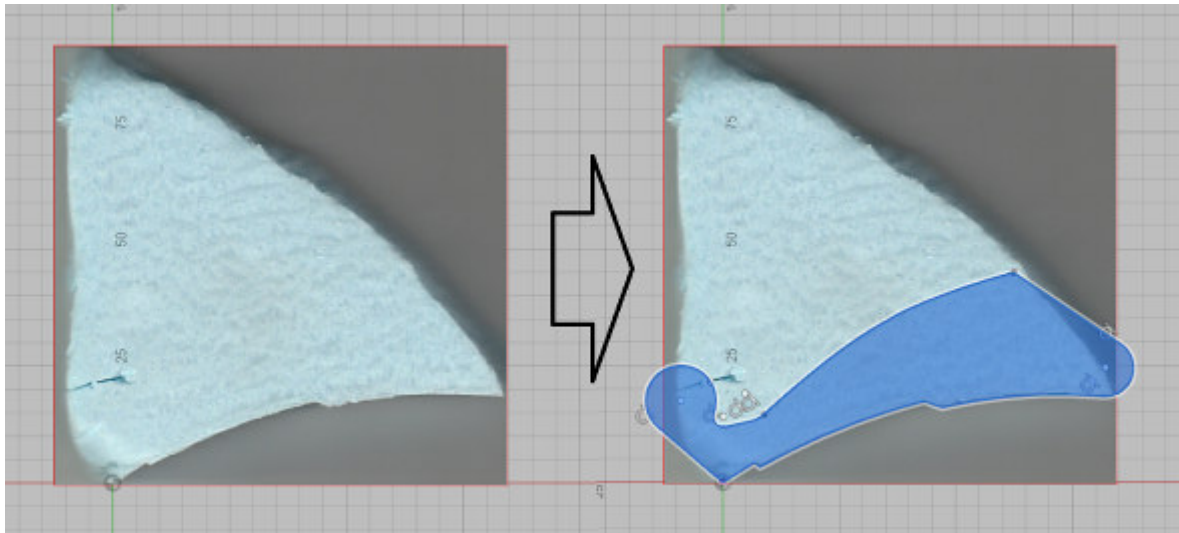The next stage was mount profile modeling by means of vector primitives (Fig. 7).

**Figure 7 – Mount profile modeling**

After comparing the vacant space under the helmet's brim, where a camera would be mounted, and the camera's dimensions, joint endpoint and the designed dimensional specifications of the mount were determined. At the first stage a sketch («Sketch» function) was drafted, and after the «Extrude» function had been used, a 3D part blank was obtained. The second stage was removal of extra volume to reduce the whole mount's weight and for efficient use of the material. The third stage was formation of a mounting site for special disarticulation of the GoPro camera for fixing it by means of a bolt-on junction, without a possibility of screwing the nut (Fig. 8).
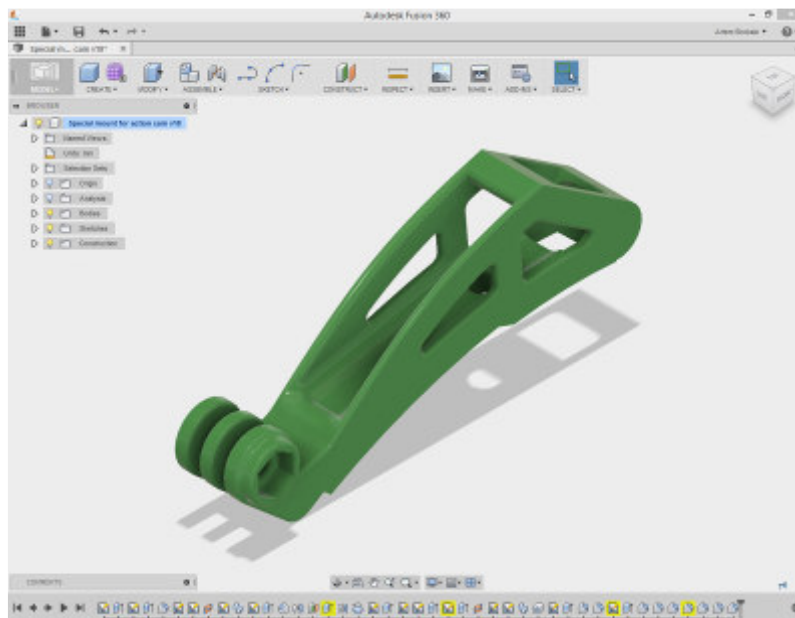


**Figure 8 – Mount model in the Fusion 360 "cloud" environment**

Version design method permitted to maximally reduce the model's weight, preserving the sufficient hardness and torsional rigidity, which have positively effected the video record.

For the preliminary modeling results assessment, the project visualization was performed (Fig. 9) using the «Render» module. After the full completion of the project, the model was 3D printed (PLA plastic was used again, but this time it was colored green).

**Figure 9 – Visualization of the GoPro camera mounting onto the safety helmet**

The item translated into reality, due to peculiar features of 3D printing, had a lot of extra supporting material necessary for building the model's fragments. After the above "support" had been removed, the model was immediately tested under the sporting contest conditions. The mount has presented itself well, camera records sustained video. The camera's mounting is simple and easy without any additional tools. Due to a specially designed mount the camera does not stand proud of the helmet, it is compactly located under the helmet's brim, which provides additional protection.

The camera mount is presented in the Autodesk Fusion 360 project gallery (https://gallery.autodesk.com/fusion360/users/V8U6L4AXRE5P) and at the International competition on students' 3D modelling in P.Y. Sukhoy State Technical University of Gomel (Belarus) (https://www.gstu.by), where the project was announced the winner and awarded the second class winner's certificate.

**Conclusions.** The implemented models have permitted to study practical application of the today's software, produced by the world leaders of CAD/CAM/CAE technologies, and to master the reverse engineering of complex shaped parts with their further 3D printing.

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