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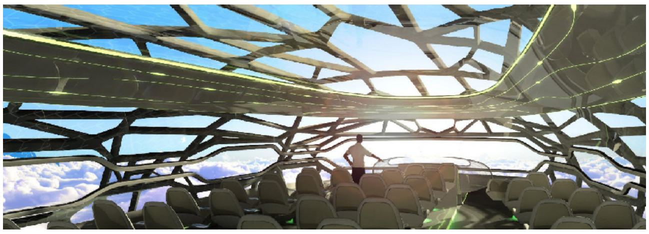
Analysis of the applicability of the bionic structures in optimizing transportation weight

Transportation is equipment which absorbs energy. In the era of the energy rising prices one seeks solutions that can result in savings due to reduced energy consumption. The world of science and industry is continuously looking for savings in this area. In simple logic, we can talk about savings when there is a reduction in kerb weight of driven object. This paper presents an optimization method that can be used to reduce the weight of vehicles. Mass optimization is a process that has to be conducted on basing on the assumed criteria and, as in the case described here, the normative requirements. Presented process begins with the definition of the area to be analysed and then decomposition and selecting the typical construction nodes after that continues to picking library solutions based on which, the selection algorithm is built. User calls back the criteria and selects it interesting solution: the extreme: a light and expensive, heavy and cheap or many other combinations. The study aimed to achieve the effect of optimization based on computational methods in the final stage of the experimental verification, depending on the case.

1. Introduction

In the paper of "Airbus Concept Cabin 2050 - A Flying Experience Inspired by Nature" by Ingo Wuggetzer it was stated, that you can't predict the future, but you can try to sketch, for example, how will look vehicle construction in the year 2050. Teory presented by Wuggetzer is based on the concept of bionic structure which is characterized by the following features: less weight is greater capacity which increases earnings, lower logistics costs and the virtual storage which then reduces the cost of additional equipment, lower weight results in reduced fuel consumption and CO_2 emissions, efficient use of raw materials.



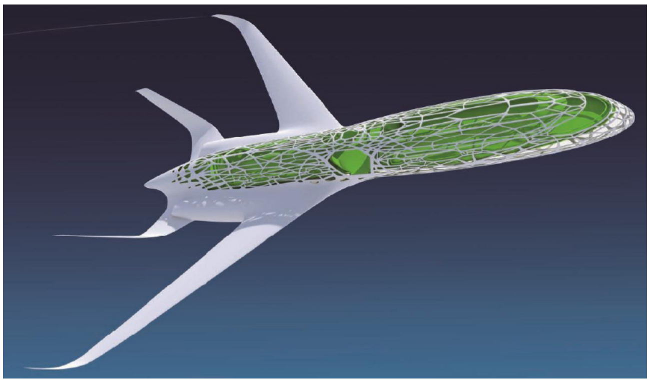


Fig.2. Airbus – the vision for 2050 [1]

The world around us is a mine of countless solutions and answers to many difficult problems faced by engineering in a broad sense. Just look around to see the many almost ideal forms, such as a spider's web-structure with properties unattainable even for the present study. Humanity, being aware of the millions of years of experience, trying to imitate nature of drawing from it a solution optimized and refined over the centuries. Among the great inventions of nature is also a beetle - Ciemnik czarny (*Melanophila acuminata*), which thanks to its infrared detecting organs can see the fire even from a distance of several kilometers.

2. Bionics

Over the years, science copes more and more efficiently with the derive inspiration from nature.

This trend has become so popular that there was created a science called Bionics (from Gr. Bios - life, and mimesis - mimic). Both in ancient times and today reaping the patterns of nature is popularized for two main reasons: aesthetic and a search for answers to various structural problems. Let's focus on the second, as it turns out, extremely beneficial in many ways. Nineteenth and twentieth centuries until the late 50's and 60's is an explosion of colored trend of modernist thought pro-organic creations. This trend would certainly progress had it not been for the restrictions caused by technological barriers.

3. Inspiring skeleton

Fig. 3. Structural components of the aircraft Airbus A350 optimized by method of bionic structures by ILAS [2]

In recent years, thanks to substantial progress in the field of materials science, we should focus our efforts on returning to the trend of thought based on bionics. Living in an era of soaring energy and fuel shortages it turns out that every kilogram of weight savings on aircraft costs hundreds of thousands of dollars. Manufacturers of transport compete in ever new solutions designed to produce in significant weight savings. Behind us many years of experience but also new challenges: namely, with the development industry to improve our means of transport in terms of safety. The result is a steadily increasing weight so look for new methods of optimization are essential. For example:

Fig. 4. Comparison of weight of cars VWGolf [3]

Despite considerable experience it is clearly visible that there is a difficult task ahead. Only the development of effective methods to optimize the weight will win the race with the loads generated by the installation of active and passive safety systems.

4. Definition of the area

Field of interests includes rail transportation, precisely rolling stock – particularly passenger one. In details it includes issues of supporting structures of selected pieces of equipment train, here: the construction of the passenger seat. Why rail vehicles? It turns out that this is an area where there are many elements which give high hopes for effective optimization. Railway unlike aviation and automotive industry does not need to float or not participate in the race. The common rail vehicles are also implemented specific design solutions. Most of them are made of metal. We apply here also specific safety standards enforced by, for example, EN 15227. In simple logic, regulations on safety generate a lot of weight. Therefore, in proportion to the increase of safety requirements there is a growing need to optimize the mass in other areas. Weight-saving (from single-seat passengers) multiplied by the number of those seats around the vehicle may result in desired value. The shape of the seat support structure, from a geometric point of view, is promising and gives you a good chance of success for the bionic method.

a) Definition of areas of the activity – roughly:

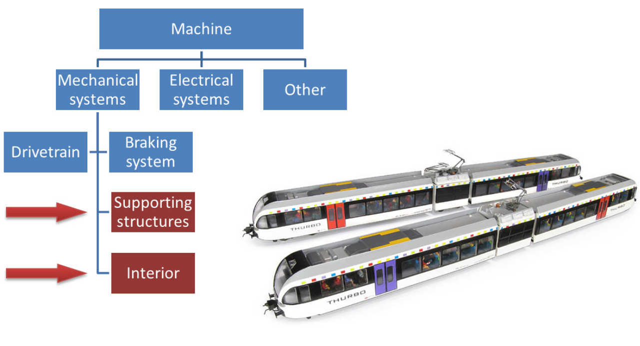


Fig.5. Coarse area scheme

b) Definition of areas of the activity - detail

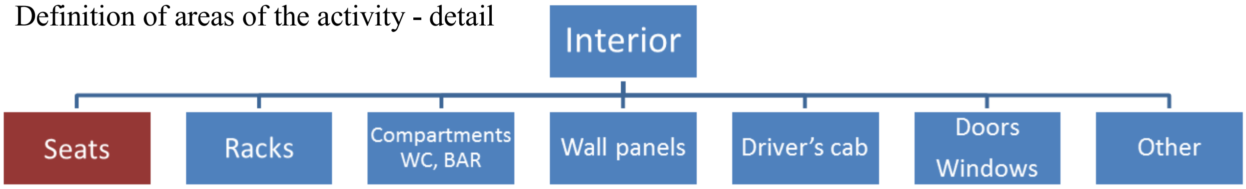


Fig.6. A detailed diagram of the area of operation

c) Object – passenger seat - decomposition

The construction system of the seat is mainly bound beams along the Z axis and the X axis, wherein the Z-axis the beam is characterized by a dominant arm length. The study was divided into sub-systems of the whole system, in order to simplify and identify the individual nodes to study. For comparison method was decided to only those nodes that are most relevant to the distribution of stresses. The calculation of these nodes form loops seeking to obtain optimal solutions of each individual derivative decomposition.

At this stage the identification of critical nodes follows according to the assumed optimization criteria:
- Mass
- Stiffness
- Durability
- The cost

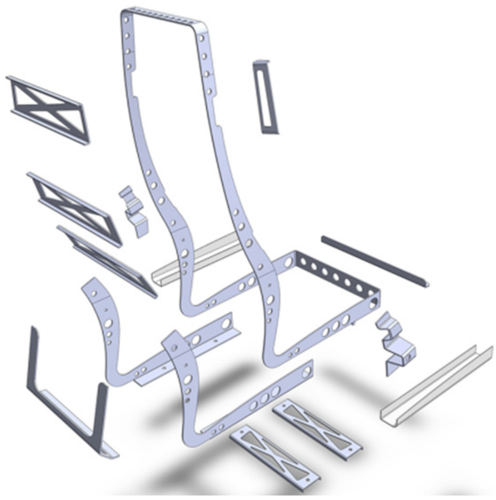
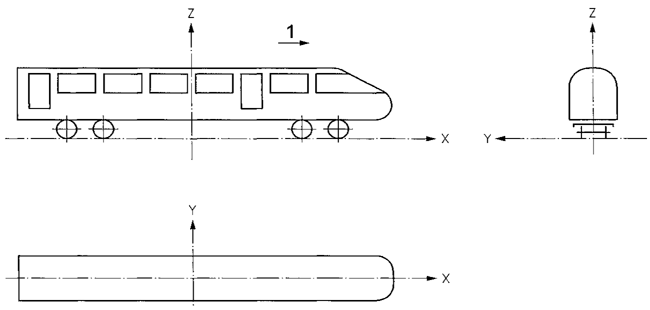


Fig. 7. Graphical model of decomposition

Optimization criteria such as normative requirements can be found in the standards such as EN 15227 EN 12663, UIC 566, UIC 567. The scope of the requirements in respect of the charges is based on the 3-axis coordinate system in which car body is entered.

5. Modelling nodes

The next step is concepts developing and modeling nodes in order to provide the required performance properties such as bending, hardness, etc. As a



Rys .8. Rail vehicle in the coordinate system to be adopted in the standard EN 12663 [4]

result of this process, we obtain n - solutions that create a library which is an input to the algorithm which creates a final product optimization. Of course, in addition to bionics, there are contributed other ways to efficiently optimize the load-bearing structures. These methods are based on: choosing a concept at the initial stage of modeling, change the cross-sectional geometry control, choice of joining techniques and material selection where as an example of effective optimization focused on the choice of material which Chiyoda subway line in Japan may exemplify [5]- there were carried out practical Energy measurements. A set of steel wagons and wagons with aluminum shells were compared. The cars made of aluminum consumed 4000 kg of aluminum instead of 9450 kg of steel.

It can be seen that wagon made of aluminum saves energy surplus in less than two years. Similar calculations were carried out among others in Atlanta in the U.S. and in Germany [5]. In Atlanta, it was found that saves additional energy within three years, while in Germany the result obtained 1.6 years. However, focusing on the method described here, following the designation of typical nodes takes painstaking 3D modeling. As a result of this process, components take the form of bionic-like skeletons. The supporting structure has a large cross-section at the relevant power transmission and low in areas where high capacity is less desirable. Figure 9 is an excerpt cantilever, subjected to loads in the x-axis and z-axis. As preliminary studies have shown numerical bionic structure successfully replaces the existing, full solid model. Further examples such as support or leaf process clearly shows there were more accurately.

Tab.1. Comparison of energy consumption and production of steel and aluminum [5]

ENERGY CONSUMPTION IN PRODUCTION[1]	Aluminum	4 000 x 37,2[2]	148 800 kWh[3]
	Steel	9 450 x 9,5[2]	89 775 kWh
	DIFFERENCE	59 025 kWh	

Tab.2. Comparison of the energy consumption during operation [5]

ENERGY CONSUMPTION IN THE TWO-YEAR OPERATION	Aluminum car	489 900 kWh
	Steel car	561 200 kWh
	DIFFERENCE	71 300 kWh

1) Without the use of metal recovered
2) Consumption estimated by Granges Technology Centre
3) 1 kWh = 3.6 MJ [5]

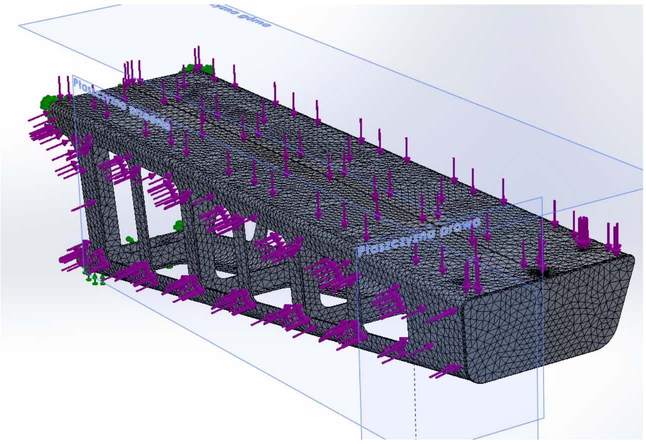


Fig.9. Figure showing the loaded cantilever forces along the X and Z axis

In the following example I will try to illustrate that one of the methods of optimization based on bionic structure pays a high rate of efficiency:

There have been research arm / bracket made of aluminum EN AW-6063 T6 able to 10mm thick. In the first study, the bracket is made of a solid material and has a mass of 1,118 kg.

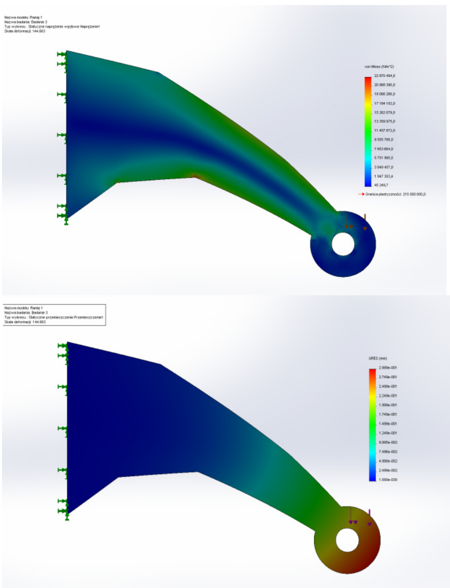


Fig.10. Diagram respectively: the distribution of stresses and displacements

During the static load 1000N force in a downward direction reaching the maximum stress was recorded 22Mpa (Yield = 215MPa)
Noted was the largest displacement of 2,999 E-001
Reducing repeated tests to support the weight of 0,696 kg

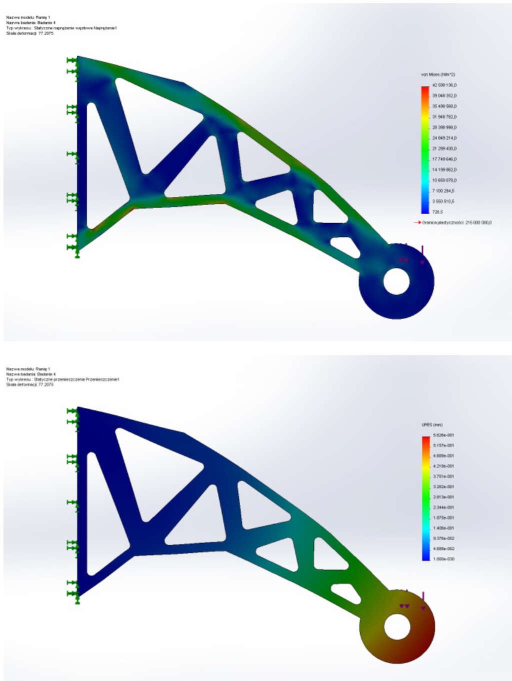


Fig.11. Diagram respectively: the distribution of stresses and displacements

Reported maximum stress reaches 32MPa and with adequate radius compensation to reduce the stress level of research first. The displacement was 5,626 E-001.

This experience shows that the adjustment of the bracket on the model of bionic structures, resulting in overall weight savings of approximately half with a slight loss in the form of a slight increase in the maximum stresses and displacements.

As it turns out, we can easily find many examples in nature of occurrence intelligently optimized structures. When we look at the construction of leaves, apart, of course, biological aspects, the list does not have the same thickness and structure of the entire area. Leaf blade "tense" is a network reinforcements like beams that extend from the tail to the brim. Imagine a tree hung with heavy leaves in a storm. Certainly would not have survived as a whole stronger gusts. To better understand the issue and transfer methodology to build such structures with the natural mechanics, load testing was performed numerical 3D model leaf in two versions: A leaf of uniform thickness, not optimized, made of aluminum and leaf B, to some extent, subject to an initial process optimization, made of the same material.

- A leaf weight is 0,081 kg, thickness 5mm, one side of the leaf was subjected to constant load of 100N. Results of the study were as follows: maximum stress was about 100 MPa at Re = 215MPa. Move to the top of the leaf was 6,116 E-001.

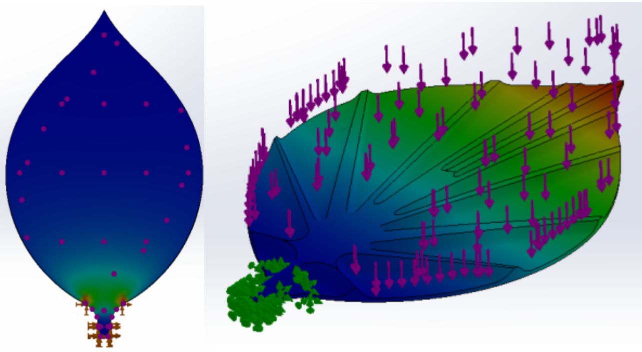


Fig.12. The graphic image at a time: the distribution of stresses and displacements

- Weight of leaf B is 0,03 kg, thickness from 1 to 5 mm, one side of the leaf was subjected to constant load of 100N. Results of the study were as follows: maximum stress was about 109MPa at Re = 215MPa. Move to the top of the leaf was about 2,7 mm.

6. Conclusions

As shown by the results of preliminary simulations, modelling on nature may bring many benefits. Thanks to tools like computer programs to simulate different load cases which structural nodes are subjected , we can in a relatively short period of time optimize every element of the structure. On the basis of certain conditions arising from the research process we can correctly interpret certain phenomena and implement solutions to the optimization process. The direction of optimization presented in the article points out the possibility of reducing mass of many elements as much as half. In addition, we can control solution with a focus on behavior or even increase the static stiffness, cost, etc.Called here methods suggest the need for an interdisciplinary optimization approach. During next stage for full application of the proposed approach, it will be necessary to develop the evaluation function of achieved results in the range of reducing weight.

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