MATEC Web of Conferences **338**, 01016 (2021) https://doi.org/10.1051/matecconf/202133801016
PRMR 2021

Development of a design concept for a prototype transport device using the Design Thinking method

Bartosz Mazurek [*1], *Jarosław* Mamala [2]

[1] Science and Technology Park, Technologiczna 2, Street, 45-839 Opole,
[2] Faculty of Mechanical Engineering, Opole University of Technology, 45-407 Opole, Mikołajczyka 5, Poland.

Abstract. The article presents the development of a multifunctional prototype transport device mounted on a towing hook of a passenger car, used to transport motorcycles and light four-wheeled vehicles, based on the Design Thinking method. The device, in its original design, has obtained patent protection from the Patent Office [1]. The use of the device in real road conditions requires the solution of many technical, ergonomic, endurance and functional problems, and in the final phase the implementation of the final device. The authors of the study presented the most important construction works described in terms of the analysis of the key strength nodes of the transport device. The boundary conditions for the weight of the device and the forces acting on the device were based on literature data on the load capacity of hooks used in passenger vehicles, the weight of motorcycles in accordance with the classification, which was verified in the identification tests on the real model, taking into account the height of the front wheel suspension of the transported motorcycle. According to the data analysis, the mass of the transport device should oscillate within 10 kg, and the reference point for the construction work is the prototype model made of s235 steel with a net weight of 28 kg. On this basis, the work presents simulations of a static load with the determination of stresses in the material, deformation and mass calculation for various design versions. In the final stage, the target construction version, designed from two materials, i.e. steel s235 and aluminium 6081, was compared. As a result of the analysis, the target construction reduced the weight of the transport device by 17 kg.

1 Introduction

The automotive market is growing year by year, the number of vehicles in use in the world already exceeded 1 billion units in 2015. However, the developing society did not give up the need to use light quadricycles and single-track vehicles, most importantly, the nature of their use has changed. More and more often users of two-wheeled vehicles and motorcycles choose this means of transport for recreational purposes. The numbers speak for it, as the potential of the automotive market increases and the number of newly registered motorcycles

* Corresponding author: b.mazurek@pnt.opole.pl

in the European Union increased by 8% in 2019 and amounted to 1,079,524 units compared to 2018 according to the European Association of Motorcycle Manufacturers (ACEM) (fig. 1.). Italy remains the largest motorcycle market, where 231.712 motorcycles were registered in the first half of 2018 (an increase of 5.4%). The next places are: France (197,470 motorcycles, +11.4%), Spain (177,037 motorcycles, +10.7%), Germany (166,676 motorcycles, +6.8%) and the United Kingdom (101,273 motorcycles, +0.9%) [2].

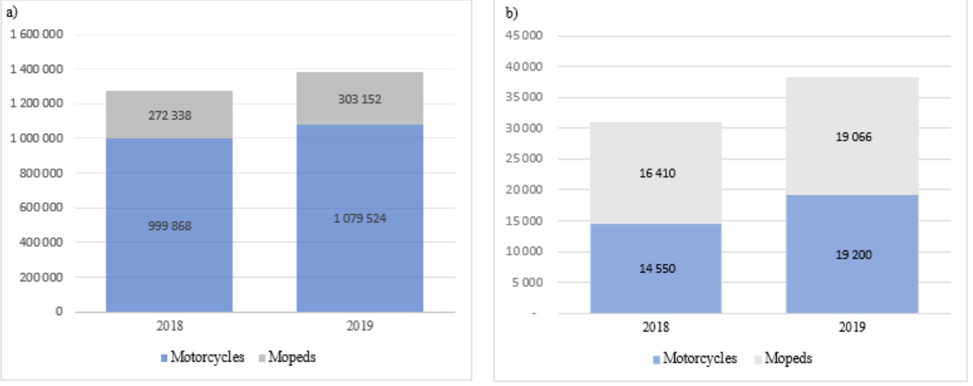

Fig. 1. Sales of motorcycles on the market of a) cumulative registrations of motorcycles and mopeds in the EU ICE + electric European Union, b) cumulative registrations of motorcycles and mopeds in the Poland ICE + electric [2]

The motorcycle sales market is stable and in the EU there are approximately 900,000 motorcycles registered annually in the period 2010-2017, while the potential of the Polish market is unstable, especially in recent years. After recording more than 2.5 times sales growth in 2015, and maintaining this level of sales in 2016, there was a decrease to over 15 thousand in 2017. However, in 2019 there was an increase in registered motorcycles compared to 2018 by over 4.5 thousand units [2].

When using motorcycles for recreational or tourist purposes, the driver often has to choose whether to go on a vacation by car or motorcycle. There is no common system on the market of transporting motorcycles behind a passenger car, which would solve the above problem. Therefore, drivers often use universal lightweight trailers with special handles mounted to transport motorcycles. Alternatively, for the transport of motorcycles, specially adapted commercial vehicles are used. The above examples are associated with significant purchase costs for the average motorcycle owner and there is also the problem of their storage. In order to meet the above-mentioned problems, the Science and Technology Park in Opole has developed a device for the transport of light vehicles, including motorcycles. This device, registered as a patent under the number PL 224395, has been protected by the Patent Office of the Republic of Poland. As part of this article, the authors analysed the proposed concepts of this solution dedicated to the transport of light motorcycles using the Design Thinking method.

2 Methodology and design tools

The methodology of the design of the transport device is based on the Design Thinking approach. According to the definition, Design Thinking is a systematic approach to the innovation process [3]. Figure 4 below shows a schematic diagram of the procedure for designing a transport device.

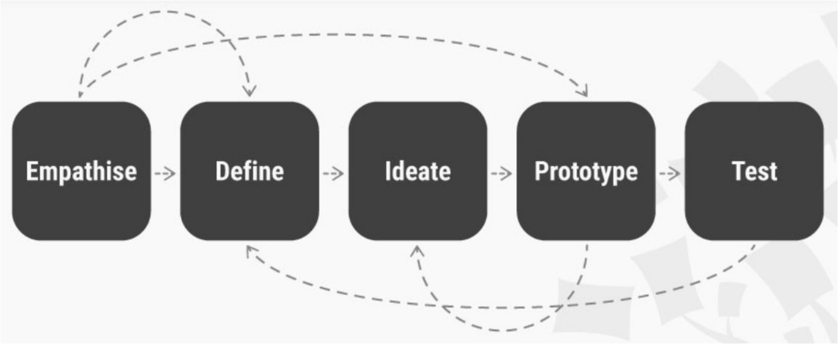

Fig. 2. The Design Thinking process [4]

In the further part of the work, individual blocks are described in detail - according to Fig. 4: the empathy and prototype stage, the problem definition stage, the idea generation stage and the testing stage.

3 Empathise & prototype

The Design Thinking process starts with empathy. The first stage is a deep understanding of the user's needs and problems. For this purpose, the research team carried out research to identify the advantages and disadvantages of the patent-based prototype. Towing motorcycles by car is not a well-known and widely used solution for transporting motorcycles. The solution allowing for the mentioned method of transport, in which the motorcycle is towed by its front or rear axle, is mounted directly on the hook of the vehicle and is shown in the prototype version in the drawing (Fig. 2). The device allows to transport a motorcycle weighing up to 150 kg with its own weight up to 28 kg. The advantage of this solution is the low purchase cost, ease of loading and storage. The device requires additional equipment in the form of transport belts stabilizing the towed motorcycle. Thanks to the mechanical or electric lifting of the front wheel, fastening of the motorcycle can be easily done by one person [1].

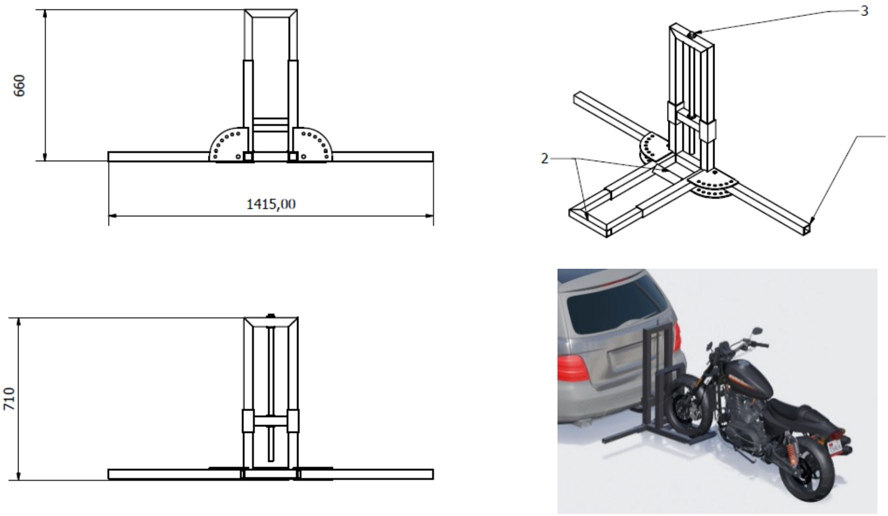

Fig. 3. Transport device based on patent PL 224395 B1 consisting of: (1) mounting holes, (2) wheel mounting beams, (3) trapezoidal screw

The method of transport consists of driving the front wheel of the motorcycle into the centre of the device (Fig. 2.) (between the beams (2)), securing the motorcycle with the belts (special places on the device (1)) and lifting the device to a given height - lifting can be done with crank and trapezoidal screw (3) or with an electric motor or a hydraulic cylinder.

The prototype concept is based directly on patent PL 224395 B1 and is made entirely of 40x40x3 steel profiles. The concept also assumes a hitch on the hook that is inseparably connected with the entire device - hook mounting with four screws. The vertical movement (which enables the wheel to be raised from level 0 to level 1 for transport) is done by trapezoidal screw. The front wheel of the motorbike is located between two crossbars. This concept was made as Prototype 1, which is the benchmark for the next steps. Table 1. presents the problems that were observed in the research group along with possible solutions.

Table 1. Observed problems during the use of the prototype

Problem	**Solution**
Difficult fastening on the vehicle hook - combined elements hindered easy fastening	Modular version of the transport device - 1. Adapter for the hook 2. Attaching the device to the adapter
The attachment was slipping on the hook - Inaccurate design of the hitch assembly	Performing a different method of attachment to the hook and checking possible movement around the hook axis. Checking the possibility of adjusting the angle of the mounting arms.
Locking of the towed vehicle lifting mechanism during lifting	Designing a different system for lifting the front axle of the motorcycle.
The weight of the device	Static analysis for various materials
In the event of possible rotation / slipping of the device around the axis of the hook, the arms may hit the car's bumper	Making changes to the prototype in order to check the optimal angle of the device arms

4 Defining the problem

At this stage, the team synthesizes the information gathered during the Empathy Phase in order to define what the actual problem is.

Taking into account the above aspects, one of the most important factors determining the shape of the device is the load capacity of towing hooks of passenger vehicles and the mass of motorcycles (Table 2. Table 3.). These data determine the boundary conditions for the designed transport device in terms of its permissible mass, which will determine the permissible mass of the transported motorcycle. The review of motorcycle masses was done according to the categories in the Act on Vehicle Drivers [5].

Table 2. Classification of motorcycle vehicles [6]

Vehicle classification	Category/subcategory name
L1e	**Lightweight two-wheeled motor vehicle**
- two wheels and propulsion according to Article 4 (3), and - an engine capacity ≤ 50 cm3 if an internal combustion PI engine is part of the propulsion configuration of the vehicle, and -a maximum design speed ≤ 45 km/h and - maximum continuous rated or net power (1) ≤ 4kW and - maximum mass = technically permissible mass stated by the manufacturer	
L3e-A1	**Low performance motorcycle**
- engine capacity ≤ 125 cm3 and - maximum continuous rated or net power (1) ≤ 11 kW and - power (1) / weight ratio ≤ 0.1 kW / kg	
L3e-A2	**Medium-performance motorcycle**
- maximum continuous rated or net power (1) ≤ 35 kW and - power (1) / weight ratio ≤ 0.2 kW / kg and - it does not come from a vehicle equipped with an engine more than twice as powerful (1), and - L3e vehicle that cannot be classified on the basis of the additional criteria of sub-classifications 7, 8 and 9 of L3e-A1 vehicles	
L3e – A3	**High-performance motorcycle**
any other L3e vehicle that cannot be classified based on the vehicle classification criteria L3e-A1 or L3e-A2	

According to the conducted review, the mass of motorcycle vehicles in the L3e-A1 category may reach 190 kg, in the L3e-A2 category up to 250 kg, in the L3e-A3 category up to 390 kg, which directly indicates that the final mass of the transportation device should be as low as possible. The mass of the transportation device was assumed to be reduced to 15 kg, taking into account the prototype device made of s235 steel.

Table 3. Overview of the weight of popular motorcycles

Classif.	Motorcycle	Mass [kg]
L3e - A1	Honda MSX125	103
	Yamaha YZF-R125	138
	Honda XL 125V Varadero	187
	Honda CBF 125	127
	Honda CBR 125 R	127.3
	Junak 121	110
	Junak 123	120
	Keeway RKS 125	117
	KTM Duke 125	132
	Yamaha YBR	125
L3e - A2	Yamaha MT-03	192,4
	Bajaj Dominar 400	183
	BMW G 310 R	164
	BMW G 310 GS	170
	Suzuki DL 650 V-Strom	213-220
	Kawasaki Ninja 400]	168
	Kawasaki Ninja 650	193
	Kawasaki W 800	217
	Honda VT750C Shadow	246
	BMW G 650 GS	193
	Suzuki Inazuma 250	183
	Yamaha XJ6	210
	Yamaha XT660Z Tenere	206
L3e- A3	Yamaha FZR 600	208
	BMW K1200LT	387
	Honda Goldwing GL1200	299
	Honda CBR600RR	196

4.1. Mass criterion

At this stage, the team focuses on generating as many possible solutions to the defined problem as possible.

Permissible towbar load

Towing hooks - this is the generally accepted name of devices for coupling a towing vehicle, most often a passenger car or a delivery vehicle with a towed vehicle - a caravan or a cargo (luggage) trailer. Towing hooks mounted on passenger cars and vans up to 3 500 kg, as defined in Directive 94 [7]. According to the guidelines, the manufacturer specifies the maximum axial load S and the towing capacity D in accordance with Fig 4.

https://doi.org/10.1051/matecconf/202133801016

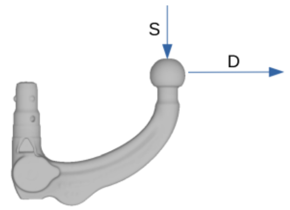

Fig. 4. Hook load in accordance with product data sheets [8]

Table 4. Load capacity of hooks of popular passenger vehicles [8]

`	**Model**	**Production date**	**Vertical load S [kg]**	**D [kN]**
Alfa Romeo	Giulia	2016-…	100	9,2
Audi	A3 Sportback	2008-2013	100	9,7
	A6 Avant C7	2011-2018		12,6
	A7	2010-…		12,6
	A8 D3 /D4	2002-2010/2010-2017		12,6-27,25
	Q2 - Q5 (to 2016)	2011-…		12,6-22,5
	Q5	2016-…	110	16,4
	Q7	2006-2015	140	16,4
	Q7	2015-…	150	16,4
BMW	5 Series GT	2009-…	100	11,9-15,5
	5 Series Touring F11/F10	2010-2017/2010-2014		11,8
	7 Series sedan E65 / F01 / F02	2001-2008/-2015/-….		15/17,5/12,15
	X3 F25 / X4 F26	2010-/2014-		12
	X5 E53 / E70 / F15	2000-2006/03-13/13-..	150	15,5/16/16
	X6 E71	2008-2014	140	16
	X6 F16	2014-	150	16
VW	Amarok	2010-	120	14,3
	Arteon	2017-	100	11,5
	Crafter van	2006-	150	17,2
	Eos	2006-	100	9,3
	Golf Cross/V1HB/Variant	2007-/08-12/09-13		9,3-9,4
	Jetta III	2005-2010		9,3
	LT van/bus	1995-2006/96-06	120	17,7/20,6
	Passat B8 Variant/Sedan	2014	100	11,5
	Sharan	2010-		12,5
	Tiguan	2015-	140	12
	Touareg I/II/III	2002-2014/-2017/-…		16,3
	Transporter T4 van	1990-1993	100	12,9

On the basis of the presented table (Table 4.), the load capacity of the hook in popular passenger vehicles is between 100 and 120 kg. The possibility of loading with the vertical load of 150 kg occurs in the case of bus-type transport vehicles, e.g. VW Crafter.

4.2. Identification tests - verification of loads

Determination of the force acting on the device during standstill was performed on the test stand (Fig. 5.), for different levels of the motorcycle front wheel`s high of the on the transport device. The tested object is Suzuki GSX-R 1100, which unladen weight is 221 kg [9]. Averaging, the force of 1kN acting along the vertical axis of the towing vehicle hook (vertical load S) was assumed for the simulation calculations.

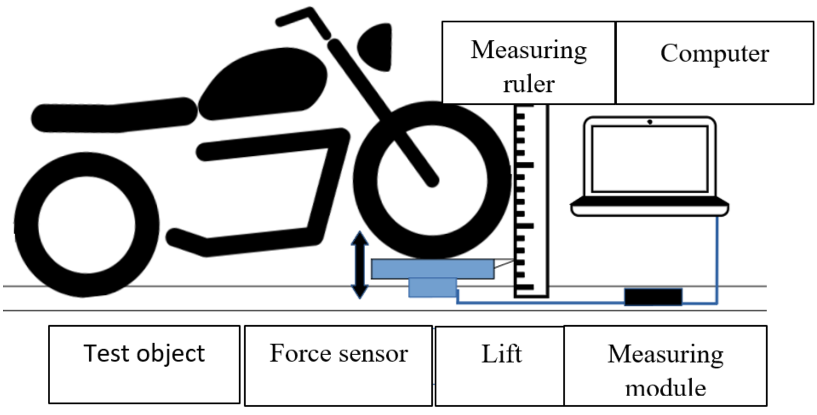

Fig. 5. Vertical force measuring station - diagram

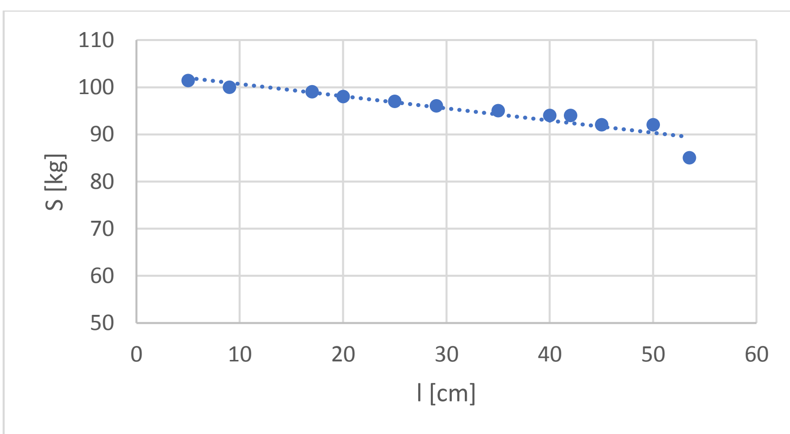

Fig. 6. The load on the transport device depending on the height of lifting the object.

Assuming the test vehicle's own weight of 221 kg, the load on the device changed with the level of lifting the front wheel of the object. According to the obtained results (Fig. 6), the object wheel raised to the transport height (the height of the towing hook of the passenger vehicle) decreased by 9.5%.

5 Generating ideas - Analysis of the structure of a motorcycle transport device

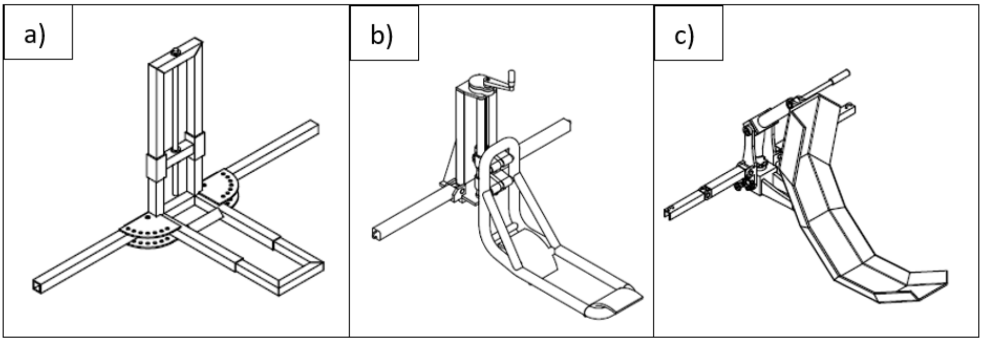

Fig. 7. Proposals for the construction of a transport device; a) concept 1, b) concept 2, c) concept 3

The analysis of the design was carried out from concept 1 (Fig. 7.a) - the prototype. Subsequent concepts (Fig. 7.) address two problems: lifting of the transported vehicle and reduction of the device weight. Concept 2 (Fig.7.b) improves the lifting of the towed vehicle by proposing circular linear guides and a trapezoidal screw with gear enabling installation of an additional motor. Another approach is concept 3 (Fig.7.c), which assumes the simplification of the components to reduce the weight of the product, as well as a changed approach to lifting the front wheel of the transported vehicle. This solution is based on rotating the profiled gutter around the main pin. The front wheel of the transported vehicle is lowered and raised using a turnbuckle.

On the basis of concepts 2 and 3, concept 4 has been created (Fig. 8.). It is distinguished by the simplification of the device frame elements, which facilitates the production process.

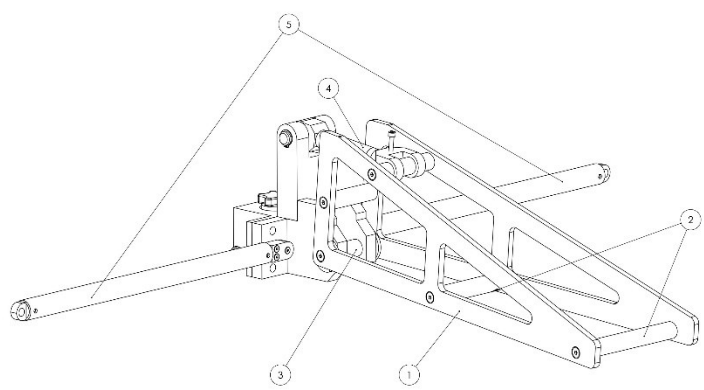

Fig. 8. Concept 4 consisting of: (1) elements made of 12mm aluminium plate, (2) aluminium shafts, (3) main pin, (4) turnbuckle, (5) mounting arms

Concept 4 (Fig.8.) is mainly based on concept 3 (Fig.7.c). The mounting point for the front wheel of the towed vehicle is made of two aluminium elements (1) with a thickness of 12 mm connected by 4 aluminium shafts (2) and a main pin (3). The front wheel of the vehicle is lifted around the main pin (3) by means of a turnbuckle (4). The mounting arms (5) are made of aluminium tubes with the wall thickness of 2 mm.

6 Test - analysis of construction

In order to perform the simulation, each concept was prepared in SpaceClaim through simplifications enabling quick model verification. The bolts were reduced to their simplified counterparts and small details not affecting the analysis were omitted. The FEM analysis was carried out in the ANSYS Mechanical program.

Boundary conditions:
Confirmation in each of the three cases was set in the same way:
• Fixed support - at the point of installation on the vehicle hook
• Load imposed on the surface in the place where the motorcycle wheel is mounted – 1 kN

The simulations were carried out for concepts 1 and 4, assuming two different construction materials described in the table (Table 5.) [10].

Table 5. Mechanical properties of materials used in simulations

Material	Aluminium 6081	Steel S235	Unit
Young's modulus	70000	200000	MPa
Poisson's Ratio	0,3	0,3	-
Yield point	270	235	MPa
Tensile strength	310	460	MPa

6.1. FEM simulation results

Results for static loading of device- concept 1 made of material: Steel S235 - mass 28 kg.

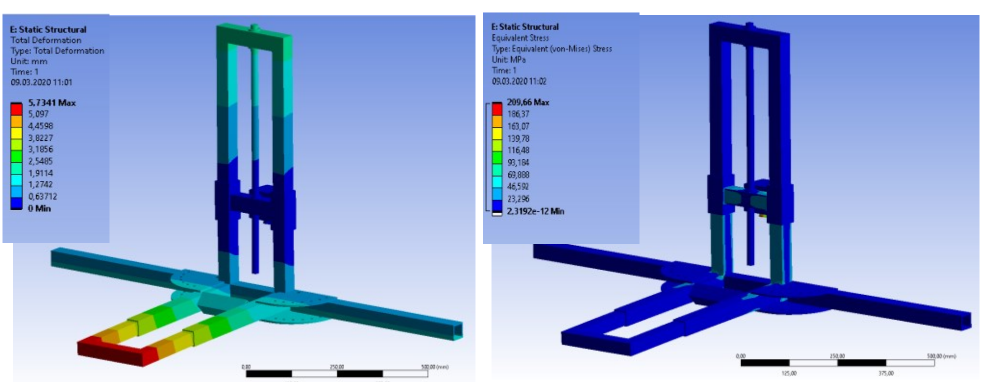

Fig. 9. Simulation results for concept 1 S235: total deformations, equivalent (von-Mises) Stress

Results for static load of device - concept 1 made of material: Aluminium 6081 - mass 13kg.

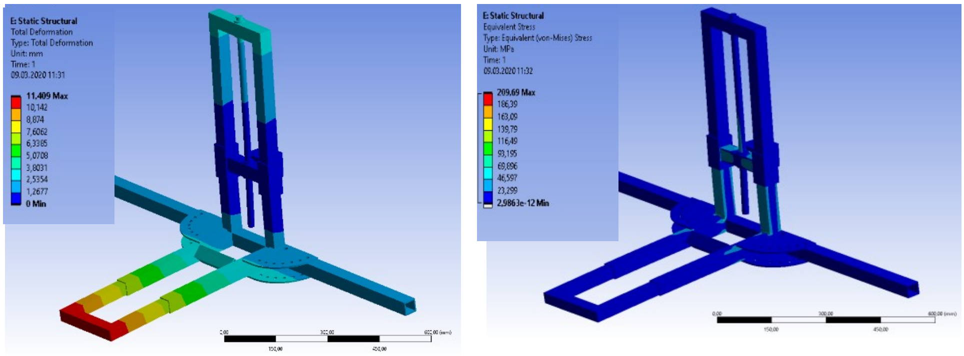

Fig. 10. Simulation results for concept 1 Aluminium 6081: total deformations, equivalent (von-Mises) Stress

Results for static load of device - concept 4 made of material: Steel S235 – mass 21 kg

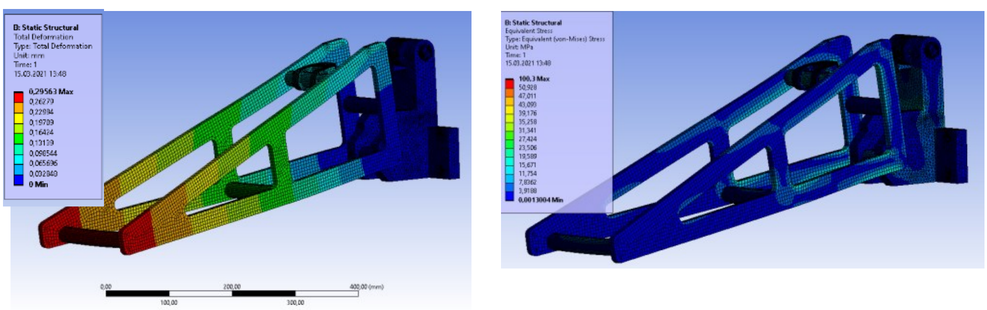

Fig. 11. Simulation results for Concept 4 S235: total deformations, equivalent (von-Mises) Stress

Results for static load of device - concept 4 made of material : Steel S235 – mass 21 kg

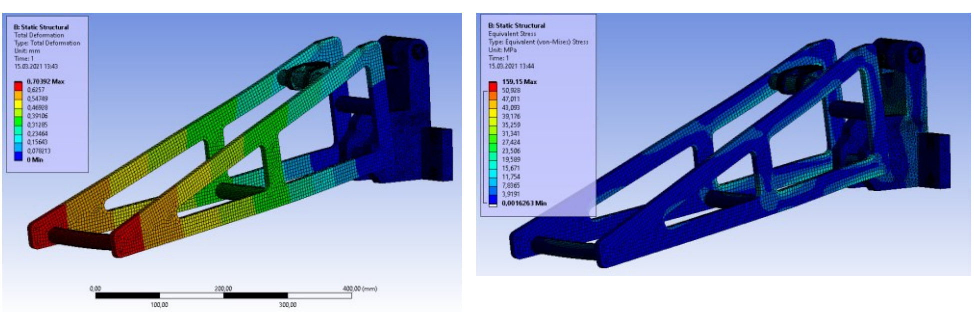

Fig. 12. Simulation results for Concept 4 Aluminium 6081: total deformations, equivalent (von-Mises) Stress

The strength analyses carried out with the use of two different materials showed the maximum stresses and deformations for concepts 1 and 4 of the device. The maximum stresses in the structure for concept 1 for steel were: 140 MPa at maximum deformations 5.7 mm (Fig.9.) and for aluminium 140 MPa at deformations of 11.4 mm (Fig.10.), for steel concept 4, maximum stresses 100 MPa (steel turnbuckle) with deformations of 0.3 mm (Fig.11.) and for the aluminium version, the stress of 159 MPa (steel turnbuckle) with deformations of 0.7 mm (Fig.12).

7 Summary

The design process presented in this paper is based on the Design Thinking method. Firstly, the prototype was shown to motorcycle enthusiasts, showing that the patented invention aroused a lot of interest. However, in order to move from the prototype phase to the commercialization of the idea, the boundary conditions defined at the very beginning of the design must be met. The vertical force acting on the hook in case of a heavier motorcycle may vary from 100 to 110 kg. The most important boundary condition is to meet the towing capacity guidelines of the tow vehicle. According to the table (Table 4.) in popular cars the vertical force acting on the hook should not exceed 100-120 kg. Meeting these guidelines determines the weight of the device, which should be within 10 kg. Therefore, this paper presents an analysis only of the static load due to the weight of the towed vehicle.

For the presented boundary conditions, four proposals have been prepared: the first one is directly based on the patent, the second with the use of guides and the possibility of implementing an electric motor or hydraulic cylinder to lift the front axle of the motorcycle, and the third and fourth based on a change in the method of lifting the front axle of the motorcycle.

Table 6. Summary of the presented concepts

Concept	Steel version Mass kg	Aluminium alloy Mass kg	Prognosis
1	28	13	- Possibility to reduce weight and improve lifting,
2	36	20	X
3	23	12	- Solution changed to the next version – 4
4	21	11	- Possibility to reduce weight by replacing selected components with other materials – composites

The performed analysis of the load capacity of the passenger vehicle hook, as well as the weight of motorcycles in the appropriate classes, determines the motorcycle influences that are part of the possible transport through the proposed device:

- Class L3e-A1 - all motorcycles in the class,
- Class L3e-A2 - most of the motorcycles in the class (compliance with the load condition of the hook)
- Class L3e- A3 - selected motorcycles in the class (fulfilment of the load condition of the hook)

According to the table (Table 6.), guidelines (Table 2-4.), the weight of the device structure cannot exceed 15 kg. Solution 1 (Fig. 7.a) and 4 (Fig. 8.), after introducing additional changes, promises the best chances of meeting both ergonomic and mass conditions. Solution 2 (Fig. 7.b) would significantly improve the quality of use of the device, but not meet the weight condition. The adopted material Aluminium 6081 for the structure allowed to significantly reduce the weight and is sufficient taking into account the adopted load conditions for this type of device.

The research was carried out as part of a project co-financed by the European Union from the European Regional Development Fund as part of the Regional Operational Program of the Opolskie Voivodeship for 2014-2020 1.1 Innovations in enterprises entitled: "BR works in the field of developing a technology for the implementation of an innovative ultralight transport device" decision no: RPOP.01.01.00-16-0007

References

1. J. Mamala, P. Kurowski, patent: PL224395 (B1) (2016)
2. *ACEM statistical release, Motorcycles registrations in the European Union grew by 8% in 2019*, ACEM report, Brussels, (11.02.2020)
3. S. J. Bell , A.L.A **39**, 1/2; p. 44-49, (2008)
4. R. F. Dam, T. Y. Siang, *5 Stages in the Design Thinking Process* [www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process] (15.02.2021)
5. OJ L **227**, p. 1–61, (28.08.2010)
6. OJ L **60**, p. 52–128 (02.03.2013)
7. Z. Budniak, A.t.e.s.t R. **12**, nr 5, p. 64-69, (2011)
8. www.ehaki.pl (15.12.2020)
9. www.gmoto.pl/motocykle/suzuki/gsx/1100/ (11.02.2021)
10. H.H. Lee, Finite Element Simulations with ANSYS Workbench 18, SDC Pub. (2018)