Lightweight Casters Design for Ambulatory Transportation Technology

Ing. Jan Andruš, Bc. Jan Lebduška, Bc. Libor Pospíšil

Abstrakt (Times New Roman, Bold + Italic, 12, řádkování 1)

Obsahem práce je nová konstrukční varianta podvozku ambulatního transportního prostředku (konkrétně záchranářského nosítka). Tato je vyvíjena za účelem redukce hmotnosti produktu. Při navrhování bylo užito analýzy napjatosti metodou MKP, při prototypování dílů byla použita moderní a velmi levná technologie 3D tisku. Dále je v článku představena metoda dlouhodobého testování stěžejního dílu podvozku, aby mohla být konstrukce řádně ověřena před sériovým nasazením.

Klíčová slova (Times New Roman, Bold + Italic, 12, řádkování 1)

Vidlice, přístrojové kolečko, ambulantní transportní technika, uhlíkový kompozitní material, podvozek nosítka.

1. Introduction

Ambulatory transportation technology as stretchers, its carriage and cardiologic chairs are cutting-edge products which help save lives every day. There is a design code for these products included in EN 1789+A1 standard. This standard provides safety for patients and crew also. Ambulatory transportation products must withstand accident, which is simulated as deceleration from speed of 30 kph with 10 *g* overload. All that with maximum of 50 kg weight for complete stretchers, according to EN 1789+A1. The weight limit is not so easy to reach. Product must be lightweight because of handling and on the other side durable. Every saved piece of weight on product do it more comfortable to use. Manufacturers want to produce lighter products than the standard prescribes and want to use it as advantage on market (compared to rivals).

1.1 EXTERO ambulance stretcher

Extero ambulance stretcher is Czech product which fully complies with EN 1789+A1. Almost every part of this product was designed by engineers for the only purpose, except casters. Whole stretcher, legs and frame were developed using technologies as CNC machining, robotic welding, jet cutting. Lightweight aerospace aluminum alloys are mainly used. Casters are purchased parts made of steel. They are cheap, but heavy and with universal purpose to fit many designs. Main goal of this project is to develop lightweight caster which fits to the rest of the stretcher and saves weight.

Figure 1: *EXTERO P113 Ambulance stretcher.*

1.2 Current casters design analysis

Current caster design is based on bended steel plates with one heavy radial bearing, which is wrongly used as axial bearing. Due to this wrong usage that bearing is heavily over designed and heavy (see Fig. 2).

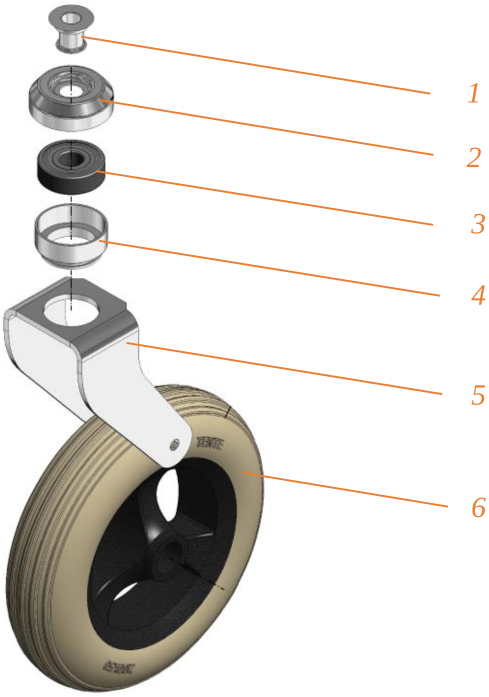

Figure 2: *Front caster assembly. 1-Insert, 2-Bearing top cover, 3-Radial ball bearing, 4-Bowl bearing, 5-Steel fork, 6-Wheel.*

Total weight of castors on stretcher undercarriage frame is slightly more than 6 kg. Durability of casters is very important during rescue operation, but weight of the original castors seems to be unnecessarily high. Compared to weight of undercarriage frame, castors represent 22% of total weight (see Fig. 3).

Figure 3: *Simple weight distribution.*

2 New lightweight casters design

Casters are under heavy load conditions during operation. Six available height positions of Extero stretcher (Fig. 4) causes six different load sets. In every position casters must hold maximum loading capacity of 250 kg plus weight of stretcher approximately 50 kg. That means 300 kg of static load divided into 4 casters under ideal conditions. In fact, rescue operations could be off road and weight division is not ideal at all. Worst case we could take into account is fully loaded stretcher going on two casters for a while (because of uneven terrain), so 150 kg of load per caster is the design value, additional static and dynamic FOS will be added.

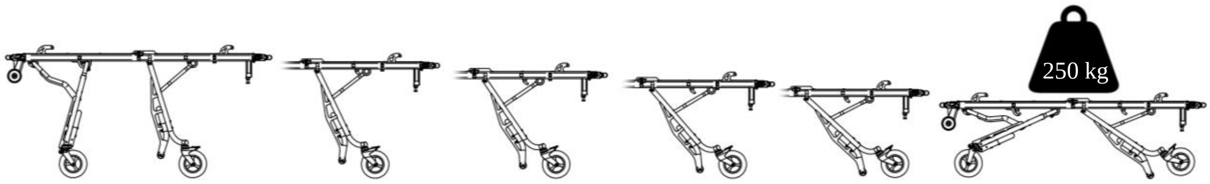

Figure 4: *Available height positions of Extero stretcher.*

New design will be based on lightweight materials and parts. For example using plastic journal bearing instead of classic ball bearing is saving approx. 100g per castor.

2.1 Carbon composite fork designs

Because of difficulties with bending of aluminium plates a carbon composite has been chosen as progressive lightweight material for caster fork.

Figure 5: *New front caster fork design made of carbon composite.*

Thickness of design draft and shapes were based on experiences of engineers and also on testing plates, which had been made before. Testing plates are about 10x10 cm square sandwich composite structures with a different compositions. Very simple strength tests had been done on those plates to imagine right composition and wall thickness of construction.

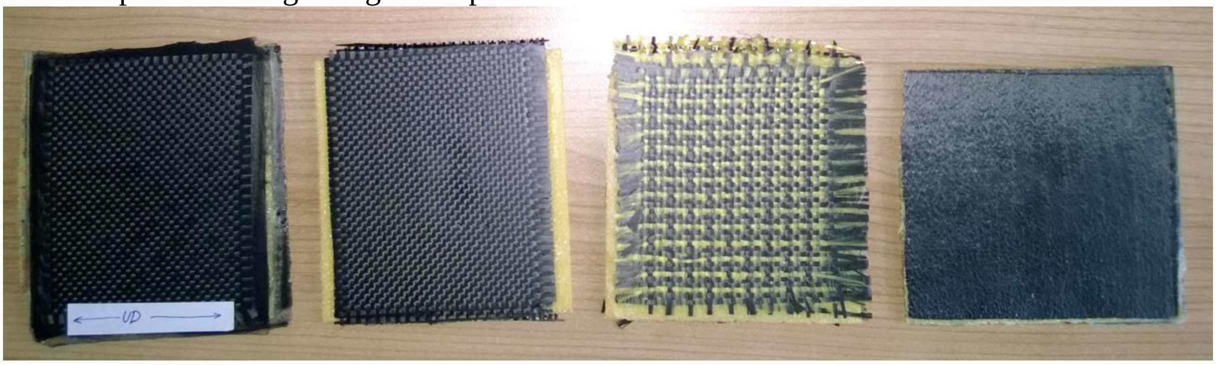

Figure 6: *Test samples of sandwich structures.*

Final layer composition of fork is based on experiences and on presumed load conditions. Thickness of wall is set between 5 - 7 mm without reinforcement.

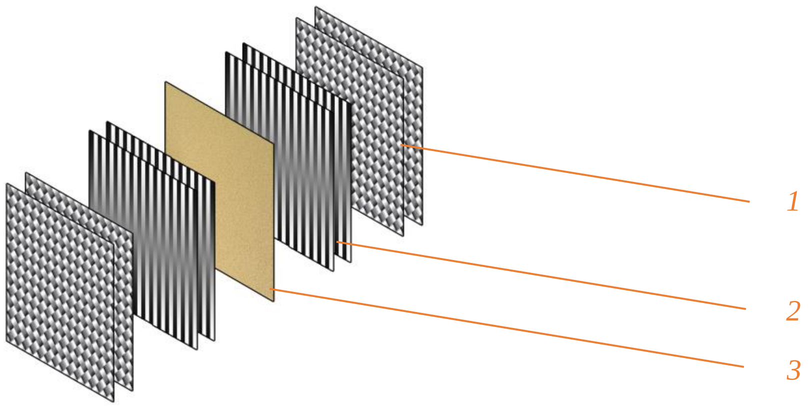

Figure 7: *Symmetric layer composition. 1-Carbon fabric, 2-UD carbon fibers, 3-Sanwich foam (3mm thick)*

2.2 FEM stress analysis

Design was approved by FEM stress analysis on simple shape shell part (Fig.8).

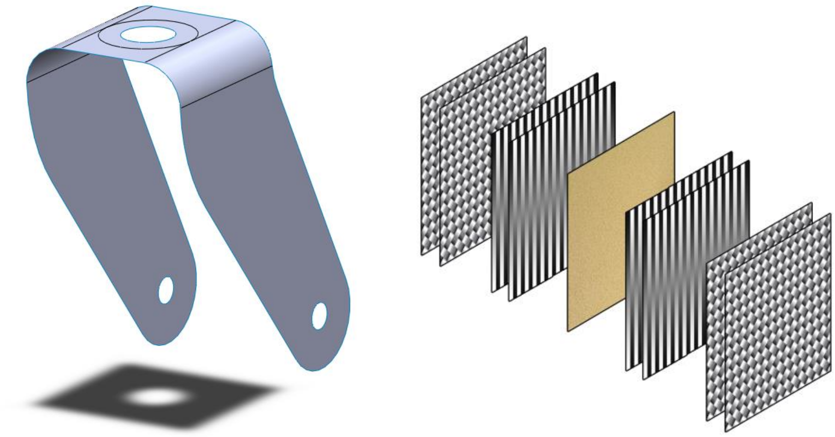

Figure 8: *Simplified fork shape (shell) with layer composition.*

Simple shape was used to simplify definition of layer composition. However simplified fork shape presents main geometry which carry load of the stretcher. Other designs can be easily build based on this geometry analysis with no worries.

Simulation has been done on shell geometry with defined composite wall. Thickness of wall was the same for whole part, reinforcement (of radius, around inserts) was not took into account. Composition of layers (Fig. 7) was defined as symmetric and individual layers were modeled as homogenized (fibers with epoxy) orthotropic material. Strength material properties used in FEM analysis are shown in Tab. 1.

Table 1. *Strength material properties*

	Carbon fabric	**UD carbon fibers**	**Sandwich foam**
σ_{1T} [MPa]	420	1100	1,3
σ_{1C} [MPa]	310	800	0,9
σ_{2T} [MPa]	420	40	1,3
σ_{2C} [MPa]	310	130	0,9
τ [MPa]	80	45	0,85

Evaluation of stress analysis results was done by checking FOS of new design. Tsai-Wu and maximum allowed stress criterions were used to determine if design is safe or not. As can be seen on Fig. 9, red places are near constrain of numeric model, so results are wrongly influenced and ignored. Rest of the construction seems to be well designed. Numeric model has the same wall thickness, in fact there will be reinforcement on the top of the caster fork around bearing hole and in radiuses. This reinforcement is done by adding small pieces of carbon fabric. It requires split shell model on many places, so simplification was used for simulation. Real results will be better with thicker wall, so if numeric results are satisfactory for simplified model, reality will be even better.

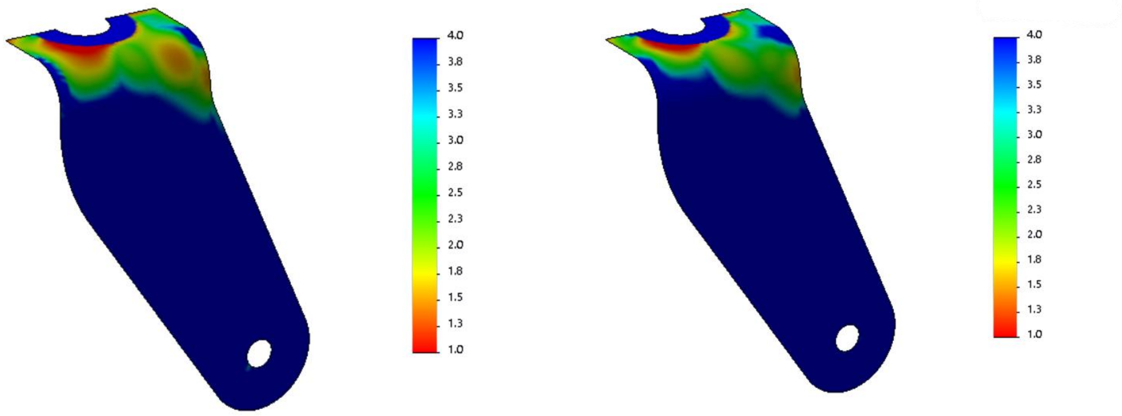

Figure 9: *Left – Tsai-Wu criterion FOS plot.*
Right – maximum stress criterion FOS plot.

2.3 Manufacturing of prototypes

First prototypes were made by using classic manual vacuum technique of setting carbon fibers with epoxy resin into simple handmade molds to approve strength of design (Fig. 10). Then a very simple a cheap technique of 3D printing had been used to build complex molds (Fig. 11).

Figure 10: *First handmade carbon composite caster fork.*

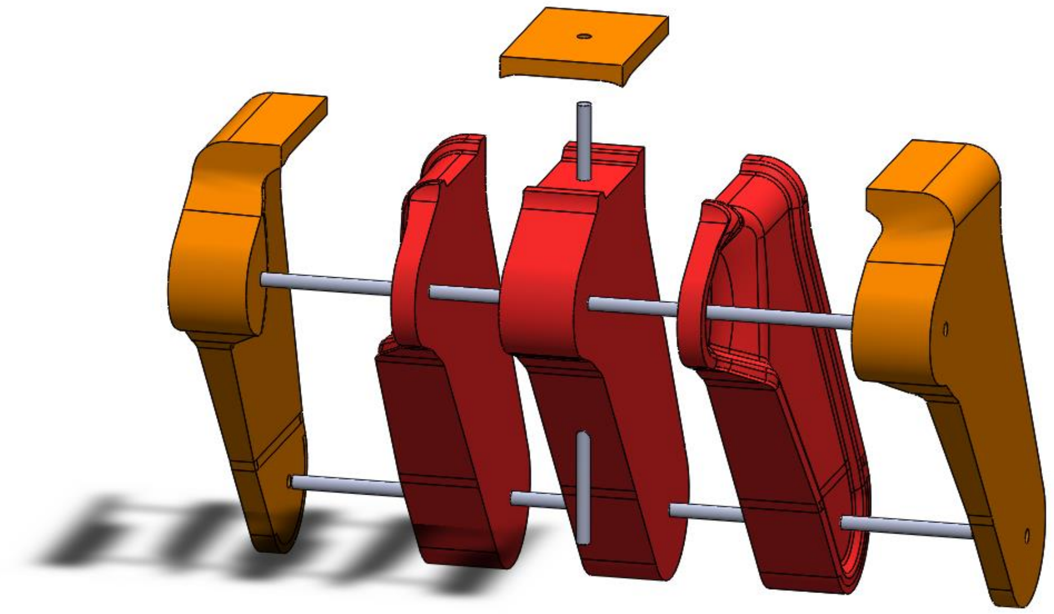

Figure 11: *CAD model of complex mold for production prototypes. CAD model was prepared for 3D printing rapid prototyping*

2.4 Long-term operating test

Although using numerical computational method is modern way of designing, we must be sure with new design before production. Classic way to approve design is to test parts in laboratory. Special stand was designed to approve new casters under working conditions (see Fig. 12). It allows test caster fork under static load and additional dynamic load. Dynamic load can occur during loading a patient or when a wheel hits barrier. Those are main dynamic loads, but standard operation contains small dynamic loads every time. Test stand is built to be able load caster fork with a static load (represents cargo) and in the same time with a small dynamic load, which represents operation on uneven terrain. Principle can be seen on Fig. 13.

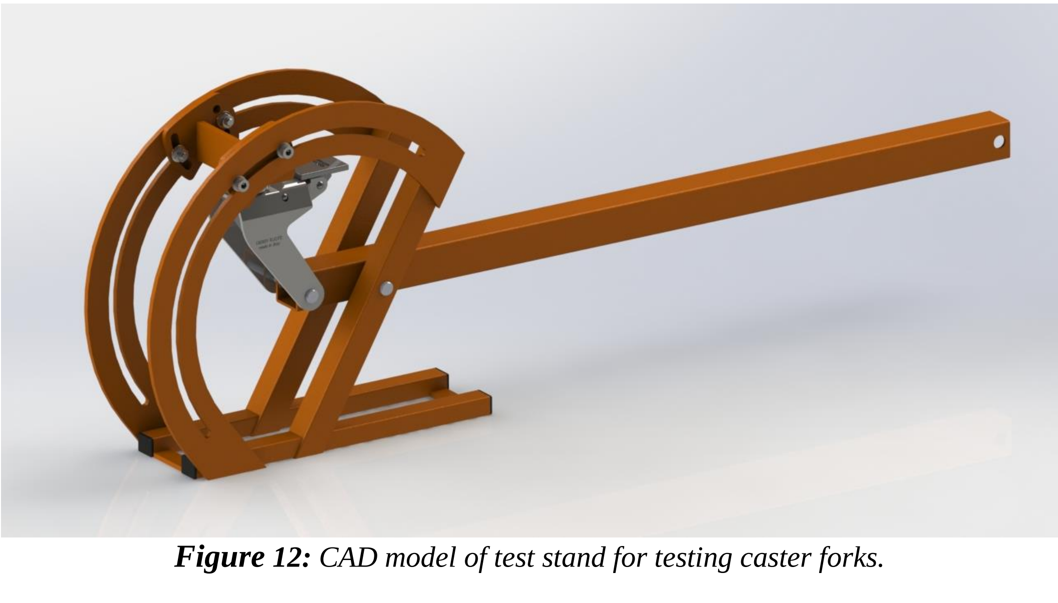

Figure 12: *CAD model of test stand for testing caster forks.*

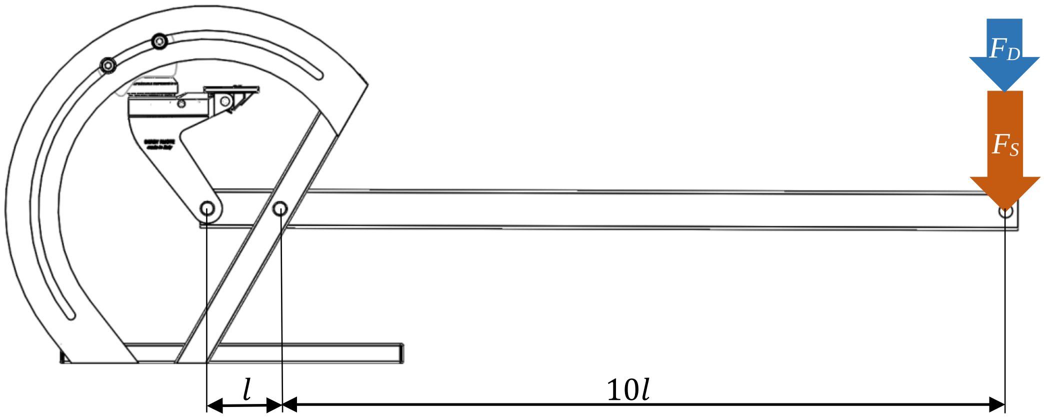

Figure 13: *Principle drawing load on the fork.*

Static force F_S is deduced by simple weight. Dynamic force F_D is result of rotation of unbalanced weight. Overall force F acting on caster fork is sum of partial forces

$$F = F_S + F_D. \tag{1}$$

Frequency of dynamic force cannot be so high. Dynamic load of high frequencies (above 10 Hz) can cause thermal degradation of epoxy resin. Then carbon composite with epoxy resin can crack up.

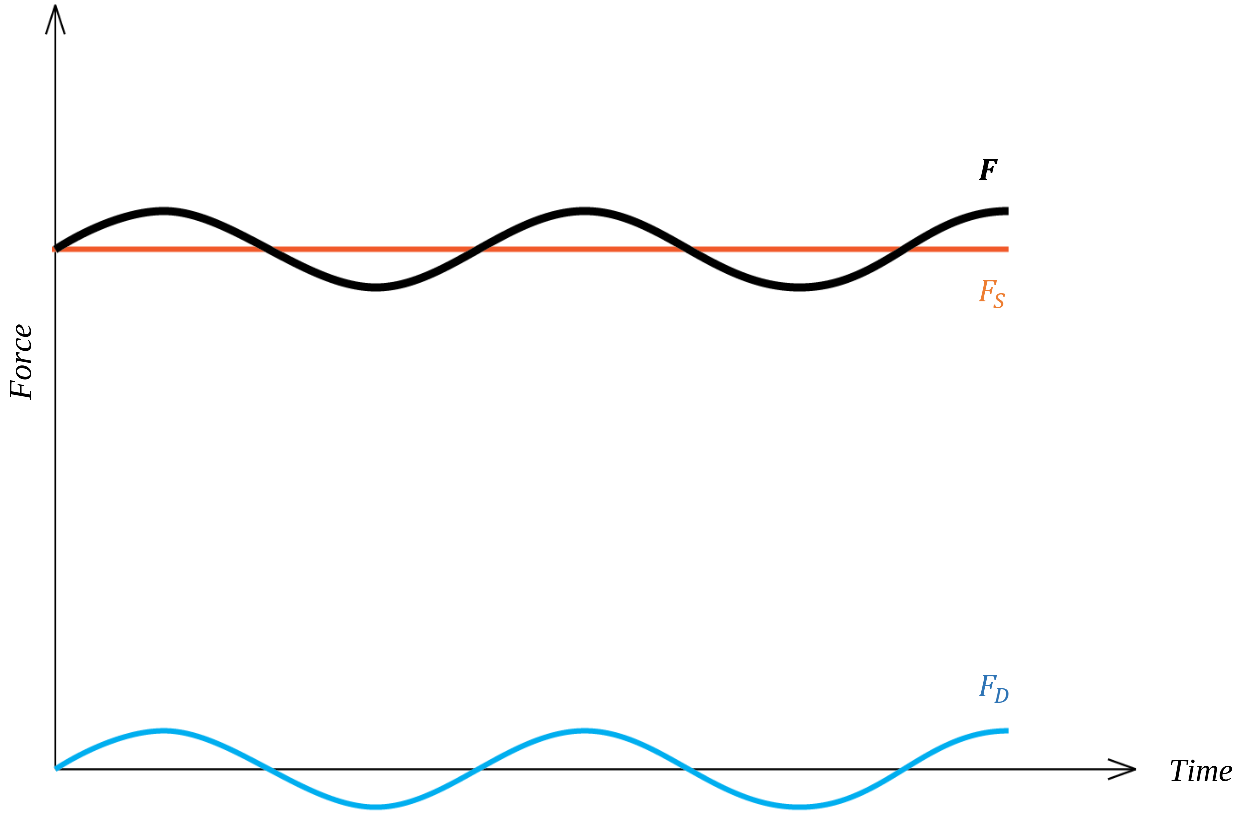

Figure 14: *Preview of development of forces F_S, F_D and F in time.*

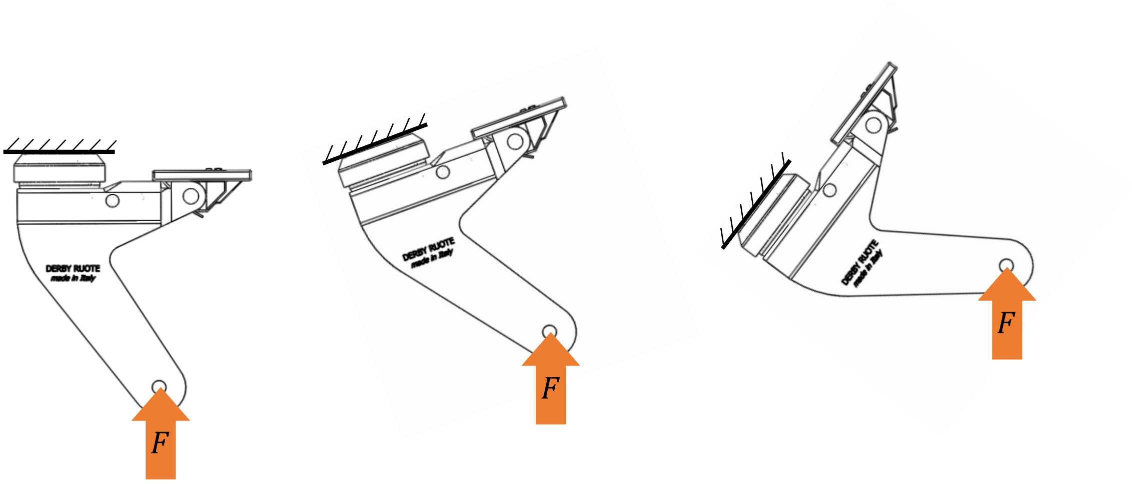

Figure 15: *Stand allows test fork under different load conditions. Corresponding to available height positions of Extero stretcher.*

3. Conclusion

Weight reduction has been reached as main goal. New castors with new wheels, which will have also new lightweight design, can save 50% – 60% of actual castors weight. It means castors can be only about 10% of undercarriage frame weight. Long-term tests will approve carbon composite design and based on those tests the composition of carbon layers will be redesigned if needed. But main goal was so "simple". On the other hand there are still a lot of problems to solve before industrial production. For example hydrophobia of fibers, UV endurance and of course price of industrial production. Problems must be discussed and solved and price really well counted to reach industrial production.

List of symbols

l	beam length	(m)
g	gravity acceleration	($m \cdot s^{-2}$)
F_S	static force	(N)
F_D	dynamic force	(N)
F	overall force	(N)
σ_{1T}	allowed stress in tension (direction 1)	(MPa)
σ_{1C}	allowed stress in compression (direction 1)	(MPa)
σ_{2T}	allowed stress in tension (direction 2)	(MPa)
σ_{2C}	allowed stress in compression (direction 2)	(MPa)
τ	allowed shear stress	(MPa)
FOS	factor of safety	(1)