Arkadiusz **MĘŻYK**
Wojciech **KLEIN**
Krzysztof **SKOWRON**
Marek Ł. **GRABANIA**

TRACKED VEHICLE WITH HYBRID DRIVE PART 1

Abstract. The paper discusses an innovative design of a tracked vehicle with hybrid drive being implemented by a research consortium. A short review of land platform of dual use, civilian and military, is presented. The position of the design discussed among other land platforms is shown. Design requirements, purpose of the work and adopted design methodology are discussed along with the creation stage and final outcome. The summary includes a reference to the developed design version and practical implementation in the form of a technology demonstrator and to further development of the project.

Keywords: land vehicle, tracked land vehicle, hybrid drive, series hybrid drive.

1. INTRODUCTION

Important feature of off-road vehicles, land platforms, is their ability to negotiate terrain obstacles. Comparison of traction properties of land vehicles with wheeled chassis to those with tracked chassis, apart from common technical characteristics, such as total weight, load capacity, off-road and on-road maximum speed, and power to weight ratio, the latter type of vehicles is characterized by particularly low ground pressure. This feature becomes very important when moving, driving in a wet, flooded or wooded terrain or in crisis situations. Often operations that have to be carried out in adverse terrain conditions pose a hazard to human health and life. A good example in this respect is the British defence standard, which specifies the pressure of the drive system on the chassis as the basic criterion [10] of vehicle mobility in a terrain, while other criteria play a supporting role, enabling the assessment of the ability to negotiate terrain obstacles. International documents use the notion of high mobility of a vehicle/land platform, which is reflected in the *NATO Mobility Reference Model* [1].

An important parameter appreciated by users, in view of the emerging energy crisis, is also maximum fuel economy. This is reflected in the growing number of new vehicle drive system designs where, for instance, hybrid drives [2] are used. Such drives are also used increasingly in passenger cars [3]. These drives are particularly efficient when driving on road or in a terrain of diversified characteristics: when driving uphill, frequent stopping, braking, long downhill drives, etc.

Those considerations were essential in the development of requirements for an innovative project [4], which gained the ability to be implemented under the first *Applied Research Program* contest financed by the National Centre for Research and Development in Warsaw.

2. LAND PLATFORMS

It is customary in automotive engineering that several design variations of a wheeled vehicle are based on a single floorpan. Such single platform solutions are also sought for non-

Prof. Arkadiusz **MĘŻYK**, Dr Wojciech **KLEIN** – Faculty of Mechanical Engineering, Silesian University of Technology
Krzysztof **SKOWRON**, Marek Ł. **GRABANIA** – Ośrodek Badawczo-Rozwojowy Urządzeń Mechanicznych "OBRUM" sp. z o.o., Gliwice

commercial land vehicles. Literature [5] provides a definition of a platform: *platform - mechanical, electrical, IT basis for special equipment application*. This is a commonly used term which encompasses a wide range of vehicle designs: land platforms, battlefield robots and special vehicles [5], [6], where *a special vehicle is, in terms of design and equipment, adapted to carry out defined tasks* [7].

Classification applied to unmanned ground vehicles (UGV) [8] includes three categories defined by:

- vehicle weight,
- driving speed,
- autonomy.

American classification [9] of UGVs with regard to weight is presented in Table 1.

Table 1. Platforms – American classification

Item	**Class name**	**Weight range (kg)**
1	Small - light	14-180
2	Small - medium	181 - 1,125
3	Small - heavy	112 - 9,000
4	Heavy	Over 13,500

In Poland the unmanned land platforms are also classified with respect to weight. That classification is shown in Table 2.

Table 2. Platforms – Polish classification

Item	**Class name**	**Weight range (kg)**
1	Lightweight platforms	Less than 400
2	Medium platforms	Less than 3,500
3	Heavy platforms	Up to 10,000
4	Very heavy platforms	Over 10,000

In terms of autonomy of actions, unmanned ground vehicles can be classified [8] into four categories.

1. Teleoperated ground vehicles (TGV) – these vehicles are controlled from a distance by an operator using sensors and navigation devices; the operator controls all operations.
2. Semiautonomous preceder-follower vehicles (SAP/F) – act in an autonomous, preprogrammed manner, and are equipped with an expanded navigation system.
3. Platform-centric autonomous ground vehicles (PC-AGV) – will execute a complete task or mission, perhaps acquiring information from other sources than on-board sensors without requiring further guidance.
4. Network-centric autonomous ground vehicles (NC-AGV) act as a distributed network; these are autonomous vehicles, but they operate as independent "nodes", receive information and commands from the communications network and distribute them among the vehicles that carry out a mission to complete a task as a team.

There are many interesting solutions [11], [12], [13] that are being developed or implemented to serve military and civilian purposes. Examples of civilian applications include fire-fighting robots, inspection robots for surveying hazard areas, or explosive ordnance disposal robots for removing dangerous or explosive materials during a terrorist attack. During natural disasters amphibious, tracked transport vehicles or motor vehicles with tracked traction systems [14] are used.

There is no room here to make a broad overview of all known solutions. We will present here a few characteristic foreign and domestic designs of land platforms that fit within the class of the vehicle (with regard to weight and functions performed) which is the subject of this paper. The trend in vehicle design observed in recent years is that military platforms are derived from civilian solutions after adapting them to new operating requirements.

2.1. Supacat ATMP (All Terrain Mobility Platform)

The Supacat ATMP [15], [16] is a vehicle designed to carry payloads and tow heavy trailers, featuring a low ground pressure. It has permanent six wheel drive with the front four wheels steered by using a motorcycle-type rotating handlebar. Aluminium body that covers steel chassis frame enables the vehicle to float. Maximum payload is 1,600 kg. It has been in service with the British Army and RAF since 1984. Supacats can be carried by helicopters and parachuted. The vehicle can be fitted with a cab. It is also used by civilian services (forestry, land surveying) and the fire brigades. Figure 1 shows Supacat ATMPs during combat action.

Fig. 1. Supacat ATMP vehicles

/Source - http://www.military-today.com/trucks/supacat_atmp_images.htm/

2.2. Beach Armoured Recovery Vehicle (BARV)

BARV is a series of recovery vehicles of British design used to assist in sea landings. The vehicle shown in Fig. 2 is an uncommon tracked version [17] based on Supacat ATMP design. The high mounted cab and other technical solutions enable underwater operation to the depth of 3 metres.

The civilian status was adapted to military tasks of providing technical support to allied forces in the coastal zone, under battlefield conditions.

The militarized version has been fitted with armour panels to protect the occupants of the cab of special design, and also with front and rear bumpers. It also incorporates special equipment, including a winch and towing point. A crane can also be mounted, if necessary.

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Fig. 2. Military version of Beach Armoured Recovery Vehicle (BARV)
/Source - http://www.shephardmedia.com/news/mil-log/supacat-launches-beach-recovery-vehicle-concept/

2.3. TAGSS –Tactical Amphibious Ground Support Systems

TAGS [18] is a Canadian 8-wheeled vehicle with rubber tracks fitted with metal reinforcements set on the wheels. The duality of the traction system is remarkable, as it consists of wheels in one embodiment, and of tracks in another embodiment. Four tracks are installed on four pairs of wheels, each pair independently suspended. This solution ensures low ground pressure and improves traction properties, manoeuvrability and mobility [1] in difficult terrain.

Basic technical specifications of the TAGS platform (with no cab):

- length - 3,000 mm,
- width - 1,900 mm,
- height - 1,260 mm,
- wading depth - ca. 900 mm,
- maximum speed - 30 km/h,
- weight of platform - ca. 2 t,
- drive type - hydraulic/hydrostatic.

The vehicle is manufactured in both civilian, as well as military versions. Examples are shown in Fig. 3.

In Poland the TAGS land platform was used as an unmanned ground vehicle (UGV) in TALOS project run by an international consortium with the participation of the Industrial Research Institute for Automation and Measurements in Warsaw [19]. The vehicle is shown during field tests in Fig. 3.

Fig. 3. TAGS as an unmanned ground vehicle (UGV)
/Source - http://www.piap.pl/layout/set/return/content/view/return/686/

2.4. LEWIATAN

LEWIATAN is an autonomous or remotely controlled rescue vehicle [20] designed for civilian rescue teams and military. A special version of the vehicle was also designed and constructed: LEWIATAN STRAŻAK (*FIREFIGHTER*) [22]. This is a completely Polish design. The base vehicle is shown in Fig. 4.

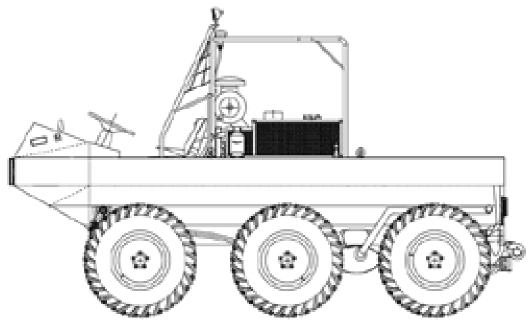

Fig. 4. Side view of LEWIATAN base vehicle
/Source-http://www.hydromega.com.pl/index.php?id=24/

The characteristics of the vehicle enable its use in the rescue of people from traffic catastrophes, removing the effects of violent weather phenomena, making firebreaks in forest fire hazard areas, evacuation of people from flooded areas and supporting logistic operations in a rough terrain. LEWIATAN is able to float and is fitted with two screw propellers arranged in the rear of the vehicle symmetrically in relation to vehicle axis.

The vehicle can carry a payload of up to 1.4 tonne. It can also be used as a tractor to pull or tow trailers and objects weighing up to 2.2 tonnes. It can negotiate water obstacles on the run. It may be used as a carrier for arms, ammunition, tanks for fluid materials and as a general logistics support. The inner power source (a hydraulic pump) enables attaching hydraulic implements, such as hydraulic tools, saws, power hammers, ploughs, street sweeping equipment.

LEWIATAN is a vehicle with a hydrostatic drive [23]. Basic specifications are given in Table 3.

Table 3. LEWIATAN - technical data

Item	Weights and traction data	Value
1	Kerb weight	2,200 kg
2	Maximum payload	1,750 kg
3	Total weight	3,700 kg
4	Weight of towed trailer	2,200 kg
5	Maximum speed	55km/h (target: 75 km/h)
	Overall dimensions	
6	Length	3,500 mm
7	Width	2,000 mm
8	Height	1,950 mm

As part of design development a platform for military applications was contrived [21]. The military unmanned remotely controlled vehicle is shown in Fig. 5.

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Fig. 5. LEWIATAN ZS unmanned vehicle

/*Source - http://www.altair.com.pl/mspo-report/view?article_id=140/*

3. MULTITASK ENGINEERING VEHICLE WITH HYBRID DRIVE (WIPH)

After having analyzed the domestic market with regard to demand for a new class of off-road transport and engineering vehicle able to perform rescue tasks and to be manufactured in various versions, the authors of development application [4] proposed a tracked vehicle with a hybrid drive as the base platform with an option of installing a cab and a load-carrying body.

The project was supported by the National Centre for Research and Development under the first *Applied Research Program* contest [24].

The following basic technical specifications of the vehicle were adopted:

- Weight (kg) – 3,500 kg,
- total weight – 5,000 kg,
- length – ca. 4,000 mm,
- width – ca. 2,100 mm,
- height – ca. 2,300 mm,

- cruising speed:
  - off-road – 30 km/h,
  - on road – target 70 km/h,
- drive/power transmission – internal combustion/electric series hybrid drive, with electric motors with permanent magnets,
- traction system – tracked chassis with rubber tracks,
- crew – 2,
- completion period – 1.01.2013 – 31.12.2015,
- resultant form – technology demonstrator.

The WIPH project is run by a research consortium comprising:

- Faculty of Mechanical Engineering, Silesian University of Technology – Consortium Leader;
- Research Institute for Automation and Measurements, Warsaw – member;
- OBRUM sp. z o.o., Gliwice – member.

The following assignment of main research and development tasks was adopted:

1. Faculty of Mechanical Engineering:
   - development of a concept of the suspension – suspension demonstrator,
   - development of a concept of the drive system, including power distribution systems – drive system demonstrator,
   - development of test programmes for stand tests, traction tests and operating tests,
   - vehicle testing,
   - verification of design guidelines,
   - development of a 3D virtual model of various versions of the vehicle.
2. Research Institute for Automation and Measurements:
   - development of vehicle control and operating data acquisition system,
   - development of a remote vehicle control system,
   - development of a vehicle autonomy system,
   - vehicle testing,
   - verification of design guidelines.

3. OBRUM:
   - drawing up documentation of vehicle units:
     - chassis – base platform,
     - cab,
     - load-carrying body.
   - construction of a complete WIPH vehicle – technology demonstrator,
   - vehicle testing,
   - verification of design guidelines.

The latest solutions in IT, automation and control systems (CANbus and CANopen protocol), image processing (image transmission cameras, range finders) as well as in data acquisition, including power transmission operating data logging, were applied in the WIPH project.

The drive system applied in the vehicle is an innovative power transmission system in the form of internal combustion/electric series hybrid drive, with electric motors with permanent magnets. This solution features limited weight and high speeds and optimized fuel consumption.

Another novelty is the power distribution system, described in a separate paper [25].

All design work was carried out using 3D virtual prototyping; design documentation was created with SOLID WORKS software. All strength-critical structural nodes were verified using the finite elements method (FEM).

Simulation techniques available in Matlab Simulink software were applied to resolve problems at the concept stage.

3.1. General structure of the vehicle

The WIPH vehicle consists of three basic units:

- chassis – base platform;
- cab,
- load carrying body.

As the philosophy was to enable different versions of the WIPH vehicle, the basic structural element of the design was the chassis/base platform, the present design of which enables installation of a cab and of a load-carrying body.

Fig. 6 shows the concept.

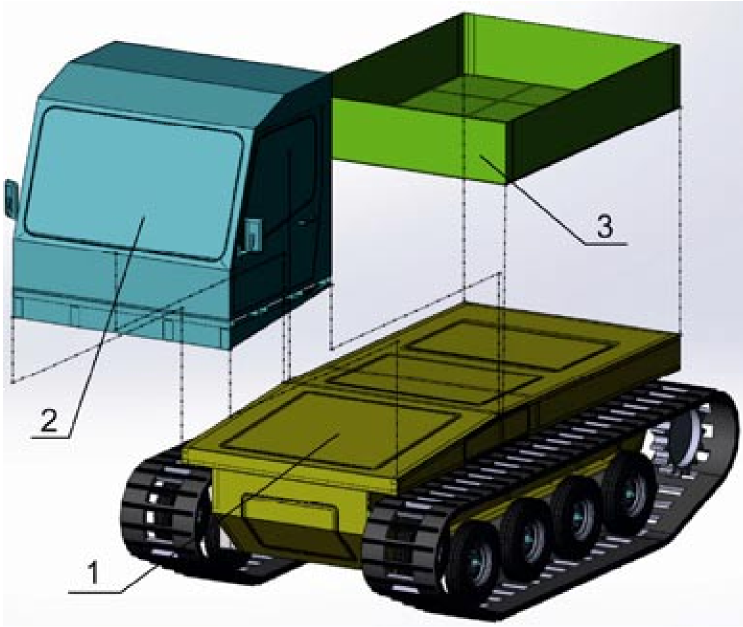


Fig. 6. General structure of the WIPH vehicle
1 - chassis – base platform; 2 - cab; 3 - load-carrying body.

The chassis body houses all basic parts and assemblies of the drive and control systems. A number of inspection doors and covers were designed in the chassis body to facilitate access to internal assemblies during vehicle testing. Fig. 7 shows the concept.

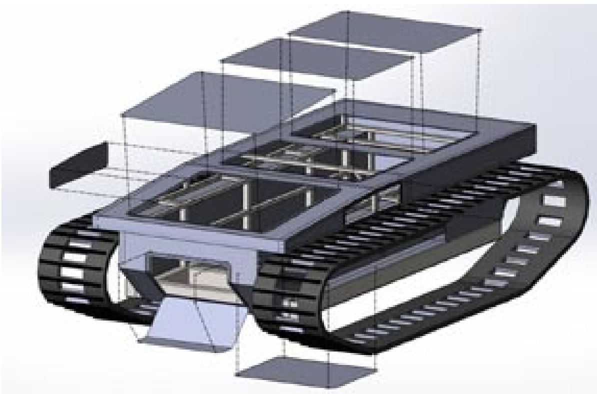


Fig. 7. Chassis body – inspection doors and covers

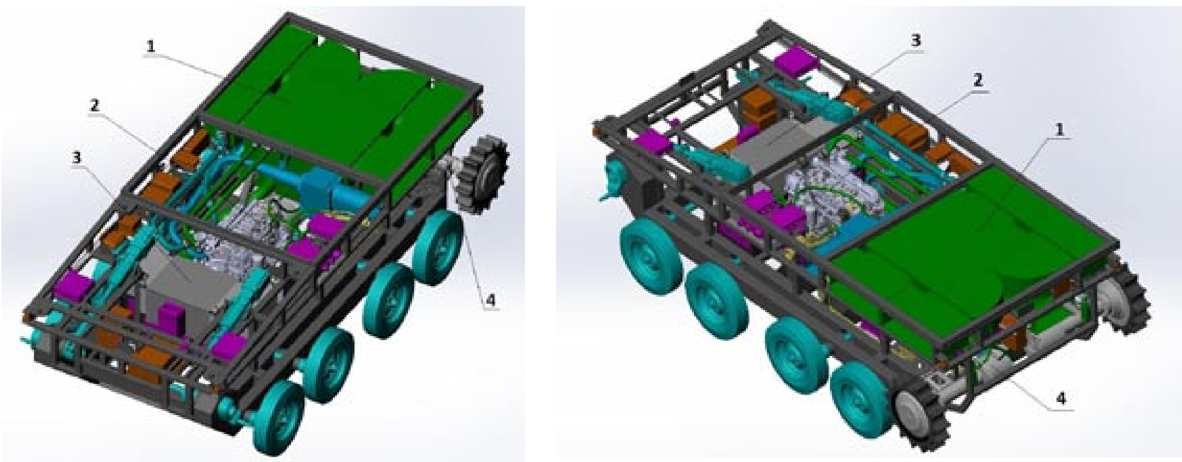
3.1.1. Chassis – base platform

One of the most difficult goals of the design, already at the concept stage, was to achieve the lowest possible chassis weight, while maintaining the required high performance. Upon analyzing the problem, a spatial model of the chassis body consisting of rectangular steel profiles, was adopted. The spatial structure of the chassis body is shown in Fig. 8.

Fig. 8. Chassis body – framework

3.1.1.2. Chassis installations

Another challenge that the designers had to face was to optimally arrange [27] within the chassis all components (drive systems, air and liquid cooling systems, power distribution system, control systems, power supply systems, lighting, etc.) while maintaining the centre of gravity of the platform in its geometrical centre. Iteration processes were completed successfully. Fig. 9 below shows the arrangement of the most important components of the drive system and other equipment inside the chassis body.



a) **b)**

Fig. 9. Arrangement of the main drive components inside the chassis
a) front view, b) rear view
1 - air cooling system, 2 - internal combustion engine coupled to a generator, 3 - battery pack, 4 - electric drive motors

3.1.2. Tracked driving system

A torsion bar suspension integrated with road wheels (4 on each side of the vehicle) was applied. Propulsion is provided by electric motors with permanent magnets. The motors are coupled by means of side gears to sprockets. Rubber tracks are provided with metal reinforcement and these will in future be replaced with synthetic polymer tracks. A special track tensioning system with a tension wheel is used to maintain constant sag of both tracks. The chassis is presented in Fig. 10.

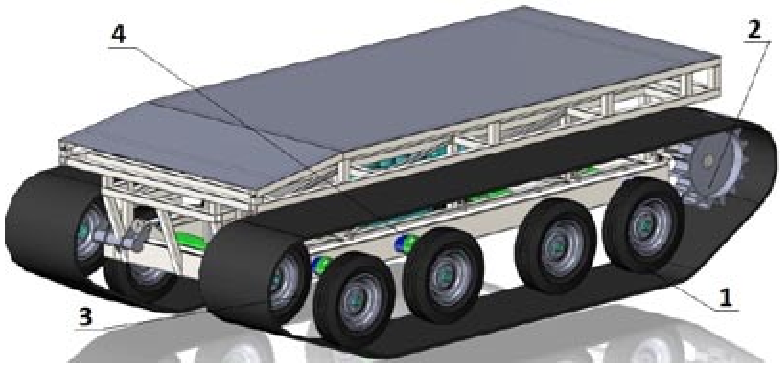


Fig. 10. WIPH vehicle chassis
1- road wheels, 2 - sprocket wheel, 3 - tension wheel, 4 - torsion bar

3.2. Vehicle cab

The cab is designed for a crew of two. The cab's design was adapted to enable its installation on the base platform – vehicle chassis. The cab's furnishing was designed according to the requirements of instruments and controls ergonomy. To keep the weight as low as possible, the framework of the cab was made of square aluminium sections. In order to ensure safety of the crew, the cab framework strength was computed using FEM techniques. Fig. 11 shows cab design made using virtual prototyping.

a) **b)**

Fig. 11. Vehicle cab – concept
a) cab framework, b) cab on chassis frame

3.3. WIPH vehicle operating modes

WIPH designed for engineering and transport tasks is controlled from the cab by the driver/operator. The target design of the vehicle is shown in Fig. 12. The controls include a control yoke and accelerator and brake pedals. The driving direction is changed by varying the speed of the motors coupled to the tracks. Braking is effected by changing the speed of the motors (engine braking). For safety reasons the vehicle is fitted with a parking brake which is controlled by an independent hydraulic system and is released when driving.

Fig. 12. WIPH vehicle – transport version
1 - camera, 2 - range finder

The chassis is a platform capable of moving independently using a remote control operated by an operator outside the vehicle. In addition the computer control system is provided with autonomous operation algorithms which enables carrying out undertaken or assigned missions. Four cameras (two on the front of the vehicle and two at the rear) and four range finders (in the four corners of the vehicle) examine the surroundings (Fig. 12) while the vehicle is moving.

4. SUMMARY

The basic version of the WIPH vehicle adopted in the project was that of an engineering and transport vehicle. Modular structure of the vehicle [26] makes it versatile and, after installing special equipment on the base platform, useful in various applications, both civilian and military.

Civilian applications include:

- transportation tasks in road maintenance, forestry and land surveying;
- engineering work (with special equipment powered from an additional hydraulic power unit placed in the load-carrying body);
- rescue operations (floods and other natural disasters).

In uniform services the WIPH base platform may serve as an unmanned vehicle for the following tasks:

- patrolling difficult to reach border areas;
- inspecting disaster areas (fires in atomic power plants, chemical plants, fuel storage facilities);
- sampling in contaminated areas;
- extinguishing fires in chemically contaminated areas.

In military applications the base platform of the WIPH vehicle can serve as a transport vehicle driven either by the crew inside the cab or remotely by an operator, or it can carry out special missions using its autonomous system.

The base platform can also carry combat equipment (e.g. arms) and then it can be used as an unmanned combat vehicle.

The innovative solutions used in the design include: modern mechanical design, remote control of the vehicle, autonomy in the control system (using scanning of surroundings and image transmission), vehicle drive system, including hybrid drive with a modern power distribution system, and drives in the form of electric motors with permanent magnets, which provide a great potential for further development. The WIPH vehicle now taking on the form of a technology demonstrator will be subjected to a number of tests to confirm or verify its design technical and operating parameters and to assess the innovative level of the design.

The project results, upon verification, will constitute a base for further development of the design, e.g. construction of a prototype or base platform, and will indicate the areas for further exploration focused on future users. The lack on the domestic market of a vehicle featuring similar, modern solutions and technical parameters, makes good prospects for the use of the project results in future civilian and military applications.

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