Advances in Military Technology
Vol. 18, No. 1, 2023, pp. 151-168
ISSN 1802-2308, eISSN 2533-4123
DOI 10.3849/aimt.01723

Evaluation of Existing Unmanned Ground Vehicles Construction and Basic Preconditions for their Design

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The manuscript was received on 29 March 2022 and was accepted after revision for publication as technical information on 27 June 2023.

Abstract:

This article deals with an approach to the development of construction of an unmanned ground vehicle (UGV) carrying weapon station where a weapon up to 12.7 mm caliber is mounted. In the first part, main preconditions for vehicle design are introduced. They are based on basic requirements for this type of vehicle. In the second part, there is an overview of recently used UGVs designed for weapon mounting or those that could be modified. There are parameters stated for each vehicle, including the description and the resulting positive and negative properties. In the last part, there are suggestions how to select the type of chassis construction and how to determine the necessary dimensions of the vehicle frame in terms of vehicle stability.

Keywords:

preconditions for the vehicle design, unmanned ground vehicle

1 Introduction

Contemporaneous technology in many domains of human activities allows us to minimize the amount of risk for operators of equipment and devices. One of the possible approaches to reduce the amount of the risk of casualties and injury occurrence, if the equipment is operated in dangerous conditions, is to allow its remote operation or to omit the necessity of present operation in full.

One of the specific areas of human activities, where the high amount of risk of casualties and injuries occurs, is the combat activity. The effort of a large part of armies of developed countries is to deploy completely autonomous means that do not require the presence of operators. Nowadays, these means are used especially for surveillance and reconnaissance purposes.

Currently, autonomous vehicles are most commonly represented as elements of manned military equipment. Active protection systems of ground vehicles and military

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aircrafts could be mentioned as an example. The autonomous device, in this case the active ballistic protection system, carries out a sequence of operations to reduce or avoid the effects of impact. Other autonomous means are systems designated for target acquisition and identification. It is therefore obvious that a great part of crew operations, connected not only with means operation but also with evaluation and decision-making, is substituted with autonomous systems. The ‘Trophy’ system and 'Arena' system that are effective in protecting against light anti-tank infantry portable weapons and anti-tank guided missiles could be listed as an example [1, 2].

The next logical evolutionary step in the field of combat means is to omit the presence of human operator entirely, or to allow their remote control at least in cases where these means are used to destroy an enemy living force. In this case, the decision-making process cannot be fully delegated to the control electronics of autonomous means [3].

The unmanned ground vehicle (UGV) operates without the necessity of physical presence of the operator. UGV is useful in many applications, where human presence in a vehicle is considered objectionable, especially because of the impossibility to provide safety to the vehicle operator.

The article generalizes principles and assumptions for the design of unmanned ground vehicle construction.

This article also provides a summary of existing vehicles which are either intended or can be modified for remote controlled weapon station (RCWS) carrying a weapon in the range of caliber 5.56-12.7 mm. For each type of UGV, the advantages and disadvantages of the construction solution are described.

2 Initial Condition for Choice of Construction Type and Specification of Parameters of UGV Chassis

The initial conditions for the choice of the type of construction and the assessment of the necessary parameters and the design feature of the UGV chassis are specified by the parameters and the construction requirements of the carried weapon station. The possibilities of prospective modularity and rapid exchange of carried weapons and means without the need for complex adjustment of the initial modification should be taken into consideration during the vehicle frame design process. The exchange of carried weaponry and means should be compatible with equipment that is accessible at the intended location of vehicle deployment.

2.1 Determination of Parameters of UGV Construction According Characteristics of Weapon Station Designated to Carry Weapons of Specific Caliber

The primary parameters are the weight and overall dimensions of RCWS designated to carry machine-gun up to 12.7 mm caliber and grenade launcher of 40 mm caliber. Other characteristics that must be taken into account during the design phase of vehicle construction are the maximum and minimal reachable elevation of RCWS. The maximum elevation range should not be limited by the construction of the UGV or the location of the weapon mount on the vehicle.

According to the performed exploration of RCWS produced by the renowned producers, the weight of frequently used RCWS, which are designed for mounting weapon of 5.56 mm, 7.62 mm and 12.7 mm caliber, ranges between 100-490 kg. The weight of RCWS depends on the mounted weapons and amount of carried ammo, robustness of construction, observational and sensory devices, and other additional equipment of RCWS (for example: smoke grenades, gunshot detection system, electro-optical and infrared (EO/IR) sensors, etc.). The parameters of the mentioned weapon stations were determined from the sources [4-13].

The average maximum elevation range reaches 60° and average minimal elevation range reaches −30°. These values should be taken into account during the design phase of vehicle construction.

The UGV designated for carrying weapon in the range of 5.56 to 12.7 mm caliber should be able to carry payload up to 500 kg according to the type of RCWS. Moreover, the possible future modernization of weapon station, change of weapon station configuration and the addition of supplementary equipment should also be taken into consideration during the initial phase of design process of construction, therefore the construction of the vehicle should be adequately oversized.

2.2 Construction Parameters Determination in Terms of Vehicle Stability

Compared to combat vehicles which are able to compensate with regard to their dimensions, forces that emerge during weapon shooting, the tilt moment should be one of the initial parameters for vehicle overall dimension proposal. The size of this force directly depends on the caliber of the weapon. The fundamental requirement for the vehicle stability is that the minimal value of stabilizing moment $\boldsymbol{M}_{\mathrm{ST_{min}}}$ must be higher than the value of tilt moment $\boldsymbol{M}_{\mathrm{KL_{max}}}$.

$$\left|\boldsymbol{M}_{\mathrm{ST_{min}}}\right| > \left|\boldsymbol{M}_{\mathrm{KL_{max}}}\right| \tag{1}$$

One of the components of the tilt moment $\boldsymbol{M}_{\mathrm{KL_{max}}}$ that arises during weapon shot is the force $\boldsymbol{F}_{\mathrm{sh}}$ that impacts on the lever arm h_{B}, which is the perpendicular distance between the center of weapon mount and the road.

$$M_{\mathrm{KL_{max}}} = F_{\mathrm{sh}} h_{\mathrm{B}} \tag{2}$$

The force arising from the shot F_{sh} can be estimated from the pressure $P_{\max}$ multiplied by the cross section of projectile S [14].

$$F_{\mathrm{sh}} = P_{\max} S \tag{3}$$

The above mentioned condition of minimal value of stabilizing moment during shot should be fulfilled also in case where the vehicle stands or drives in maximal transversal and longitudinal inclination, to avoid the possibility of vehicle overturn. Cases where transversal and longitudinal stability has to be taken into consideration are mentioned below.

The Stability of Vehicle in a Turn When Shooting into the Center of Turn Radius

When the vehicle drives through the sloped turn, the centrifugal force in the center of gravity of the vehicle comes into existence. This force can cause a breach of vehicle transverse stability, and the overturn or transverse skid of the vehicle can occur. The value of this force is defined as the quotient of the total vehicle weight m_{a}, which includes the weight of the weapon station multiplied by the velocity squared $\boldsymbol{v}$, divided by the radius of turn R (Fig. 1).

$$\boldsymbol{F}_0 = \frac{m_{\mathrm{a}} \boldsymbol{v}^2}{R} \tag{4}$$

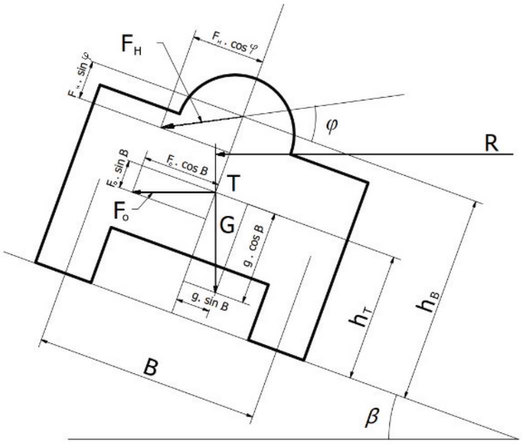

Fig. 1 Forces that have an effect on the vehicle in sloped turn

If the shot is fired towards the center of the radius of the turn, the force from the shot impact $\boldsymbol{F}_{sh}$ affects in the same direction as the centrifugal force. To determine the dimensions of the vehicle from the viewpoint of its stability, the effect of suspension is neglected and the vehicle is considered such as a rigid body. If we express the relation of moments, the below mentioned inequality is given, where the minimal stabilizing moment $\boldsymbol{M}_{\mathrm{ST}_{\min}}$ is represented by its minimal lever arm, which is the wheelbase of vehicle B, under the condition of maintaining the center of gravity T in half of the vehicle wheelbase. Half of the wheelbase of vehicle $B/2$ is multiplied by the sum of the components of the vehicle weight, centrifugal force $\boldsymbol{F}_0$ angle of turn incline β, the force from the shot impact $\boldsymbol{F}_{sh}$ and the angle of elevation of barrel φ. The tilting moment $\boldsymbol{M}_{\mathrm{KL}_{\max}}$ acts as the multiple of the center of gravity height h_T and components of forces affecting in center of gravity. Acting forces are the gravitation force of vehicle G, the centrifugal force $\boldsymbol{F}_0$ and the force from the shot impact $\boldsymbol{F}_{sh}$ which impacts on lever arm h_B.

$$\frac{B}{2}\left(G\cos\beta + F_0\sin\beta + F_{\mathrm{H}}\sin\varphi\right) \geq h_{\mathrm{T}}\left(F_0\cos\beta - G\sin\beta\right) + h_{\mathrm{B}}F_{\mathrm{H}}\cos\varphi \qquad (5)$$

The Stability of Vehicle on Transverse Slope

In this case, the overturn or transverse skid of vehicle can also occur. Contrary to the previous case, the critical tilt moment arises when shooting in the direction of ascent of the slope (Fig. 2).

The fundamental requirement for vehicle stability, as in the previous case, is that the minimal value of the stabilizing moment $\boldsymbol{M}_{\mathrm{ST}_{\min}}$ must be higher than the value of the tilt moment $\boldsymbol{M}_{\mathrm{KL}_{\max}}$ according to the condition stated in Chapter 2.2 by Eq. (1).

Work with the assumption that the vehicle is a rigid body, the maximal tilt moment $\boldsymbol{M}_{\mathrm{KL}_{\max}}$ in this case consists of the component of the force from the shot impact $F_{\mathrm{H}}\sin\varphi$ on the lever arm h_B and the component of the weight of the vehicle $G\sin\beta$, where G is the weight of the vehicle and β is the angle of the slope inclination. The stabilizing moment consists of the component of weight $G\cos\beta$ which affects in the half of the vehicle wheelbase and of the force of the shot impact $F_{\mathrm{H}}\sin\varphi$.

$$\frac{B}{2}\left(G\cos\beta + F_{\mathrm{H}}\sin\varphi\right) \geq F_{\mathrm{H}}h_{\mathrm{B}}\cos\varphi + Gh_{\mathrm{T}}\sin\beta \tag{6}$$

The value of stabilizing moment in both cases mentioned above can be mainly augmented by convenient design of the vehicle wheelbase. The value of the tilt moment, under the condition that the weapon caliber is maintained, can be influenced by the height of the weapon station mounting, the appropriate location of aggregates and units in the vehicle, which results in the lowering of the vehicle center of gravity.

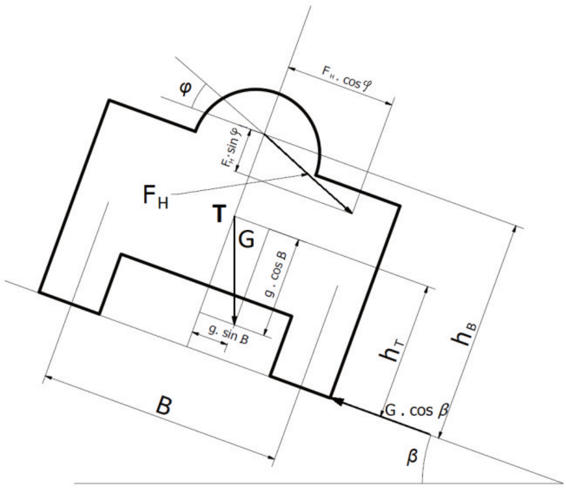

Fig. 2 Forces that have an effect on the vehicle on the transverse slope

The Power Supply of Remote Controlled Weapon Station

Another initial requirement for vehicle construction is the mode of power supply. RCWS are usually powered from vehicle network by the direct current of the nominal voltage of 24 V. These devices are mainly installed on light combat vehicles, whose network works on the mentioned nominal voltage of 24 V. This fact should be taken into account when designing the vehicle's electrical system.

3 The Overview of Recently Used UGVs that Comply with Vehicle Load Capacity Requirements to Carry RCWS

The condition of vehicle load capacity complies with the following available vehicles, which are used or will be used in operation.

At the beginning of the chapter there is a description of the construction solution of each vehicle, at the end there is a table which offers clear arrangement of the available technical parameters of the vehicles (Tab. 1).

 DOI 10.3849/aimt.01723

Tab. 1 Parameters of unmanned ground vehicles

Name/parameters	UGV TAROS V2 6×6	SSMS	Rheinmetall Master SP	Gladiator Tactical UGV	Milos UGV	TheMIS
Type of propulsion system	Hybrid diesel-electric	Diesel-hydraulic	Electric	Hybrid diesel-electric	Electric	Hybrid diesel-electric
Type of construction of propulsion system	Wheeled (6×6)	Wheeled (6×6)	Wheeled (8×8)	Tracked	Tracked	Tracked
Dimensions and weights:						
Vehicle Curb weight [kg]	1 400 (empty)	1 724 (empty)	1 100 (empty)	726 (empty)	680 (fitted with RCWS)	850 (empty)
Vehicle length [mm]	2 740	3 600	2 950	1 780	1 725	2 400
Vehicle width [mm]	1 770	1 800	1 500	1 120	770	2 000
Vehicle height [mm]	2 040	2 100	1 400	1 350	475	1 150
Effective payload [mm]	500	540	600	400	300	750
Parameters influencing drive dynamics:						
Maximum speed [km/h]	25	24	30	N/A	12.5	20
Maximum speed of travel in water [km/h]	0	8	5	0	0	0
Vehicle Specific Power [kWt^{-1}]	42.85	40.02	40	N/A	N/A	N/A
Driving range [km]	700	200	240	N/A	56	300
Maximum acceleration (calculated) [m/s^2]	5.75	5.64	5.6	N/A	N/A	N/A
Special abilities:						
Ability to swim [Yes/No]	No	Yes	Yes	No	No	No
Airless tires [Yes/No]	No	No	Yes	Tracked	Tracked	Tracked
Level of ballistic protection [STANAG 4 569]	0	0	0	0	1	3
Possible track mount [Yes/No]	No	Yes	Yes	Tracked	Tracked	Tracked

3.1 Unmanned, Modular and Automated Robotic Ground Vehicle TAROS 6×6 **V2**

It is the TAROS 6×6 wheeled vehicle (Fig. 3) produced by the Military Technical Institute SOE and VOP CZ, SOE, Nový Jičín, Czech Republic [15].

The vehicle is primarily intended for combat and logistic support; also in cooperation with VTÚ SOE it has recently been produced as a reconnaissance vehicle to carry optoelectronic and radar sensors and electronic warfare systems [15].

The development of the weapon mount of the CZ 805 BREN infantry weapon or a 12.7 mm DSKM heavy machine gun is currently in process [16].

Fig. 3 UGV TAROS 6×6 V2 chassis [17]

The propulsion system of the TAROS vehicle in the 6×6 variant drive is hybrid, a diesel generator is used to generate electricity. Each wheel of TAROS 6×6 is driven by one electric motor [16].

The vehicle uses an independent suspension of all wheels, which is provided by a double wishbone suspension. Each wheel is driven by one electric motor supplemented by a reducer gearbox (Fig. 4 – pos. 1), each wheel is steerable, and its turning is provided by a screw-driven electric linear actuator (Fig. 4 – pos. 2), which ensures efficient maneuverability to the vehicle.

The design of suspension and steering, with identical wheelbase of all vehicle axles, allows the zero-radius turning to the vehicle. Turning the wheels on the first and last axles to the opposite direction and reversing the wheel on one side of the vehicle allows its rotation on zero radius. Moreover, the crab mode of vehicle drive could be used by turning all wheels in the same direction.

Each electric motor of the wheel has an output of 10 kW and a torque of 1 000 Nm. This means that for the 6×6 vehicle version, the total output of the vehicle propulsion system is 60 kW [17].

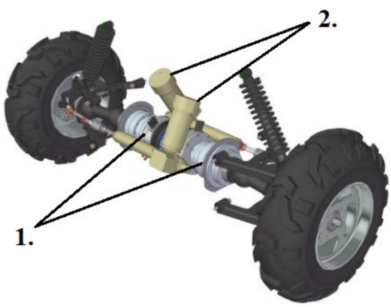

Fig. 4 The axle of the TAROS 6×6 vehicle [17]

3.2 Robotic Vehicle SMSS (Squad Mission Support System)

The SMSS vehicle (Fig. 5) is produced by Lockheed Martin. The vehicle is currently operated by the United States Army. It was first deployed in combat in 2011 for the logistic support of infantry units exclusively. However, the concept of vehicle is modular, with the proviso that the vehicle can also be used as a transport or reconnaissance vehicle or a platform to carry communication means [18].

The vehicle can overcome a vertical step up to 0.55 m height and overstep the 0.7 m wide trench. The vehicle reaches a maximum speed of 24 km/h. The range of the vehicle is 200 km [19].

Fig. 5 The robotic vehicle SMSS [18]

The vehicle is produced with six-wheel chassis, all wheels are driven. The vehicle is also able to overcome water obstacles by floating. The construction of vehicle is based on the already existing amphibious vehicle platform ATV Land Tamer from Hydratek [20], the adoption of already existing vehicle construction has significantly simplified the design process of the vehicle.

The supercharged diesel engine with an output of 69 kW is used for vehicle propulsion. The power transmission is hydrostatic, with one hydrostatic unit for one wheel, as in the case of amphibious Hydratek vehicles [21].

The axles of the vehicle are beam and unsprung, moreover, in the construction of the vehicle the steering gear is not used. Vehicle suspension is provided solely by deformation of the low-pressure tires when crossing an obstacle. The biggest advantage of this solution is its constructional simplicity, high durability, and the axle takes very little space in hull. In addition, the vehicle can be equipped with tracks to improve its passability (Fig. 6).

The significant disadvantage of this constructional solution is the impossibility to ensure constant contact between the wheel and the road, because of absence of suspension, as well as non-smooth driving performance, which is connected with the considerable stress of vehicle parts, special mount and carried means.

Regarding the above-mentioned construction of vehicle propulsion system, the steering is accomplished by skid-steer drive, while the maneuverability is worse in comparison with the above-mentioned UGV TAROS 6×6.

3.3 Rheinmetall Mission Master SP

Another representative of the wheeled UGV is the Rheinmetall Mission Master SP produced by Rheinmetall Canada [22].

Fig. 6 The basic platform of the UGV SMSS, the ATV Land Tamer equipped with tracks [20]

The vehicle was originally intended for logistical support of infantry units, i.e. to carry loads up to 600 kg and to evacuate the wounded. At present, reconnaissance equipment is being mounted on the vehicle, and a weapon station has already been mounted. According to the available information, the vehicle was equipped with a weapon station Fieldranger from Light Series produced by Rheinmetall weighing 75 kg, which can be equipped with a weapon caliber 5.56 × 45 mm or 7.62 × 51 mm [23]. The use of a heavier Rheinmetall Multi weapon station, where the option of mounting a 12.7 × 99 mm caliber weapon or a 40 mm grenade launcher is also in consideration. The weight of this weapon station is 200 kg [23].

The German Army and the Royal Netherlands Army are currently considering the implementation of the vehicle into their arsenal [23].

The company is working on the installation of the Northop Grumman M230 LF 30 mm short recoil cannon using 30 × 113 mm ammunition.

A variant to carry two Eurospike missiles and a 40 mm automatic grenade launcher is also in development [23] (Fig. 7).

a) b)

Fig. 7a) A-UGV Mission Master SP carrying weapon mount Rheinmetall Multi with machine gun 12.7 mm *caliber; b) A-UGV Mission Master SP carrying weapon station equipped with EuroSpike and* 40 mm *caliber grenade launcher* [24]

The propulsion system of this vehicle is exclusively electric. The system is powered by lithium accumulators, while the operating time can reach up to 72 hours. Assuming the condition that the vehicle carries 300 kg load at a speed of 30 km/h, the accumulator holds to supply the vehicle approximately for 8 hours. The accumulator loses its capacity at low temperatures. At −30° C the accumulator loses approximately 40% of its capacity [23].

Similarly to UGV SMSS, this vehicle is designed using beam, unsprung axles without steering mechanism. Therefore, the steering is accomplished by skid-steer drive again. The suspension is provided by low-pressure tires or by special wheels fitted with airless tires with lower stiffness (Airless Tire System) (Fig. 8).

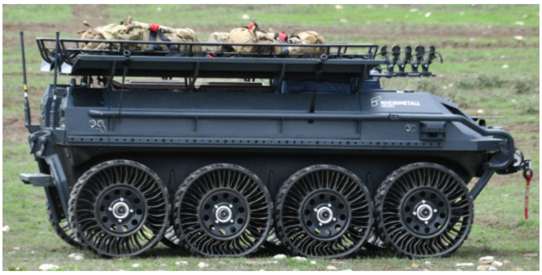

Fig. 8 The UGV Mission Master SP fitted with special wheels using the Airless Tire System [24]

3.4 Gladiator Tactical Unmanned Ground Vehicle

One of the oldest representatives of tracked UGVs is the Gladiator vehicle (Fig. 9), which was designated to be employed by the United States Marine Corps. In 2007, six prototypes were handed over to the United States Marine Corps for testing. The project and the possibility of combat deployment of the vehicle were eventually abandoned [25].

The vehicle was to be designed for armed surveillance, simple reconnaissance, and fire support and it should be easy to transport it to the area of operation. The vehicle was dimensioned to be transportable in the cargo space of the HMMWV vehicle [26].

Due to the period of its design process and its potential use, the vehicle is not capable of an autonomous mode of operation and therefore has to be remotely controlled throughout its operation [25].

Fig. 9 Gladiator Tactical Unmanned Ground Vehicle [25]

The arrangement of tracked propulsion system is designed in the way that the drive sprockets are located at the rear of vehicle above ground level and the idlers are also located above ground level at the front of the vehicle.

Road wheels have a small diameter and they are sprung using an individual suspension. The tracks are made of rubber.

In the design phase of the construction of the Gladiator vehicle, the need for ballistic protection was taken into account. This provides the vehicle with protection against the impact of a 7.62 mm projectile from close range [26].

3.5 Milos UGV

The Milos UGV (Fig. 10) was designed and constructed by the MTI (Military Technical Institute) in Belgrade to meet the requirements of the Serbian Army. The vehicle is primarily intended for reconnaissance and the subsequent conduct of a combat operation. On the vehicle, a 7.62 mm machine gun is mounted, fed by an ammunition box holding 500 rounds. There is also a 40 mm grenade launcher with a supply of 6 grenades [27].

Fig. 10 The UGV Milos [28]

The vehicle is not capable of an autonomous mode of operation and must be remotely controlled; therefore, the remote control is designed to be feasible by one person for both chassis control and weapon station control.

The propulsion system is pure electric, the electricity is provided by accumulators, which are able to keep the vehicle in continuous operation for 1 hour.

The arrangement of tracked propulsion system is designed in the way that the drive sprockets are located at the rear of vehicle above ground level, and the idlers are also located above ground level at the front of the vehicle.

Four road wheels for each track have a large diameter in comparison to the overall size of the vehicle using an individual suspension. Tracks are made of rubber. To limit the vibration of the upper section of the track, the tracked propulsion system is equipped with three support rollers for each side. The tracks are metal as standard, but can be substituted by rubber ones.

The vehicle can be transported on a trailer towed by an off-road vehicle; for this purpose, the Land Rover Defender 110 vehicle is used in the conditions of the Serbian Army [29].

3.6 TheMIS (Tracked Hybrid Modular Infantry System)

The UGV TheMIS is a modular autonomous platform produced by the Estonian company Milrem Robotics and its first prototype was designed in 2015 [30].

The vehicle is designed to perform a variety of tasks. It can be modified for reconnaissance, logistic, and communication purposes; in addition, it can also serve as a means of the evacuation of the wounded and, of course, during the installation of a weapon station as a means of combat (Fig. 11) [30].

Fig. 11 The UGV TheMIS [31]

Due to its unconventional construction, the ground clearance reaches 600 mm. The vehicle is able to cross a water obstacle to a maximum depth of 610 mm.

The parameters of the passability of the vehicle through the terrain are as follows: vehicle can overstep the trench wide 0.9 m; its stability on transverse slope reaches 30 %; maximum grade is 60 % [30].

The construction of the vehicle lies in the connection of two individual units in which all components of the vehicle propulsion system are located. This design solution ensures high mobility of the vehicle and its overall low height [30].

The vehicle uses a hybrid propulsion system. Each track is driven by an electric motor. Electric power is generated by the JP-8 produced MAINSTREEM ENGINEERING CORPORATION generator and its output is 10 kW. The generator is located in the right vehicle unit (Fig. 12a) and generates an electric current of nominal voltage of 24 V. Either conventional lead-acid or lithium ion accumulators are charged by electricity (Fig. 12b).

Another initial requirement for vehicle construction is the mode of power supply. RCWSs are usually powered from vehicle network by direct current of nominal voltage of 24 V. These devices are mainly installed on light combat vehicles, whose network works on the mentioned nominal voltage of 24 V. This fact should be taken into account when designing the electrical system of the vehicle. Accumulators are able to ensure vehicle operation on pure electricity for 0.5-1.5 hours, depending on the type of the battery used. In hybrid mode, the vehicle can operate for 12 to 15 hours [31].

The arrangement of the tracked propulsion system is designed in such a way that drive sprockets are located at the front parts of vehicle units above ground level, and idlers are also located above ground level at the rear of the vehicle. Six road wheels for each track have a relatively small diameter in comparison to the overall size of the vehicle using an individual suspension. Support rollers are used to limit vibration of the upper section of the track. Tracks are made of rubber [31].

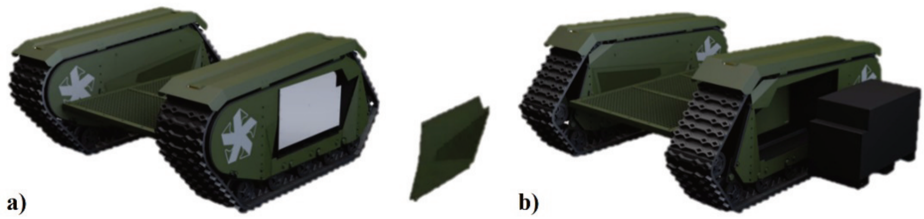

Fig. 12 Location of power units in the UGV TheMIS [30]

The transportability of this vehicle has also been dealt with in an interesting way. The vehicle can be towed by another vehicle at a maximum speed of 80 km/h, which eliminates the necessity to transport the vehicle on a trailer.

Armies of the following countries operate or plan to operate TheMIS vehicle: Estonia, the Netherlands, the USA, France, the United Kingdom, Germany, Norway, Australia, Thailand, and Indonesia [32].

4 Discussion

Currently, both types of UGV chassis (tracked and wheeled) are being developed and used. The final variant of the solution depends primarily on the user's choice, based on the expected vehicle deployment condition. Each design solution has its advantages and disadvantages. Their summarization is given in the following chapter.

4.1 Advantages of Wheeled UGVs Chassis

The undeniable advantage of a wheeled chassis resides in the very good maneuverability of the vehicle, especially if each vehicle wheel is driven by its own electric motor. In addition, maneuverability is enhanced by the presence of a steering mechanism, as in the case of the TAROS 6×6.

This vehicle is able to turn on the zero radius in a certain chassis adjustment, and this type of chassis also allows the possibility of the crab drive mode.

Another advantage is that if the same vehicle weight is determined, a lower value of rolling resistance and moment of inertia is reached. Therefore, less power of the propulsion system is required to drive a wheeled vehicle of the same weight than its tracked variant. This enables to reduce the weight of the whole propulsion system. In the case of wheeled chassis, where the skid-steer drive is utilized, there exists another possible advantage, which resides in the possibility of tracks installation, thus reducing the nominal ground pressure, increasing the contact area and thus increasing the vehicle passability.

4.2 Disadvantages of Wheeled UGVs Chassis

A significant disadvantage, especially in the case of the TAROS 6 × 6 vehicle, which is equipped with independent wheel suspension ensured by double wishbone axles and a steering system, is the considerable complexity of the entire construction. It is considered to be more prone to damage and requires more extensive maintenance to ensure its function. In the case of the use of a steering mechanism, the advantages associated with improving the maneuverability of the vehicle partially outbalance the disadvantage of the complexity of the construction, as it was already mentioned.

The use of an unmanned ground vehicle design equipped with sprung axles and independent wheel suspension can be considered unjustified. The sprung suspension system in vehicle construction is used primarily for the comfort of the crew, which is not present in the UGV. The influence of the suspension on the transmission of traction force can be neglected in the case of a UGV due to its weight, dimensions, and maximal achieved driving speed. This statement is substantiated by the fact that for most UGVs this construction solution is abandoned and the vehicle suspension is replaced in these cases by the use of low-pressure tires or using an airless tire system, because the stabilization of the weapon is able to compensate for shocks arising during crossing terrain unevenness.

4.3 Advantages of Tracked UGVs Chassis

The undeniable advantage of the tracked vehicle is its better passability. Assuming that the vehicle with same dimensions is determined, the tracked vehicle is able to overcome higher vertical steps and the vehicle can overstep wider trench than its wheeled variant. Due to the larger contact area, i.e., the contact of the entire track area with the road, the vehicle is able to achieve higher values of transverse slope compared to the wheeled vehicle, and due to the higher toughness of the chassis it achieves a greater maximum inclination in terms of the same height of the center of gravity. The height of the center of gravity itself is lower due to the construction and weight of the tracked suspension system itself.

- Due to the contact of the entire length of the track with the road, the adhesive force of the vehicle is better utilized, so the transferable traction force on the road is higher.
- Another advantage of the tracked chassis is the better distribution of the nominal ground pressure on the road, which is related to the better passability of the vehicle on less bearable terrain.
- The tracked chassis also has the option of turning at zero turning radius when reversing one belt (pivot turn).
- The occupied space of tracked propulsion system is smaller than when using an independent suspension and steering mechanism in a wheeled vehicle construction. Thus, there is a presumption of better usability of the vehicle hull space and the related possibility of reducing the dimensions, especially the height of the vehicle and lowering its center of gravity.

4.4 Disadvantages of the Tracked UGVs Chassis

The disadvantages of the tracked chassis are considerable power losses in the propulsion system. For this reason, the vehicle must have a higher performance power unit than in the case of a wheeled vehicle of the same weight.

An indisputable disadvantage of the tracked chassis is the considerable noise of the propulsion system while driving, especially in the case of the use of a segmented metal track, as in the construction of the UGV Milos. This fact is particularly disadvantageous if the UGV is operating in a pure electric or hybrid silent mode. This drawback can be eliminated by using a continuous track, especially a continuous rubber belt.

Another disadvantage of using a tracked undercarriage is the higher ratio of unsprung mass to sprung mass of the vehicle. These results in a lowering driving smoothness, the impulses of the forces transmitted to the sprung masses, i.e. in the case of the UGV on the vehicle body and the purpose-built mount, are larger than in the case of a wheeled vehicle, where the ratio of non-sprung mass is lower. For this reason, the design of all tracked UGVs includes the conventional tracked propulsion system using the suspension, in other words, the suspension of the road wheels are a necessity in this design solution.

In case a mechanical transmission of torque is used in the vehicle construction, it is necessary to take into account the adaptation of the transmission. An essential part of the vehicle must be the steering system to ensure vehicle turning.

4.5 Pre-conceptual Design Phase of the UGV, Choice of Type of UGV Chassis, and Vehicle Dimension Determination

During this phase, the design should be adapted according to the intended purpose of the UGV. In the case where it is considered to carry the weapon of the mentioned caliber, the character of future intended deployment of the vehicle should be taken into account from the point of view of the terrain in which the vehicle will usually operate. Proposed design has to allow the vehicle operation in usual conditions, i.e., in terrain with obstacles that the vehicle has to overcome, with respect to their dimensions and profile. Further, based on these conditions, a suitable type of vehicle chassis and its arrangement should be selected. It follows from the above mentioned text in chapters 3 and 4 of this article. Considering the fact that wheeled chassis using beam and unsprung axles without vehicle, the steering mechanism offers the most universal range of use across all existing and described types of chassis. In addition, the passability in specific tasks in less bearable terrain can be increased using the installation of rubber tracks.

From the above given assumptions results the need of the minimal load capacity of the vehicle chassis in terms of the total weight of the weapon station.

When determining the preliminary dimensions of the vehicle frame it is necessary, especially in case of UGV, to calculate, except forces emerging from drive itself, also the effect of forces emerging during weapon shooting, provided by the condition stated in Chapter 2.2 by Eq. (1) to ensure the required dynamic and static stability of the vehicle. The influence of these forces should be taken into consideration especially in limit conditions of stability using Eq. (5) for vehicle driving through the sloped turn and Eq. (7) for the case of transverse slope. Another input condition for the calculation is the selection of the type of vehicle propulsion system and its arrangement, also the location of weapon mount and the related height of vehicle center of gravity. Subsequently, to assess calculated dimensions of vehicle regarding purpose of vehicle use, in case that the vehicle does not meet requirements for given purpose, it is necessary to rework the conception of propulsion system in order to lower the height of center of gravity.

In addition to the mentioned preconditions in this design phase, the following aspects should also be considered for the necessity of potential ballistic protection and its level: the specific power of the vehicle and its dynamic characteristics, the requirements for drivability, and the requirements for reliability and maintainability.

5 Conclusions

For the purpose of mounting 5.56 mm, 7.62 mm or 12.7 mm caliber weapons using NATO ammunition, the article describes recently used remote-controlled weapon stations that could be mounted on an autonomous ground vehicle. The analysis shows the need for the minimal load capacity of the vehicle in terms of the total weight of the weapon station.

There is also a requirement for the overall stability of the vehicle due to the tilt moment that arises during shooting, especially when the vehicle is situated on a transverse slope or during turning. The way how to calculate the necessary dimensions from the point of view of the demanded vehicle maximum transverse inclination is given in the second chapter of this article. Moreover, compared to combat vehicles, which are able to compensate, with respect to their dimensions, for the forces that arise during weapon shooting, the effect of these forces is included in the calculation.

The requirement of supplying the weapon station from the vehicle network is also defined, usually by a current of nominal voltage of 24 V.

In the article, frequently used UGVs with both wheel and tracked construction of the chassis are mentioned, giving their advantages and disadvantages. The advantages and disadvantages of design solutions are generalized in the fourth chapter for greater clarity, whereas the final choice of the design solution of the vehicle depends on the user preferences and the purpose of the vehicle.

Further work in the field of vehicle design choice and determination of combat UGV chassis parameters should be focused on defining and evaluating requirements of vehicle passability, potential ballistic protection, necessary vehicle-specific power regarding to required vehicle dynamic characteristics, vehicle performance, reliability and maintainability. Another potential research area could deal with the evaluation of the possibility of adopting the already existing and commercially available chassis design with its unchanged propulsion system.

Acknowledgement

Presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development and Specific Research and the project VAROPS (*DZRO VAROPS*), Department of Combat and Special Vehicles, University of Defence, Brno

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