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MOBILITY IMPROVEMENT OF HEAVY TRACKED VEHICLES: THE "PAN" TANK EXPERIENCE

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ABSTRACT

This paper shows that the sinkage of the tracked vehicle is the most important parameter in its mobility. Power and fuel consumption follow cubic power law with sinkage. So the usual strategy to increase power is not the more convenient way to improve vehicle off road performance. The Ground Pressure (GP) is the critical parameter. Power requirement goes with the cubic power of sinkage. GP above 0.9 daN/cm^2 should be avoided at all costs. The best way to obtain this result on an existing design is to increase track length. However it is easier to work on track width. The easiest modification is to add "Duckbill extensions" in the outer part of the shoe. This system was used on the Sherman Tank when additional armor was added. With modern technology it is perfectly possible to perform experimental tests with new shoes. This can be done by manufacturing prototypes of high stress nitrided steel shoes, usually with 300M high strength steel. Comparative fuel consumption is a good index of vehicle performance. Also wheel diameter and width can be increased to improve off-road performance. Specialized tracks for different terrains should also be designed. The gravity center should be kept slightly rearward. This attitude should not be excessive to keep the pressure value more even possible along the track. In any case the vehicle naturally assumes the backward inclination due to terrain compression. Another important improvement is the addition of computer controlled directional control to improve the accuracy of trajectories. This is particularly important for tracked vehicles where turning involves extremely high energy consumption.

Keywords: tracked vehicles, mobility, ground pressure.

INTRODUCTION

It is estimated that there are about 108,000 battle tanks currently in service across the globe. Of these, 10,000 are M1 Abrams belonging to the US Army, USMC, Australia and various Arab nations. There are about 4,800 Leopard 2s in service with the armies of Germany, Switzerland, Canada, Australia, Norway, Holland, Finland, Sweden, Spain, Greece, Turkey, Singapore and Chile. Japan has 340 tanks consisting of Type 90s, plus 200 of the newer Type 10. South Korea has more than 1,000 K1 tanks. Israel may still have around 1,000 Merkavas of various marks serviceable. France has 400 Leclercs and Italy has 200 Arietes. Britain has 250 Challenger 2s. All these tanks are described in the category of "Main Battle Tanks". Unfortunately they belong to the category of the "pan" tank. As we will demonstrate, they are, in fact, Heavy Tanks: a completely different vehicle. This paper focuses on the vehicle mobility, that is the key of the Main Battle Tank. The Bekker model is discusses and some evaluations are made. Finally some recommendations are made on how to improve the "pan tank" off-road behavior with modern techniques.

The origin of the "pan" tank

In the seventies, the experience of the M60 was very clear to tank designer. During the Vietnam War it proved to be an unuseful weapon. In the jungle environment, the terrain can make it difficult to deploy armored forces, or any other kind of forces on any large scale. M60 heavy armored tanks limped on improvised roads only to get stuck in the mud or be stopped by enemy ambushes. In this condition the vehicle was immobilized by the soft ground or by track damage and then targeted with shaped charged weapons until the destruction. A popular document of that age was the cost-effectiveness of an automatic fire suppression system for this tank. It was very clear that additional protection was necessary. At the same time lighter tanks with much more mobility were requested. The huge works on armor in the 80s have produced various "lightweight" armors like the "Chobham" one. In this case the armor is quite thick and cumbersome but its density is not very high since a large part or the room is empty. The popular concept was that the new tank should be a large but light tank. To keep the frontal section as small as possible, the height should be limited, so the tank would have a shallow shape. From this fact came the "slangy" surname "pan tank", from the cooking pans. The available papers on heavy vehicle track requirements, most from the work of Bekker [1], demonstrated that it is convenient to have long and not excessively large tracks, these "thin" tracks were opened to allow lodging the large but light vehicle. Then a new additional specification came: the armor should withstand a large number of rounds of the very popular 14.5 mm Russian automatic cannon. An (a few) additional external high strength steel layer(s) was added on the external of the vehicle armor for this purpose. This was a lot of weight since steel is a high density material. Then the Yom Kippur war took place. In this war a large tank battle took place on the Golan Heights. The Main Battle Tank main role became the anti-tank one. The 120 mm smooth bore substituted the original 105 mm rifled cannon.

Internal room should be added to have a sufficient number of internal rounds. The pan tank was then enlarged to accommodate the new weapon. The engine and the transmission grew accordingly, the engine passed from the 830 HP of the Leopard I to the 1,200 HP of the initial Leopard II. The new engine, the new transmission and the new fuel tanks required an enlargement of the vehicle hull. The track width was enlarged but not too much, to avoid to add “not useful” mass. On the other side the "Bekker equations" [1][2], based on the much lighter vehicle data, were comfortably giving good mobility results. Unfortunately, as we will see, the Bekker model underestimates the power needed to traction. As time passed, the armor was increased, new devices were added, power was increased but tracks remained the same. The true vehicle mass remained a well kept secret, but the "pan tanks" began to be seen more on roads than in cross-country. The number of available bridges was progressively reduced and new tracks shoes/systems were studied for the new heavy vehicle. The Main Battle Tank (MBT) has become a Heavy Tank (HT) with all the problems of the case.

MBT tactics

The first and still best example of use of the MBT remains Guderian's Blitzkrieg tactics, in particular during the invasion of France in 1940. This tactic is based on superior mobility, knowledge, communications and firepower. Initially the German army fled into France through the unprotected Ardennes. This was done thanks to the low ground specific pressure of the German vehicles of the periods, tanks included. The blitzkrieg was based on the fifth column, a net of French speaking German undercover agents, already infiltrated into the territory that convinced entire communities to flee in front of the incoming Germans clogging the roads with people and carriages and slowing down the Allied operations. Often these German soldiers disguised themselves as government agents and talked directly with city mayors to obtain this precious result. In fact Blitzkrieg required superior mobility of the attacking forces. These people also gave to their Commands precious information of the current situation. Situation awareness and communication was the basis of the success. In fact scouting squads entered deeply into the enemy territories ahead of the attacking columns. Aerial superiority was carefully kept. Obstacles were attacked by the air to ground forces (Stukas) and then by the MBT (Panzers) protected by artillery fire and anti-tank cannons. The infantry units mounted in Sd. Kfz. 253 half-tracks operated on foot during the attack operations. Infantry moved behind and under the protection of the MBTs. A unique command system communicated with the MBTs, the infantry and the artillery. Almost every vehicle was equipped with radio. Direct tank-to-tank combat with Allied tanks was avoided. In fact German tanks tended to attire Allied Armored Units into ambushes where the German artillery engaged the Allied tanks. This tactic was widely used also in North Africa. The multicrew approach was used for the tank units to keep the momentum. Curiously, the lesson was lost during the Kursk battle (1943), where the German used the Panther, the Tiger I and the Heavy Tank Elefant. This latter proved to be a complete disaster and the initiative wad definitively lost on the eastern front. The Soviets were prepared and used everything available to defeat the Germans. In Kursk the Russian lacked of air superiority that is the key to anti-tank warfare. Aircrafts and attack helicopters are still the best anti-tank weapons. On the western front, the Allied used the Blitzkrieg tactics to win the war. The Heavy Tank concept was pursued by the Soviet during WWII with many designs that proved to be complete failures.

MBT mobility

Table-1 summarizes the Ground Pressure (GP) of several different tracked vehicles

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Table-1. Ground pressure of several different MBTs.

Armored vehicle	HP/t	GP (daN /cm^2)	M (t)	L (cm)	B (cm)	LxBxH (m x m x m)
M113	20.4	0.6	10.4	267	38	5.3x2.69x2.52
Centurion	15.3	0.73	42.5	271	61	8.29x3.39x2.94
Stalin	13	0.81	46	436	65	9x3.1x2.5
KV1	13.8	0.77	43.5	65	433	6.8x3.3x2.7
T34A	16.18	0.64	26	372	55	5.92x3x2.41
PIII (1940)	15.4	1.01	19.5	286	36	5.38x2.91x2.44
Sherman M4	13.2	0.96	30.3	373.4	42.1	5.89x2.62x2.74
Cromwell	21.4	1.05	28	373.4	35.6	6.35x2.91x2.49
Tiger I	12.1	0.97	57	361	72.5	8.45x3.7x2.93
Panther	15.6	0.9	44.8	392	66	8.66x3.42x2.85
Elefant	9.2	1.23	65	419	65	8.14x3.38x2.97
Leopard 2	24.1	0.83	55.1	525	64	7.72x3.54x2.80
AMX-56 Leclerc	27.2	0.9	54.5	432	63.5	7.03x3.71x2.92
Challenger 2	19.2	0.9	62.5	479	65	8.03x3.5x2.49
Merkava	23	0.96	60	478	64	8.68x3.7x2.75
M1 Abrams	24.5	1.08	67.7	457.5	64	7.91x3.65x2.88
Ariete	26	0.9	54	460.2	65	9.67x3.61x2.5

The mass (M) and the power of table 1 should be taken with attention, since the weights are often underestimated while the power is overestimated. The power does not mean much for a vehicle. It is vaguely linked to the maximum speed, but the amount of energy usefully used for traction depends from many factors. Much more important is the maximum torque, the number of speeds of the gearbox and the steering system. For example, a tank with a CVT (Continuously Variable Transmission) may be easily equivalent to the same vehicle with 1.5 times the available torque. In particular, for modern "pan tanks" the true ground pressure is much higher and classified. The continuous increase of engine power put under high pressure transmission, fuel requirements, maintenance and reliability [3-28]

BASICS OF TRACKED VEHICLES MOBILITY

At low speeds, the track works as an “iron path”. The most advanced shoe rotates towards the ground. Its weight helps to compress the ground before the first wheel passes and further compresses the ground. The wheeled vehicle advances on the iron road of the track. Since the ground is compacted by the dynamic load of the wheels, the vehicle assumes a rearward inclined configuration on the mud. This configuration is favorable since the vehicle tends to press the terrain in front of the tank with a downward movement, facilitating the frontal bulldozing. From this concept comes the interleaved wheel arrangement of the German WWII tanks (Figure-1). The very large diameter interleaved wheels are conceived to distribute the load over the track that should work as an iron road. This slack track configuration, allowed the track to droop and run along the tops of large road wheels. This system is extremely efficient at low speeds and it the reason of such a "high" specific pressure for the Tiger I and the Panther. In any case, the original GP design values had been lower also for these WWII German tanks, since armor width was continuously increased during the development phase for better survivability. As vehicle velocity is increased, the centrifugal force tends to pull the track outside. The wheels and the highly nonlinear suspension system tend to follow the ground with a delay that depends on suspended wheel mass. For high speed, it is convenient to have small wheels and light tracks. Better track arrangements use return rollers to keep the top of the track running “straight” between the drive sprocket and the idler one. In normal operations, the tracked vehicle is always steering also in a straight path. The tracks always skid laterally on one side or the other. This is due to many factors, the principal one being the unevenness of the ground. The tank is then always bulldozing. For this purpose it is particularly important the "duck sitting" of the vehicle (figure 2), with the outer part of the track rotated in the upward direction. This fact is due to the built-in flexibilities the track suspension system and the reduced lateral stiffness of the tank track system. This effect is particularly important when bulldozing sideways, since the main problem of the tracks on soft terrain, snow and sand is throwing. This event is contrasted by the inner surface of the track links that usually have vertical guide horns engaging gaps between the doubled road and idler/sprocket wheels. However as the terrain accumulates in the inner side of the track, it tends to disengage the hornets, leaving the vehicle immobilized. Besides the weight, the main defect of the interleaved wheel arrangement was the possibility to absorb large amount of power due to the accumulation of "dirt" between the wheels.

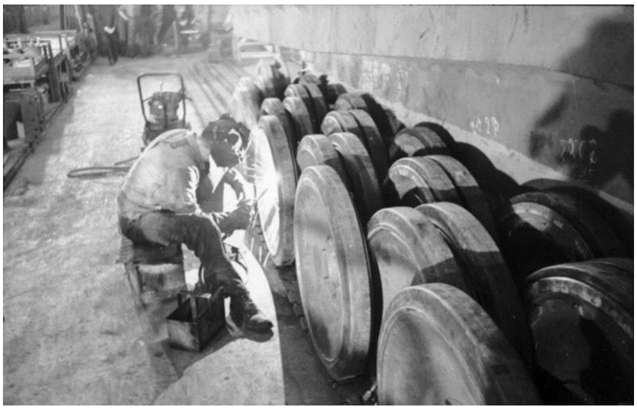

Figure-1. Interleaved wheel configuration of German WWII tanks.

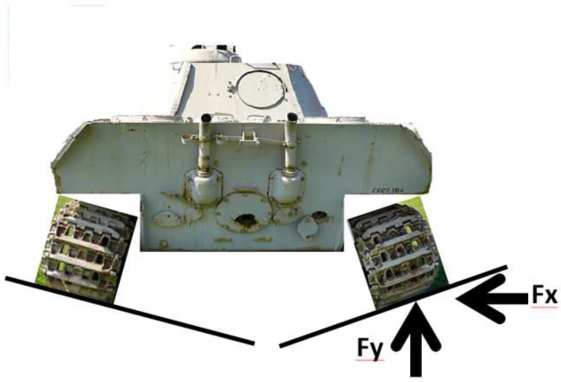

Figure-2. "sitting duck" configuration.

Table-2. Pressure sinkage parameters.

Terrain type	n [-]	Kc [kN/mn+1]	Kq [kN/mn+2]
Dry Sand	1.1	0.733	1131.89
clay	0.11	2.208	123.924

Soil Stress due to soil deformation

Bekker [1] proposed the following empirical equation for pressure-sinkage relationship in homogeneous terrains (1):

$$z = \left(\frac{p}{\frac{k_c}{b} + k_\varphi} \right)^{\frac{1}{n}} \tag{1}$$

The result with b=640 mm are shown in Figure-3. As it can be seen the limit value of the specific pressure is about 100kN (1 daN/cm^2), since from this value up the sink value increases in a very nonlinear way. The vehicle cannot operate in any case on sand (dunes in the desert) since it will sink considerably.

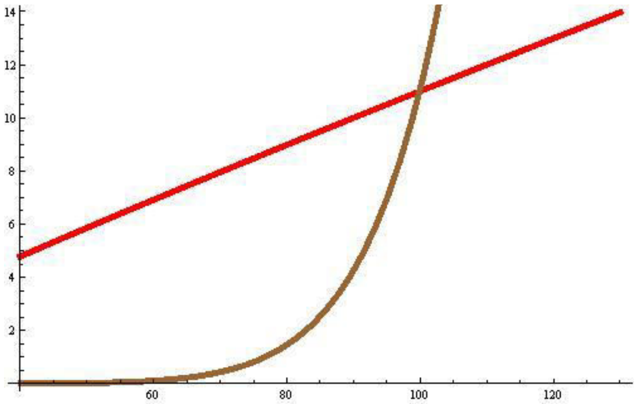

Figure-3. Specific pressure (kN) vs sinkage (cm) for clay (brown) and sand (red) for track-width=64cm.

Figure-4 shows how the width of the track should be increased considerably (in clay) to obtain relevant results.

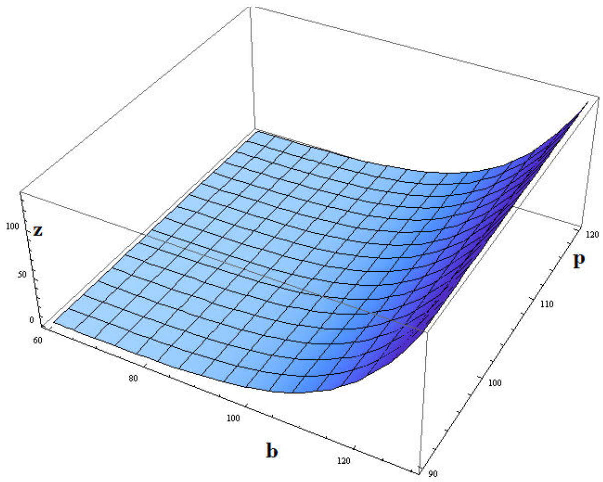

Figure-4. Sinkage z (cm) vs. ground-pressure p (kN) and track width b (cm).

Figure-5 shows that the impression of Figure-4 is misleading since at parity of mass the sinkage depends on track width.

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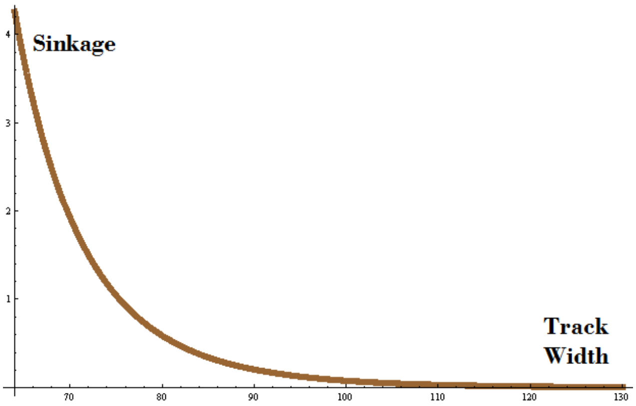

Figure-5. Sinkage (cm) vs. track width (cm) with the same vehicle weight (p=900kN,b=65cm).

However, the "sitting duck" configuration is not considered by Bekker's equation (3) so the effect of track width increment is not as important as shown in Figure-5. The stress on track and on the suspension system increase with a quadratic law with track width b with constant specific pressures. In fact, the maximum moment for a cantilever beam is $M_{max}=p*b^2/2$. Tracks chain element and shoes are much stressed parts. The increase in b unavoidably increased the track weight. However, the highly nonlinear behavior of clay should be taken into consideration. Equation (2) give the ultimate shear of a terrain:

$$\tau_{\max} = c + p\tan\varphi \qquad (2)$$

The shear displacement increases to a maximum from the front shoe, up to the one when the maximum shear displacement. Depending on the soil type, this stress limit may be reached quickly. From this point on the displacement increases without a corresponding increase in the shear (traction) force. This is and elasto-plastic model that can be modeled with equations (3) and (4).

$$\tau = \tau_{\max}(1 - e^{\frac{-j}{k}}) = (c + p\times\tan\varphi)(1 - e^{\frac{-j}{k}}) \qquad (3)$$

$$k = \frac{\sum_{i=1}^{n}\left(1 - \frac{\tau_i}{\tau_{\max}}\right)^2 j_i^2}{\sum_{i=1}^{n}\left(1 - \frac{\tau_i}{\tau_{\max}}\right)^2 j_i \log\left(1 - \frac{\tau_i}{\tau_{\max}}\right)} \qquad (4)$$

Shear stress initially increases with shear displacement at a rate determined by k, and then reaches a constant value for any increase in shear displacement. Equation (3) is used as an initial approximation to determine the tractive force *F* of a track on a given terrain (5).

$$F = b\int_0^l (c + p\times\tan\varphi)(1 - e^{\frac{-j}{k}})dx \qquad (5)$$

From equation (5) the best tractive effort ratio with minimum possible slip occurs when the normal pressure increases from front to rear end. This happens when most of the weight is in the rear part of the tracked vehicle.

Repetitive loading

Track shoes encounter the same section of terrain with different vehicle loads, which requires repetitive loading to be taken into consideration. For example, an element of terrain will be initially compressed when a track shoe first encounters it. Then, as the vehicle moves, wheel passage, track slippage and vehicle dynamics causes the track-soil forces to vary. Due to the elasto-plastic nature of the soil there will be a certain amount of permanent plastic deformation as well as elastic deformation which will be recovered when an element of soil is unloaded. If this soil element will experience reloading, equation (3) should be modified (6).

$$z = \frac{p - p_u}{k_u} + z_u \text{ , } p \in \{0, p_u\} \qquad (6)$$

As the pressure is reapplied, up to the pressure p_u the terrain will behave as a pure elastic material with a modulus k_u, that is significantly higher than the elastic modulus of equation (3) that describes the first loading cycle. p_u is the pressure level reached by the previous loading cycle. So the terrain will behave as a “perfect” elastic material up to the maximum pressure reached in the previous cycle. So the first track wheel will sink deeply, then the terrain will rebound of the elastic amount which is very little. When the following wheel passes, the terrain will be elastic and will sink a little amount. The presence of the track as an iron road will reduce the amount of the sinkage. This effect is positive since the wheel will compact the terrain under the track. The velocity of the tank reduces the sinkage, since the terrain tends to stiffen with the increase of load velocity.

Turning

The track slides back and forth for a turning tracked vehicle. This track slide will produce lateral soil displacement. Equation (3) can then be applied to determine the resulting lateral forces. The Von Mises failure criteria should be used for the lateral and longitudinal shear stresses. In addition, during a turn, the outside track slips and the inside track is being dragged forward. Soft soil piling during turning changes the vertical profile of the terrain. The sinkage results in a bulldozing effect that pushes the soil to form outside piles on the sides of the track. The forces resisting bulldozing are the weight of the soil and the shear forces along the failure surface. To simplify calculations, the failure surface is assumed to be a straight plane between the bottom of the track and the soil. The friction between the soil and the track interface is assumed negligible. The angle between this failure plane and the ground is then π/4-φ .

$$F_b = (\rho \frac{1}{2} z^2 \tan^2(\frac{\pi}{4} + \frac{\varphi}{2}) + 2\,c\,z\sqrt{\tan^2(\frac{\pi}{4} + \frac{\varphi}{2})} \qquad (7)$$

As it can be seen from equation (7), the bulldozing force goes with the sinkage squared. This means that high sinkage reduce mobility and increase power required in a very significant way, since the tracked vehicle is always turning even on a straight path. The first rule to increase power in a tracked vehicle it is not to increase the engine power, since it increases the weight of the vehicle and the sinkage, but to reduce the sinkage. Energy loss goes with the cube of the sinkage or the cube of the mass on a given track system. So the classical equations should be corrected to consider the fact that a "straight path" for a tracked vehicle is purely theoretical.

CONCLUSION: Improvement of the vehicle performances

As it was shown in the previous paragraphs, the sinkage of the tracked vehicle influences its ability to negotiate off-road path in a very important way. In fact, power requirement goes with the cubic power of sinkage. So the usual strategy to increase power is not the more convenient way to improve vehicle off road performance. The pressure is the critical parameter. Specific pressures above 0.9 daN/cm^2 should be avoided at all costs. The best way to achieve lower ground pressure is to increase track length. However, it may be simpler to modify track width. The easiest modification is to add "Duckbill extensions" in the outer part of the shoe. This system was used on the Sherman Tank when additional armor was added. With modern technology, it is perfectly possible to perform experimental tests with new shoes. This can be done by manufacturing prototypes of high stress nitrided steel shoes, usually with nitrided 300M high strength steel. Comparative fuel consumption is a good index of vehicle performance. The traditional approach of keeping the "already optimized" track system should be revised. In addition, wheel diameter and width can be increased to improve performance. Specialized tracks for different terrains should also be designed. Another important improvement is the addition of computer controlled directional control to improve the accuracy of trajectories. This is particularly important for tracked vehicles where turning involves extremely high energy consumption. Tracked vehicle always turn even in straight path. The gravity center should be kept slightly rearward. This attitude should not be excessive to keep the pressure value more even possible along the track. In any case, the vehicle naturally assumes the backward inclination due to terrain compression.

REFERENCES

[1] M.G. Bekker, Introduction to Terrain-Vehicle Systems. 1969, Ann Arbor, MI: University of Michigan Press.

[2] J.Y. Wong, Terramechanics and Off-Road Vehicles. 1989, Amsterdam: Elsevier Science.

[3] L. Piancastelli, L. Frizziero, S. Marcoppido, E. Pezzuti. 2012. Methodology to evaluate aircraft piston engine durability. edizioni ETS. International Journal of Heat & Technology. ISSN 0392-8764, 30(1): 89-92, Bologna.

[4] L. Piancastelli, L. Frizziero, G. Donnici. 2015. The Meredith ramjet: An efficient way to recover the heat wasted in piston engine cooling. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(12): 5327-5333, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[5] L. Piancastelli, A. Gatti, L. Frizziero, L. Ragazzi, M. Cremonini. 2015. CFD analysis of the Zimmerman's V173 stol aircraft. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(18): 8063-8070, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[6] L. Piancastelli, L. Frizziero. 2014. Turbocharging and turbocompounding optimization in automotive racing. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(11): 2192-2199, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA

[7] L. Piancastelli, L. Frizziero, G. Donnici. 2014. The common-rail fuel injection technique in turbocharged di-diesel-engines for aircraft applications. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(12): 2493-2499, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[8] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Turbomatching of small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 172-178, 2015, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[9] L. Piancastelli, L. Frizziero. 2015. Supercharging systems in small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1) 20-26, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA

[10] P.P.Valentini, E. Pezzuti E. Computer-aided tolerance allocation of compliant ortho-planar spring mechanism. Int. Jou. Of computer applications in technology, 53: 369-374, ISSN: 0952-8091, doi: 10.1504/IJCAT.2016.076801

[11] E. Pezzuti, PP. Valentini PP.Accuracy in fingertip tracking using Leap Motion Controller for interactive virtual applications. Int. Jour. On interactive design and manufacturing, p. 1-10, ISSN: 1955-2513, doi: 10.1007/s12008-016-0339-y

[12] E.Pezzuti E, PP. Valentini P. Design and interactive simulation of cross-axis compliant pivot using dynamic spline. Int. Jour. On interactive design and manufacturing, 7: 261-269, ISSN: 1955-2513, doi: 10.1007/s12008-012-0180-x

[13] L. Piancastelli, S. Cassani. 2017. Maximum peak pressure evaluation of an automotive common rail diesel piston engine head. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(1): 212-218, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[14] S. Cassani. 2017. Airplane design: the superiority of fsw aluminum-alloy pure monocoque over cfrp “black” constructions. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 377-361, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[15] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviation part 2: general design, optimum bearing selection for propeller driven aircrafts with piston engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 544-550, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[16] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviation part 5: housing/casing optimized design for propeller-driven aircrafts and helicopters. Asian research publishing network (arpn). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 602-608, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[17] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviation part 3: simplified gear design piston-powered, propeller-driven general aviation aircrafts. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(3): 870-874, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[18] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviation part 4: simplified gear design for piston-powered, propeller-driven heavy duty aircrafts and helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(5): 1533-1539, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[19] L. Piancastelli, S. Migliano, S. Cassani. 2017. AN extremely compact, high torque continuously variable power transmission for large hybrid terrain vehicles. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(6): 1796-1800, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[20] L. Piancastelli, S. Cassani. 2017. Mapping optimization for partial loads of common rail diesel piston engines. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2223-2229, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[21] L. Piancastelli, S. Cassani. 2017. High altitude operations with piston engines power plant design optimization part v: nozzle design and ramjet general considerations. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2242-2247, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[22] L. Piancastelli, R. V. Clarke, S. Cassani. 2017. Diffuser augmented run the river and tidal picohydropower generation system. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(8): 2678-2688, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[23] L. Piancastelli, M. Gardella, S. Cassani. 2017. Cooling system optimization for light diesel helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(9): 2803-2808, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[24] L. Piancastelli, S. Cassani. 2017. Study and optimization of a contra-rotating propeller hub for convertiplanes. Part 1: vto and hovering. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(11): 3451-3457, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[25] L. Piancastelli, S. Cassani. 2017. On the conversion of automotive engines for general aviation. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(13): 4196-4203, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[26] L. Piancastelli, S. Cassani. 2017. Convertiplane cruise performance with contra-rotating propeller. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(19): 5554-5559, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[27] L. Piancastelli, S. Cassani. 2017. Tribological problem solving in medium heavy duty marine diesel engine part 1: journal bearings. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(22): 6533-6541, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[28] A. Ceruti, T. Bombardi, T. and L. Piancastell. 2016 Visual Flight Rules Pilots Into Instrumental Meteorological Conditions: a Proposal for a Mobile Application to Increase In-flight Survivability. International Review of Aerospace Engineering (IREASE). 9(5).