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POTENTIAL FOR IMPROVEMENT OF COMFORT PARAMETERS IN OFF-ROAD VEHICLES OF SERBIAN ARMED FORCES

Aleksandar Mićović, Vladimir Popović, Aleksandar Sedmak

Original scientific paper
The paper presents the comparative results of comfort parameter testing inside the cabin of Land Rover Defender off-road vehicles. The measurements were carried out on two vehicle models – 110 GS Hard Top and 110 GS Soft Top Heavy Duty. Tests on comfort parameters were performed only on the military off-road vehicles, or to be more precise on the military off-road vehicles used by the Serbian Armed Forces. The results of the performed tests offer some suggestions for the improvement of comfort of military off-road vehicles used by the Serbian Armed Forces.The comfort elements have been compared from the aspect of accommodation of the crew, noise, vibrations and heating efficiency. A part of the experiment was performed by intensive driving of these off-road vehicles in real world conditions, on three pre-selected types of terrain surface, in order to ensure the repeatability of the testing results: heath, gravel and asphalt base (a portion of the Belgrade – Zagreb highway at the territory near Šid was used due to its less frequent traffic and surface quality). Noise and vibration measurements were carried out at the driver's seat, co-driver's seat and other passenger seats under strictly defined vehicle speeds. Testing of the heating efficiency inside the cabin was carried out under laboratory conditions in the cold chamber of the artillery range at Nikinci at a constant ambient temperature of –16 °C.

Keywords: *comfort parameters, military off-road vehicles, noise, vibrations*

Mogućnost unapređenja parametara udobnosti kod terenskih vozila Vojske Srbije

Izvorni znanstveni članak
U radu su prikazani usporedni rezultati ispitivanja parametara udobnosti u kabini terenskog automobila Land Rover Defender. Mjerenja su provedena na dvije varijante vozila 110 GS Hard Top i 110 GS Soft Top – heavy duty. Testiranja parametara udobnosti obavljena su samo na vojnim terenskim vozilima, ili još preciznije, na terenskim vozilima koja su u uporabi u Vojsci Srbije. Rezultati obavljenih testiranja nude neke prijedloge za poboljšanje udobnosti vojnih terenskih vozila koja se koriste u Vojsci Srbije. Uspoređeni su elementi udobnosti s aspekta smještaja posade, buke, vibracija i efikasnosti grijanja. Dio eksperimenta je obavljen u realnim eksploatacijskim uvjetima, prilikom intenzivne vožnje terenskih vozila na tri odabrane opitne staze, kako bi se osigurala ponovljivost rezultata ispitivanja: ispresijecana ledina (Deliblatska peščara), ravničarski makadam (Fruška gora) i asfaltna podloga (dionica autoputa Beograd – Zagreb pored Šida zbog manje frekvencije saobraćaja i kvalitetne podloge). Mjerenja buke i vibracija su obavljena na mjestima vozača, suvozača i članova posade pri strogo definiranim brzinama gibanja vozila. Ispitivanje efikasnosti grijanja u kabini obavljeno je u laboratorijskim uvjetima u hladnoj komori poligona Nikinci pri konstantnoj temperaturi okoline od –16 °C.

Ključne riječi: *buka, parametri udobnosti, vibracije, vojna terenska vozila*

1 Introduction

The definition of military vehicles in this case refers primarily to special-purpose engine-driven vehicles. As they are used not only in war-time but also in peace time, it is necessary to ensure certain standards are applied in order to protect the health of their occupants. Due to the fact that military vehicles can have lengthy service lives (more than 50 years), this creates additional special problems in that they have not followed the standards which have been applied within the automobile industry during the last decade [1, 8, 14].

Figure 1 Defender 110 GS Hard Top and Defender 110 GS Soft Top

There are several models of off-road vehicles used by the Serbian Armed Forces, but for this research the testing of the sample Land Rover Defender 110 GS off-road vehicle was carried out in the Technical Test Center Belgrade. This vehicle is equipped with an up-to-date four-cylinder turbocharged-diesel engine with intercooler.

The engine is manufactured by Ford and the engine belongs to the DuraTorq-DI generation. It is equipped with two cam shafts and four valves per cylinder. The cam shaft is driven via chain, which drives the high pressure pump as well. Fuel is injected through the Common Rail system. Maximum vehicle length (without/with bumpers) is 4439/4578 mm, while the maximum width (including mirrors) (SAE W104) is 1992 mm. The weight of empty vehicle with full tank is 1888 kg. The allowed total weight of the loaded vehicle (GVW) is 3500 kg [2].

2 Crew accommodation

Both versions of the vehicle can comfortably accommodate 6, and if required, even 7 (Hard Top), or 8 people (Soft Top) with combat equipment and weapons. The Defender can transport up to 1,5 t of cargo (Soft Top) which is 500 kg more than other vehicles in the same category such as PUCH 300 GD and Pinzgauer 710M.

The driver with combat equipment has difficulty getting in and out of the vehicle. The space for engine starting is rather limited.

The analysis shows that the cause of the problems is due to the adaptation of the vehicle from the original English specification, i.e. relocation of the steering wheel from the right hand side to the left hand side of the vehicle. The starter switch in the standard manufactured vehicle is in the middle of the instrument panel, so engine starting is very comfortable. During the adaptation it is moved very close to the driver's door. It was proven whilst testing that individuals who were over 185 cm tall had a particular problem in that they did not have enough space for left hand manipulation of the starter switch. Also, when soldiers with equipment were seated in the co-driver's position, the entire accommodation space was taken up (all testees who were tall reported their knees hitting the control board and a subjective cramped feeling in the leg area).

Figure 2 Soft Top – Accommodation of 6 and 4 crew members

Figure 3 Driver getting in the vehicle and the arm position while starting

Figure 4 Vehicle cabin and Co driver's accommodation

3 Internal noise

Very often sound action can disturb and endanger a man as well as his health. In such cases sound is treated as noise. The level of disturbance caused by the sound depends on the characteristics of the sound signal, as well as on the attitude of the recipient to it (subjective dimension). Besides the negative effects of disturbance and endangering, depending on the intensity, the noise can also have harmful consequences on the hearing organ (human ear) perception [3]. The subjective feeling of the sound volume, in addition to the actual value depends also on frequency, since the human ear tolerates higher levels on lower frequencies than lower levels on high frequencies. The noise which originates in the motor vehicle cabin is complex and originates from a number of sources [12, 13].

In addition to the undesired effect on concentration and fatigue of the driver, when testing noise inside military vehicles, as opposed to commercial vehicles, special attention should be paid to its influence on communication disturbance between crew members, as well as their perception and speed of reaction to external factors. Considering that the main purpose of the vehicle is off-road transport, comfort testing inside the vehicle for the noise level has been carried out by driving on gravel paths, in addition to driving on an asphalt base according to ISO 5128 standard, and also on heath land, which represent the expanded scope of testing in accordance with the Directive on noise exposure 2003/10/ES. Special attention was paid to measurements in off-road use (due to the purpose of the vehicle and the greatest frequency of use in these conditions), at constant speeds which corresponded to previously determined average modes of vehicle speed on these types of surface (30 ÷ 40 km/h).

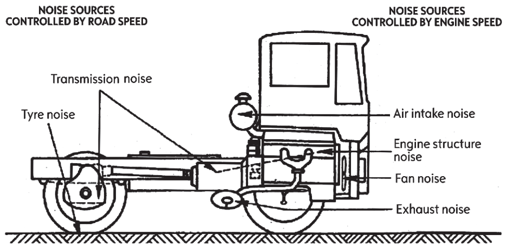


Figure 5 Possible noise sources on a vehicle

The first part of testing referred to the measurement of maximum vehicle speed in order to determine the speed mode of the vehicle at which internal noise is measured in the second stage (stable speed mode and full acceleration mode). Measurement was performed by Corrsys-Datron device for non-contact measurement of dynamic characteristics of the vehicle which is equipped with Correvit L-350 Aqua optical one axis sensor.

Measurements were performed on the runway at Kovin airfield and a part of the Beograd-Šid highway [4] [15]. The maximum measured speeds in individual gears corresponded to the declared speeds by the manufacturer and they are presented in Tab. 1.

Table 1 Maximum speeds in individual gears

Gear	Max. speed (with reduction on) km/h (mph)	Max. speed (with reduction off) km/h (mph)
1	10,64 (6,61)	28,73 (17,85)
2	20,4 (12,68)	55,06 (34,22)
3	33,65 (20,91)	90,84 (56,45)
4	47,35 (29,42)	127,83 (79,43)
5	57,92 (35,99)	132 (82)
6	77,96 (48,43)	132 (82)

In order to define engine working mode at the full acceleration test, the measured speed values of the vehicle have been compared with the engine values declared by the manufacturer [2]:

- Engine speed at max power - 3500 rpm
- maximum power output (EEC) - 90 kW
- Engine speed at max torque - 2000 rpm
- maximum torque (EEC) - 360 N·m
- Pass by Noise (EC Type approval) - 73 dB.

It can be concluded from the aforesaid that the stable speed in 5th gear at 1575 rpm (45 % of the number of rotations at which the engine develops its maximum power) is 55 km/h. The speed of the vehicle at 3150 rpm (90 % of the number of rotations at which the engine develops its maximum strength) in 5th gear is 115 km/h.

The measurements were carried out with the vibroacoustic measuring system NetdB12 (01dB Metravib) and with three microphones fitted to adapters level with the driver's and passengers' heads. "Fast" time dynamic characteristic and "A" frequency weighting of sound pressure were chosen. During all measurements the weather conditions were satisfactory (humidity, temperature and wind), as well as ambient noise (considerably lower than 10 dB when compared to the cabin), so that subsequent corrections of the results were not necessary. A driver, co-driver and one passenger were present in the vehicle during the measurement.

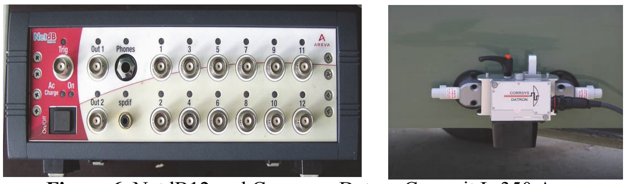


Figure 6 NetdB12 and Corrsys – Datron Correvit L-350 Aqua

Simultaneous noise measurements at the driver's and passengers' seats were carried out during the drive on asphalt, with the windows closed, in two phases:

- At stable speeds ranging from 55 km/h (40 % maximum speed) to 115 km/h (80 % maximum speed) in 5th gear;
- During acceleration from 55 km/h to 105 km/h until the number of rotations reaches 3150, which was also performed in 5th gear.

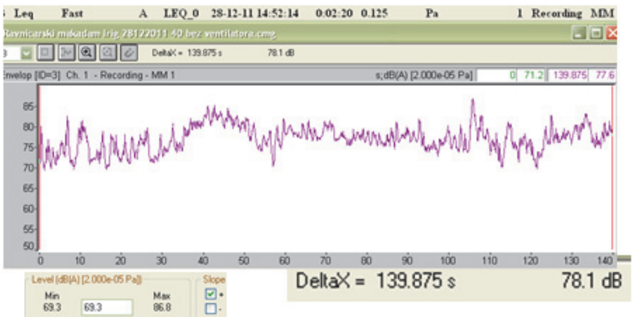


Figure 7 Noise measured at the driver's seat at stable speed of 40 km/h on gravel

Table 2 The results of noise measured at stable speeds and during acceleration on asphalt and gravel

Stable speeds on asphalt in V gear: km/h – rpm	Measuring point	L_A(dB)	
		Soft Top	Hard Top
55/ 1500	Driver	69.9	67.7
	Crew	71.5	66.9 – 68
65/ 1750	Driver	72.3	73
	Crew	74.4	70.8 – 74.8
75/ 2050	Driver	74.4	71.0
	Crew	77.1	70.8 – 73.3
85/ 2350	Driver	77.2	72.1
	Crew	80.3	71.3 – 74
95/ 2550	Driver	79.1	74.2
	Crew	81.8	73.6 – 76.4
105/ 2900	Driver	82.7	75.8
	Crew	84.6	75.3 – 77.7
Stable speed of 40 km/h on Heathland	Driver	73.2	73.3
	Crew	73.5	72.6 – 72.8
Stable speed of 40 km/h on Gravel	Driver	78.1	78.4
	Crew	78.6	79.7 - 80.6
Acceleration 55÷ 115 km/h, i.e. until 3150 rpm, V gear on asphalt	Driver	82	74.7
	Crew on the left	83.7	77.6
	Crew on the right	84.2	75.1

Measurements were repeated several times on all surfaces, but since there were many results, the following Fig. 12 and Tab. 2 show only some equivalent levels of noise in dB(A), with the description of minimum, maximum and observed periods.

As for the Hard Top vehicle, noise was simultaneously measured at three points: driver's seat, II row of seats diagonally across from the driver, III row (additional seats) in line with the driver. As for the Soft Top vehicle, measurements were carried out next to the driver's seat and on the benches in the load area at both the left and right sides.

Considering the minimum differences in values of the results obtained measured at the load area, the Table shows the values at the seat diagonally across from the driver.

The analysis of all measured noise levels shows that the Hard Top vehicle is far more comfortable regarding the internal noise when driving on asphalt. It is obvious that the noise is more prominent on passenger seats in the Soft Top vehicle. The difference in the level of measured noise goes as high as 7 dB (A) at the driver's seat with a stable speed of 105 km/h. The dominant cause of this noise is the flickering of the canopy, i.e. the worst acoustic insulation of this model of the vehicle. The difference regarding the acoustic comfort is also influenced by the use of the more robust GOOD YEAR Wrangler 235/85R16 M+S off-road condition tyres, fitted to this model of the vehicle. However, when the vehicle is driven in off-road conditions (heath, gravel) there are hardly any differences regarding the internal noise.

4 Testing comfort during driving from the aspect of exposure of the driver and other passengers to vibrations

The phenomenon of the influence of vibrations on the human fatigue and their transfer through the human body is a very important factor which is taken into consideration when designing motor vehicles [18] [19]. Environmental vibrations are classified into two groups as follows:

- vibrations transferred over the seat or floor to the entire body, and
- local vibrations, which have impact on hands during driving or using other devices in the vehicle.

Harmful influences of vibrations of the entire body are described by:

- decreased comfort,
- obstructed perception and activity, and
- influence on health [5].

Table 3 Symptoms of exposure to vibrations which are dominant at frequencies ranging from 1 Hz to 20 Hz

Symptoms	*f* / Hz
Feeling of discomfort	4 ÷ 9
Head disturbance	13 ÷ 20
Trembling of the lower jaw	6 ÷ 8
Influence on speech	13 ÷ 20
"A lump in the throat"	12 ÷ 16
Chest pains	5 ÷ 7
Abdominal pains	4 ÷ 10
Urination urge	10 ÷ 18
Increased muscle tone	13 ÷ 20
Respiration obstacles	4 ÷ 8
Muscle contractions	4 ÷ 9

Decreased comfort. The vibrations of the entire body are just one of a series of factors influencing the feeling of comfort. The testing results for harmonic vibrations are represented in the form of comfort limit curves. These curves offer effective values of acceleration dependent on the frequency of vibrations for certain direction of vibrations and the period of exposure as parameters. The area of decreased comfort is above the limit curves. As an example here we have taken ISO 2631 standard, Fig. 8, for the evaluation of comfort of the entire body in transport vehicles. It can be seen that the feeling of discomfort increases when the period of vibration duration decreases, and it decreases when frequencies rise above 10 Hz. Accidental vibrations and vibrations from various directions increase the feeling of discomfort.

Disturbed perception. The vibrations of the entire body influence both the comfort and the perception, primarily the vision. At frequencies above (2 ÷ 3) Hz monitoring becomes more difficult and the image on the retina is blurred. If both the eye and the observed object vibrate simultaneously, the movement of the image on the retina is the greatest so the visibility is considerably decreased.

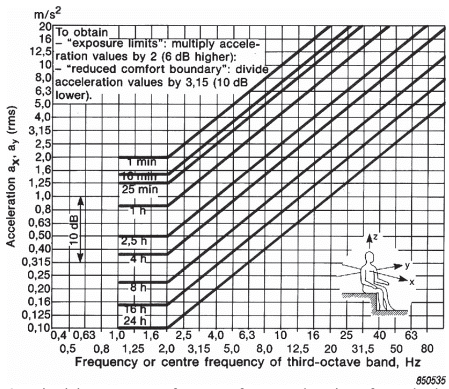


Figure 8 Limiting curves for comfort evaluation for whole body vibration in transport vehicles

Influence on health. The exposure to long-lasting and "strong" vibrations can result in injury or deterioration of health. The influence on the human body depends on effective value, frequency, direction and duration of the vibrations. The most dangerous vibrations are within the range from 45 to 100 Hz with the amplitudes above 100 µm. The vibrations can have negative psychological and physiological influence, similar to noise. The low frequency vibrations can cause the so-called motion sickness, which is followed by vertigo, nausea and vomiting.

In order to determine quantitative oscillatory load of the driver and the crew in the vehicle, in addition to the stated guidelines, the selection of adequate seats is also very important. The vibrations on the vehicle seat are transferred during driving (forced oscillations) to the entire body of the passengers in three axes. Measuring acceleration per axes with other relevant parameters and the evaluation of the results has been done according to ISO 2631 standard (comfort) and the European Directive EC/44/02 (criteria of harmful effects on health). ISO 2631 standard enables the evaluation from three various aspects: human health protection, preservation of abilities (limit of fatigue) and preservation of the comfort [9, 10].

The analysis is carried out within the frequency range from 0,5 Hz ÷ 80 Hz. However, the risk of exposure is not the same at all frequencies, so frequency weighting is used on order to present the risk as objectively as possible. The result is the drop of weighted acceleration in relation to the rise in frequency. For the vibrations of the entire body two various frequency weightings are used. The first weighting (Wd) is for two lateral axes, x and y, and the other one (Wk) is for vertical z axis of vibrations. From the aspect of human health protection, for x and y lateral axes the value of measured acceleration is multiplied with a factor of 1,4 (it is considered that the vibrations in these directions are 40 % more dangerous for spine than those in longitudinal direction), while for vertical z axis the factor of weighting is 1,0. From the aspect of preservation of comfort, the weighting factor for the seating position is 1,0.

The Directive on vibrations allows for the evaluation of the level of vibrations using two methods:

- determining the level of daily exposure A(8) – equivalent continuous acceleration calculated for 8-hour work time. Value A(8) is based on root-mean-square averaging of the acceleration signal (m/s^2);
- value of vibration dose (VDV), which represents a cumulative dose and it is obtained as the fourth root of effective value (root-mean-quad) of the acceleration signal ($m/s^{1,75}$).

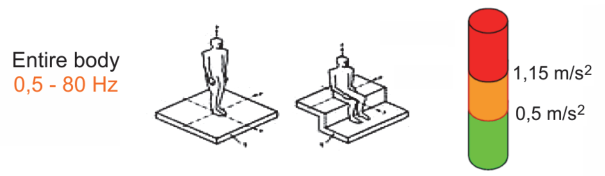


Figure 9 Limit values of daily exposure A(8)

The value of daily exposure A(8) as the end value of measurement is compared with the limit values which are set by the European Directive "Vibrations" (2002/44/EC): action threshold at which it should take action A(8) = 0,5 m/s^2, and maximum threshold A(8) = 1,15 m/s^2. The measuring of vibrations in three axes was performed by the use of a three-axis accelerometer fitted into the seat adapter as an integral part of the set of specific-purpose measuring instrument Maestro 01dB produced by Metravib, which was manufactured according to ISO 8041 standard requirements.

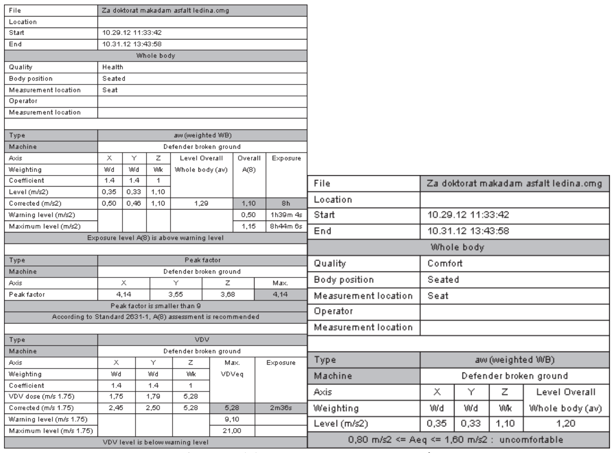
Figure 10 Seat vibration measuring device

Considering the purpose of the vehicle, the scope of testing was expanded for exploitation in off-road conditions [6, 7, 17]. Testing vehicles for oscillatory comfort was performed as follows:

- When testing was performed on heath or gravel, the measurements were made at speeds of 30 and 40 km/h respectively.
- On asphalt the measurements were made using an unloaded vehicle with the driver, co-driver and passenger (3 persons) present, at speeds of 60 and 80 km/h respectively.

In all cases measurements were performed at the following measuring points: driver (co driver) – D, on the left and right bench in the vehicle load area, i.e. on the second row of seats diagonally across from the driver – P, as well as on additional seats in the third row in the case of the Hard Top vehicle – E. The testing results are given in abridged test reports from the aspect of comfort and daily exposure to vibrations (in relation to alarm threshold of 0,5 m/s^2 and danger to health threshold of 1,5 m/s^2).

As the results for the driver and co-driver seats differ slightly, only the driver's results have been presented. Due to the comprehensiveness of the results we have presented only the test report from the gravel surface testing, at the vehicle speed of 30 km/h, on the driver's seat.



File	Za doktorat makadam asfalt ledina.cmg					
Location						
Start	10.29.12 11:33:42					
End	10.31.12 13:43:58					
Whole body						
Quality	Health					
Body position	Seated					
Measurement location	Seat					
Operator						
Measurement location						
Type	aw (weighted WB)					
Machine	Defender broken ground					
Axis	X	Y	Z	Level Overall	Overall	Exposure
Weighting	Wd	Wd	Wk	Whole body (av)	A(8)	
Coefficient	1.4	1.4	1			
Level (m/s2)	0,35	0,33	1,10			
Corrected (m/s2)	0,50	0,46	1,10	1,29	1,10	8h
Warning level (m/s2)					0,50	1h39m 4s
Maximum level (m/s2)					1,15	8h44m 6s
Exposure level A(8) is above warning level						

Type	Peak factor			
Machine	Defender broken ground			
Axis	X	Y	Z	Max.
Peak factor	4,14	3,55	3,68	4,14
Peak factor is smaller than 9				
According to Standard 2631-1, A(8) assessment is recommended				

Type	VDV				
Machine	Defender broken ground				
Axis	X	Y	Z	Max.	Exposure
Weighting	Wd	Wd	Wk	VDVeq	
Coefficient	1.4	1.4	1		
VDV dose (m/s 1.75)	1,75	1,79	5,28		
Corrected (m/s 1.75)	2,45	2,50	5,28	5,28	2m36s
Warning level (m/s 1.75)				9,10	
Maximum level (m/s 1.75)				21,00	
VDV level is below warning level					

File	Za doktorat makadam asfalt ledina.cmg			
Location				
Start	10.29.12 11:33:42			
End	10.31.12 13:43:58			
Whole body				
Quality	Comfort			
Body position	Seated			
Measurement location	Seat			
Operator				
Measurement location				
Type	aw (weighted WB)			
Machine	Defender broken ground			
Axis	X	Y	Z	Level Overall
Weighting	Wd	Wd	Wk	Whole body (av)
Level (m/s2)	0,35	0,33	1,10	1,20
0,80 m/s2 <= Aeq <= 1,60 m/s2 : uncomfortable				

Figure 11 Test report example

Table 4 The results of vibrations measured on Land Rover Defender Hard Top vehicle

Type or surface	speed km/h		Health aw (weighted WB) x Wd	Health y Wd	Health z Wk	L_{Wb} (av)*	overall A8	Max Peak factor	Vibration dose value VDV x Wd	VDV y Wd	VDV z Wk	max VDV eq	Comfort aw (weighted WB) x Wd	Comfort y Wd	Comfort z Wk	L_{Wb} (av)*	
gravel	30	D	0.35 0.50	0.33 0.46	1.10 1.10	**1.29**	**1.10**	**4.14**	1.75 2.45	1.79 2.50	5.28 5.28	**5.28**	0.35	0.33	1.10	**1.20**	**U**
		P	0.30 0.42	0.33 0.46	1.69 1.69	**1.80**	**1.69**	**3.82**	1.48 2.07	1.65 2.31	7.95 7.95	**7.95**	0.30	0.33	1.69	**1.75**	**VU**
		E	0.43 0.60	0.41 0.58	1.27 1.27	**1.52**	**1.27**	**3.95**	2.11 2.95	2.24 3.14	6.22 6.22	**6.22**	0.43	0.41	1.27	**1.40**	**VU**
	40	D	0.39 0.55	0.29 0.41	1.11 1.11	**1.31**	**1.11**	**4.00**	1.77 2.48	1.28 1.79	4.90 4.90	**4.90**	0.39	0.29	1.11	**1.22**	**U**
		P	0.33 0.46	0.38 0.53	1.88 1.88	**2.01**	**1.88**	**4.48**	1.50 2.10	1.80 2.53	8.35 8.35	**8.35**	0.33	0.38	1.88	**1.95**	**VU**
		E	0.60 0.84	0.37 0.52	1.20 1.20	**1.56**	**1.20**	**3.79**	2.92 4.08	1.67 2.33	6.09 6.09	**6.09**	0.60	0.37	1.20	**1.39**	**VU**
heath	30	D	0.32 0.44	0.49 0.69	0.96 0.96	**1.26**	**0.96**	**3.72**	1.69 2.36	2.51 3.51	4.76 4.76	**4.76**	0.32	0.49	0.96	**1.11**	**U**
		P	0.60 0.83	0.50 0.70	1.04 1.04	**1.51**	**1.04**	**3.82**	3.22 4.51	2.48 3.47	5.15 5.15	**5.15**	0.60	0.50	1.04	**1.30**	**VU**
		E	0.75 1.05	0.58 0.82	1.36 1.36	**1.90**	**1.36**	**3.61**	4.16 5.82	2.98 4.17	6.76 6.76	**6.76**	0.75	0.88	1.36	**1.66**	**VU**
	40	D	0.39 0.54	0.63 0.88	1.06 1.06	**1.48**	**1.06**	**3.68**	2.04 2.85	2.92 4.09	4.92 4.92	**4.92**	0.39	0.63	1.06	**1.29**	**VU**
		P	0.82 1.15	0.69 0.97	1.19 1.19	**1.92**	**1.19**	**3.79**	4.15 5.80	3.22 4.51	5.86 5.86	**5.86**	0.82	0.69	1.19	**1.61**	**VU**
		E	1.15 1.61	0.89 1.25	1.52 1.52	**2.54**	**1.61**	**3.89**	6.00 8.40	4.13 5.78	7.46 7.46	**8.40**	1.15	0.89	1.52	**2.10**	**EU**
asphalt	60	D	0.06 0.08	0.08 0.11	0.20 0.20	**0.24**	**0.20**	**3.60**	0.19 0.26	0.28 0.40	0.83 0.83	**0.83**	0.06	0.08	0.20	**0.22**	**C**
		P	0.08 0.11	0.07 0.10	0.22 0.22	**0.27**	**0.22**	**3.53**	0.29 0.40	0.23 0.32	0.87 0.87	**0.87**	0.08	0.07	0.22	**0.25**	**C**
		E	0.25 0.35	0.14 0.13	0.38 0.38	**0.55**	**0.38**	**3.64**	0.83 1.16	0.50 0.70	1.38 1.38	**1.38**	0.25	0.14	0.38	**0.48**	**slightly U**
	80	D	0.08 0.11	0.12 0.17	0.23 0.23	**0.30**	**0.23**	**4.12**	0.29 0.40	0.47 0.66	0.87 0.87	**0.87**	0.08	0.12	0.23	**0.27**	**C**
		P	0.07 0.10	0.09 0.13	0.27 0.27	**0.31**	**0.27**	**5.00**	0.24 0.33	0.30 0.41	1.02 1.02	**1.02**	0.07	0.09	0.27	**0.29**	**C**
		E	0.22 0.31	0.18 0.25	0.36 0.36	**0.54**	**0.36**	**3.46**	0.83 1.16	0.75 1.06	1.33 1.33	**1.33**	0.22	0.18	0.36	**0.46**	**slightly U**

* Level overall Whole body

Table 5 Comparison of the comfort results from the aspect of oscillatory comfort

Parameter	Land Rover	Measuring point	Type of surface: heathland v=40 *km/h*		gravel v=40 *km/h*		asphalt v=80 *km/h*	
a_v (m/s^2)	Soft Top	Driver	**1.65**	**VU**	**1.27**	**VU**	**0.45**	**slightly U**
		Passengers	**2.05**	**EU**	**2.46**	**EU**	**0.97**	**U**
	Hard Top	Driver	**1.29**	**VU**	**1.22**	**U**	**0.27**	**C**
		Passengers	**1.61**	**VU**	**1.95**	**VU**	**0.29**	**C**

The measuring results for all three surfaces are given in Tab. 5. More detailed tests have been performed on the Hard Top model of the vehicle which is equipped with the seats for each crew member and which has been in use with the Serbian Military (Tab. 3). According to the criteria for comfort, the vehicle can be assessed as (EU – extreme uncomfortable, VU – very uncomfortable, U – uncomfortable, C – comfortable).

Based on the criteria for oscillatory comfort, the drive for both types of vehicles when measured at either the driver's, co-driver's seat and other passengers belongs to the very uncomfortable drive categorization, when performed on heathland and gravel surfaces. The results obtained during the drive on asphalt show that for the Defender 110 Hard Top the drive for the driver and co driver is comfortable, whilst it is still uncomfortable at the other passengers' seats. More unfavourable results are for the passengers, particularly on the left side of the load area where the greatest discomfort appears. Taking into account the criteria for harm to health, the results obtained suggest that driving in off-road vehicles should be limited according to the speed and type of surface in peace time exploitation.

5 Heating system efficiency

A very important parameter of vehicle comfort is the efficiency of the heating of its useful/working space. As a part of these tests the efficiency of the heating system of the Land Rover Land Rover Defender 110 GS-Soft Top (passenger + load area) and Land Rover Defender 110 GS-Hard Top (driver + passenger + load area) off-road vehicles has been made. The tests were performed according to the conditions, methods and criteria defined by the standards of defence of the Republic of Serbia COPC 0114/87 (The characteristics of comfort of military vehicles) and COPC 8419/02 (Testing heat comfort of working space of military vehicles). These standards are in harmony with ISO 7730 – Moderate thermal environments-Determination of the PMV and PPD indices and specification of the conditions for thermal comfort [12]. The tests have been performed under laboratory conditions, in a climatic chamber at the environmental temperature of −16 °C, as required by the stated military standard.

Figure 12 Thermal comfort meter 1212 B&K and Digital thermometer Omega 199

On the Soft Top vehicle (vehicle with detachable canopy roof), three temperature sensors (thermal pairs type K) were fitted in the driver's space at the co-driver's seat. These were positioned at the co-drivers head, knee and foot height levels. In addition to these sensors, an integrated sensor MM0023, connected to the instrument COMFORT METER TYPE 1212 Brűel & Kjaer, Fig. 12 was fitted in the space between the driver's and co-driver's seat. In the load area of the vehicle there were seven temperature sensors (thermal pairs type K) fitted. Four sensors were fitted at the head height of the four crew members who were sitting on additional seats in each corner of the load area, and three sensors were fitted at foot height level of the same three crew members. All temperature sensors were connected to a multichannel digital thermometer Omega 199. The sensor layout as fitted to the Soft Top vehicle is schematically presented in Fig. 13.

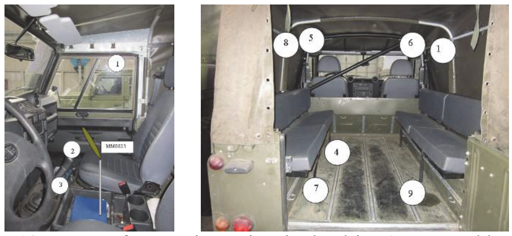


Figure 13 Layout of measuring points in the driver's area and layout of measuring points in load area

In order to be able to compare the results, the Hard Top vehicle was also equipped with 16 temperature sensors according to a similar layout. 12 sensors were fitted on the seats in the driver's and co-driver's space, three were fitted in the middle of the load area, while 1 was set on the hot air outlet grill. The Hard Top vehicle is shown in the cold chamber in Fig. 14.

Before the measurements began, the gas tanks from both vehicles were removed and thoroughly cleaned, engine oil was replaced, as well as all filters. The fuel used is a special mixture of 30 % motor petroleum and 70 % Euro diesel. The heating systems on both vehicles were set to circulate internal air in the cabin, maximum hot air fan speed, simultaneously towards the floor and the driver's glass. The ventilation outlets grills on the control panel were fully open. Engine work was set to 2000 rpm in idle gear. The measurement results are shown in Tabs. 6 and 7. Tab. 6 shows the results related to the Soft Top vehicle, and Tab. 7 for the Hard Top vehicle. Vertical positions of measuring points are: V – fan, G – head, K – knee, S – feet.

During the 90 minute test on the Soft Top vehicle, the condition of comfortability at 16 °C on all seats in the vehicle was not achieved. The lowest temperature of 2 °C was measured at the feet of crew members in the load area of the vehicle. The maximum allowable temperature distribution of 10 °C was not achieved. According to SORS 8419 standard criteria, the parameters of thermal comfort have not been fulfilled, since the parameters for the tested space have not been achieved within the 60 minute period timed from the beginning of heating.

- PMV index: $-0,5 \leq \text{PMV} \geq +0,5$, (achieved −2)
- PPD index: $\text{PPD} \leq 10$ %, (achieved 18 %)
- Uneven distribution of temperature: $\Delta t \leq 5$ °C, (achieved $\Delta t = 21$ °C).

As expected, the Soft Top vehicle proved uncomfortable regarding heating efficiency. In the load area, which can be used for the transport of people as well, there are not any ventilation system outlets. The target temperature of 16 °C at the co-driver's head is achieved in 30 minutes of vehicle work, but at the same time the temperature does not exceed 10 °C in the area around the feet. The speed of air circulation at the places where the driver's and co-driver's heads are does not exceed 0,2 m/s. The average temperature of 16 °C for heating is achieved in the driver's space in 60 minutes of work. However, on the crew member seats in the loading space, the heating comfort is unsatisfactory, which was probably not the target set by the manufacturer.

Table 6 Temperatures in useful space of Soft Top vehicle at the ambient temperature of −16 °C

	MEASURING POINTS									
	Driver's space			Load area						
	co driver			Front left		Back left		Front right	Back right	
	G (°C)	K (°C)	S (°C)	G (°C)	S (°C)	G (°C)	S (°C)	G (°C)	G (°C)	S (°C)
Start (min)	-15	-15	-16	-15	-17	-15	-16	-15	-16	-16
5	-3	-7	-11	-12	-16	-13	-16	-12	-12	-16
10	2	-2	-5	-7	-13	-8	-10	-11	-10	-14
15	9	5	2	-3	-9	-6	-8	-6	-8	-11
20	12	8	4	3	-7	-3	-9	1	-5	-11
25	15	11	6	5	-6	1	-9	2	-2	-9
30	16	13	8	7	-3	3	-7	5	0	-7
35	17	14	10	9	0	4	-4	5	1	-5
40	17	15	11	10	1	6	-2	7	2	-3
45	17	15	12	10	1	7	-2	8	3	-3
50	18	16	12	11	2	9	0	8	5	-1
55	18	16	13	12	3	9	-1	10	6	-1
60	19	16	13	13	2	10	1	11	8	1
65	20	17	13	13	3	10	2	11	8	1
70	21	17	13	14	3	11	2	12	9	2
75	22	18	14	14	4	11	3	12	10	1
80	22	19	14	13	4	12	2	13	10	1
85	22	20	15	14	4	12	2	13	10	2
90	22	20	15	14	4	12	3	13	11	2

Table 7 Temperatures in useful space of Hard Top vehicle at ambient temperature of −16 °C

		Driver's space						Passengers' space						Loading space		
		DRIVER			CODRIVER			II ROW BEHIND THE DRIVER			II ROW BEHIND THE CODRIVER			(center)		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
time (min)	V (°C)	G (°C)	K (°C)	S (°C)	G (°C)	K (°C)	S (°C)	G (°C)	K (°C)	S (°C)	G (°C)	K (°C)	S (°C)	G (°C)	K (°C)	S (°C)
0	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16
10	55 °C -60 °C	5	-1	-1	4	-1	0	-15	-16	-10	-14	-15	-9	-14	-13	-7
15		10	7	7	11	6	8	12	-6	-9	11	1	-9	10	0	1
20		16	8	13	14	9	12	15	2	-6	16	1	-5	17	2	9
25		18	12	15	16	12	13	17	7	-6	18	5	-5	18	5	12
30		19	15	16	19	14	16	18	10	-5	19	8	-5	20	9	15
35		22	17	18	21	15	18	20	12	-2	20	9	-3	20	13	17
40		25	17	17	24	17	18	22	13	-1	22	14	0	23	15	18
45		26	19	19	24	18	19	23	13	0	24	16	2	24	17	19
50		26	20	19	25	18	19	23	14	0	24	16	2	25	17	20
55		27	21	21	26	19	20	24	14	1	25	16	3	25	18	20
60		28	21	21	27	19	20	24	15	3	25	17	4	26	18	21

Due to the afore stated reasons, the Hard Top vehicle had additional temperature sensors placed at the ventilation outlet grills on the control panel, as well as on the positions given in Tab. 6.

It can be seen from Tab. 7 that the ventilation system outlet temperature in the cabin reaches the maximum of 60 °C, which at an air flow speed of 0,2 m/s enables relatively high measured temperatures at the heads of the driver and co-driver respectively (from 21°C to 28 °C) [11]. However, the temperatures measured at the feet of cabin crew during the same time interval, varied −3 °C to +4 °C, which represents an exceptionally big temperature difference. A mean temperature value of +16 °C in the driver's space is provided by the heating system in 30 minutes of work. However, the temperatures at foot level in the second row passenger seat area are extremely low and the vertical temperature difference is unsatisfactory.

Figure 14 Hard Top in cold chamber and layout of sensors on the seats

According to SORS 8419 standard criteria, the parameters of thermal comfort have not been fulfilled, since they have not been achieved within the maximum 60 minute period timed from the start of heating within the tested space.

- PMV index: $-0{,}5 \leq PMV \geq +0{,}5$, (achieved +2)
- PPD index: $PPD \leq 10$ %, (achieved 15 %)
- Uneven distribution of temperature: $\Delta t \leq 5$ °C, (achieved $\Delta t = 26$ °C).

5 Conclusion

The results of these tests, as expected, confirm that the Hard Top model, which is equipped with a seat for each passenger is far more comfortable. However, from the point of view of flexibility of use (transport of passengers and cargo), the control of the environment by the vehicle crew members (armed attack), as well as the mounting of additional weapons on the vehicle, the Soft Top off-road vehicle with load area is more adaptable for use by armed forces. The results obtained suggest that it is necessary to make modifications to the heating system for the needs of the Military of Serbia by fitting the ducts near the floor of the vehicles, which would then distribute heated air into the back part of the cabin (Hard Top), or the middle of load area (Soft Top).

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Authors' addresses

Aleksandar Mićović, MSc.
Technical Test Centre
Vojvode Stepe 445
11000 Beograd, Serbia
E-mail: amicovic1@gmail.com

Vladimir Popović, Professor PhD
University of Belgrade
Faculty of Mechanical Engineering
Kraljice Marije 16
11120 Belgrade 35, Serbia

Aleksandar Sedmak, Professor PhD
University of Belgrade
Faculty of Mechanical Engineering
Kraljice Marije 16
11120 Belgrade 35, Serbia