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Modeling and simulation study for enhancement of crew comfort of an off-road heavy vehicle

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Abstract- In the current work, an attempt is made to verify the earlier research conclusion that maximum vibration responses occur at the bodily parts of vehicle occupant rather than at vehicle part, using two Simscape models. 7 and 8 degrees of freedom Armoured Fighting Vehicle (AFV) – Crew integrated configurations are visualized first. Then two Simscape models corresponding to the above two configurations are formulated using Matlab2014a software. Parameters of AFV and those of bio-dynamic model obtained from literature are used in the simulation and resulting responses to the idealized road inputs, of selected lumped masses are obtained for both the Simscape models for study.

Index Terms- In plane model, Integrated system, Parameters, Simscape modeling, Simulation, Single wheel station model, Two wheel station model.

1 Introduction

VEHICLE suspension system, as an important device, plays the key role with respect to the comfort and security of vehicle crew [1]. Main factor contributing to the safety and fatigue of occupant of high - speed tracked vehicle including its driver is the vibration environment resulted when the vehicle is negotiating rough off-road terrains. A very effective tool for evaluating the ride characteristics of ground vehicles is the computer simulation.This avoids expense and time consumption involved in repeated testing [2].Vibration is the basic cause for discomfort and fatigue and sometimes leads to even an injury. Especially in the seated posture human beings are most sensitive to whole-body vibrations under low frequency. As a result, bio-dynamics of seated human subjects is becoming a topic of interest over the years leading to the development of number of mathematical models. Discomfort and fatigue estimation of crew using experimental methods is, however, a time-consuming process requiring much effort. As an alternative method, biomechanical modeling helps well in predicting mechanical response of human body in vibrating environment. Therefore, simulations of the mechanical human models are contributing a lot to predict the dynamic characteristics of human body. Thus mathematical models of the human body are becoming useful tools for optimising civilian and military vehicle seating system designs aiming at vibration elimination [3].

However, measurements of vibration on the suspened seat alone do not truly reflect the vibration level, to which the crew is ex posed. Therefore, such seat suspension designs done without taking the combined effect of the vehicle and crew into account did not yield satisfactory results. Work at the National Institute of Agricultural Engineering, United Kingdom, also supports this view

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stressing that a mechanical simulation of human body characteristics together with the seat is necessary [4].

Following the above concept, M.K.Patil and M.S.Palanichamy [4] modeled the occupant along with the tractor, a typical heavy vehicle, including the driver seat, in the form of a lumped mass system interconnected by springs and dashpots, subjecting the composite model to sinusoidal (idealized field or road profile) vibration at the tire contact points and found out the resulting responses of each body part, by computer simulation. They have also demonstrated that maximum vibration responses occur only at the bodily parts of the vehicle occupant and not at vehicle level, thus insisting the need for vehicle-occupant composite model study.

In the present work, an attempt is made to verify the above argument using the Simscape modeling approach, in lieu of the governing equations approach used by the above researchers. Also the current work is specifically carried out for the off-road heavy vehicle viz. Armoured Fighting Vehicle.

Firstly, two different configurations of AFV-crew integrated system are formed, as depicted in Fig. 1 and Fig.3. In case1, 3 degrees of freedom (dof) Single Wheel Station (SWS) AFV configuration including crew seat is integrated with the 4 dof bio-dynamic human model suggested by Mahesh P.Nagarkar, et al. [5], resulting in 7 dof integrated SWS AFV - Crew configuration. In case 2, same biodynamic model is integrated with the 4 dof Two Wheel Station (TWS) AFV configuration including crew seat, resulting in 8 dof integrated TWS AFV – Crew configuration. Simscape models corresponding to the above two configurations are formulated using Matlab2014a software and depicted in Fig. 2 and fig. 4 respectively. Parameters of AFV and those of biodynamic model obtained from literature [5], [6] & [7] are used in the simulation and resulting responses to the idealized road inputs, of selected lumped masses are obtained for both the Simscape models and studied.

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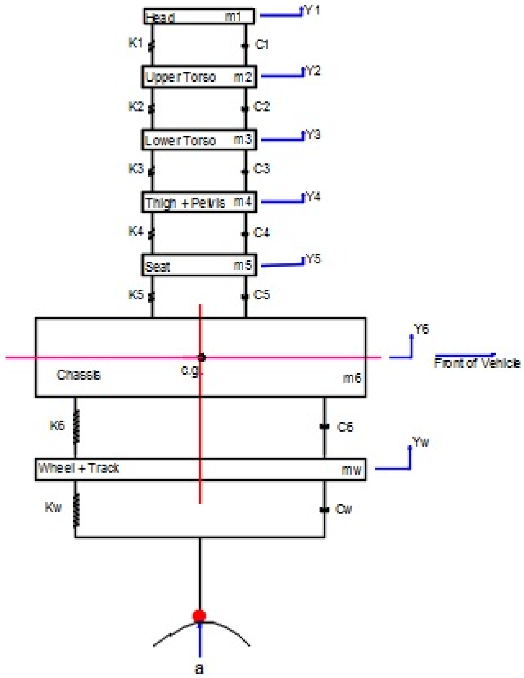

Fig. 1 - Seven dof integrated SWS AFV-Crew Configuration

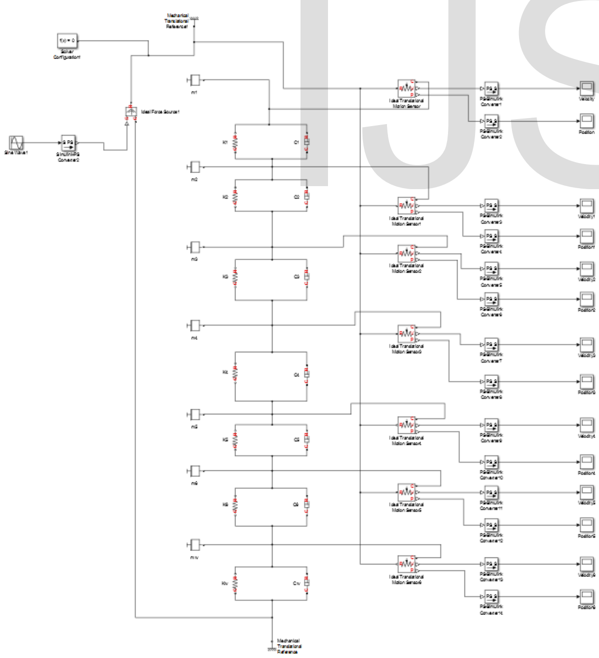

Fig. 2 - Seven dof SWS AFV-Crew integrated Simscape Model

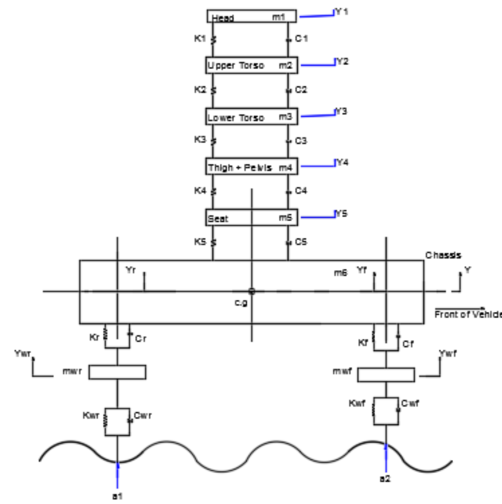

Fig. 3 - Eight dof integrated TWS AFV-Crew configuration

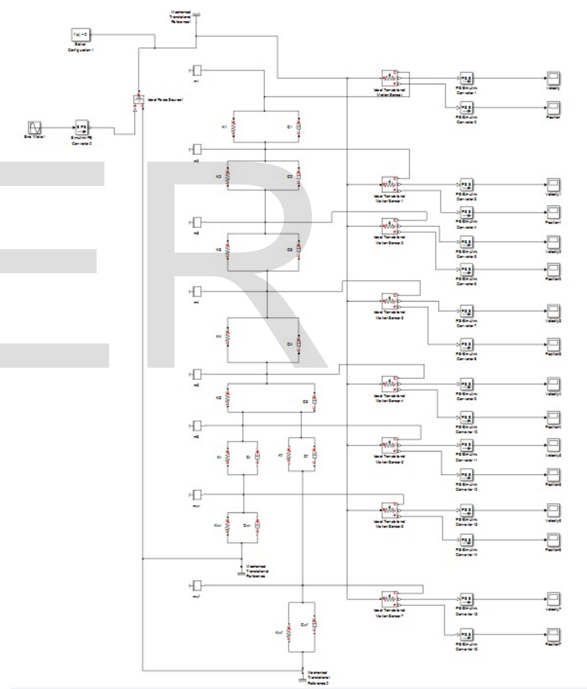

Fig. 4 - Eight dof TWS AFV-Crew integrated Simscape model

2 LITERATURE SURVEY

Limited works only are available in the literature dealing with off-road vehicle-occupant integrated model. Also they are not relating to AFV applications.

A seat suspension system for the use of AFV was developed by N.V.Ramamurthy and K.MothiramPatil [8]. However said researchers adopted the parameter values used in their design from the results of research works carried out earlier. An analytical experimental investigation of the driver-seat suspension system was carried out by S.Rakheja et. al. [9] for the ride vibration environment of off-road vehicles, but the work was not done specific to the AFV environment.

A study on optimal design of passenger car suspension for ride and road holding was made by Anil Shirahatt et. al. [10], but the mathematical model covered the chassis with the passenger seat and not the bodily segments of vehicle occupant.

Modal analysis of human body vibration model for Indian subjects under sitting posture was carried out by Isbhir Singh et. al. [3] but the vehicle model was not included in their study and also un-damped bio-dynamic model only was considered, thus ignoring the damping characteristics of connective tissues between various body segments.

Wael Abbas et. al. [11] carried out a study on occupant seat design wherein 4 dof biodynamic model interfaced with an on- road vehicle model was considered for study. Thus it did not discuss about off-road vehicle.

But in the current work, above technological gaps have been addressed and man-machine integrated Simscape model for AFV crew is formulated and analysed.

3. MODELING AND SIMULATION

3.1 SIMSCAPE MODELING

The biodynamic lumped model of 4 dof, suggested by Mahesh P.Nagarkar, et al. [5] is adopted here and integrated with the simplified 3 dof SWS AFV & 4 dof TWS half plane AFV configurations, thus leading to the 7 dof & 8 dof integrated AFV –Crew configurations of fig. 1 & Fig. 3 respectively. Corresponding Simscape models formed are illustrated in Fig. 2 & Fig. 4 respectively. The notations of said 4 dof biodynamic model originally proposed by the above authours are slightly modified in the present work. In the original model, human body was constructed with four separate mass segments interconnected by five sets of springs and dampers, resulting in the total human mass of 55.20 kg. As per the revised notations of current model, the four masses m1, m2, m3 & m4 represent four body segments viz. head (m1), chest & upper torso (m2), lower torso (m3) and thigh & pelvis (m4) respectively. Also the stiffness and damping properties of thighs with pelvis are K4 & C4, those of lower torso are K3 & C3, those of chest & upper torso are K2 & C2 and K1 & C1 are those of head respectively. The vertical displacements experienced by body parts viz. head, chest with upper torso, lower torso and thigh with pelvis, about the c.g of chassis (sprung) mass are given by Y1, Y2, Y3& Y4 respectively. Parameters of biomechanical model of occupant are given in Table 1 and those of half plane AFV configuration are given in Table 3.

Table 1. The biomechanical parameters of Occupant model, as adopted from the model of Mahesh P.Nagarkar, et al. [5]

Mass (kg)	Damping co-eff. (N.S/m)	Spring constant (N/m)
m1= 5.31	C1 = 400	K1 = 310000
m2 = 28.49	C2 = 200	K2 = 183000
m3 = 8.62	C3 = 330	K3 = 162800
m4 = 12.78	C4 = 909.1	K4 = 90000

The two integrated Simscape models formulated are subjected to idealised road inputs during simulation, thereby representing the ground reaction forces. While formulating the TWS AFV half plane model, virtual front & rear wheel stations are visualized by arriving at the equivalent suspension parameter values from those of the actual seven wheel stations of AFV. During simulation, only the vertical vibration response, which is considered to be predominant and more harmful to vehicle crew is studied. Table 2 depicts the description of various variables with respect to the half plane vehicle model and Table 3 illustrates the parameters of the AFV model obtained from literature & reports [6],[7].

Table 2. Description of variables of AFV model

Symbol	Description
m6	Chassis mass (kg)
Y6	Vertical displacement of c.g (for SWS AFV model) (m)
Y	Vertical displacement of c.g (for TWS AFV model) (m)
mw	Mass of virtual road wheel with track pad (for SWS AFV model) (kg)
mwf	Mass of virtual road wheel (front) with track pad (for TWS AFV model) (kg)
mwr	Mass of virtual road wheel(rear) with track pad (for TWS AFV model) (kg)
m5	Passenger Seat mass (kg)
K6	Stiffness/ spring const. of suspension unit (for SWS AFV model) (N/m)
C6	Damping co-eff. of suspension unit (for SWS AFV model) (N.S/m)
Kf	Stiffness/ spring const. of virtual suspension unit (front) (for TWS AFV model) (N/m)
Cf	Damping co-eff. of virtual suspension unit (front)(for TWS AFV model) (N.S/m)
Kr	Stiffness/ spring const. of virtual suspension unit (rear) (for TWS AFV model) (N/m)
Cr	Damping co-eff. of virtual suspension unit (rear)(for TWS AFV model) (N.S/m)
Kw	Stiffness/ spring const. of road wheel

	rubber with track pad (for SWS AFV model) (N/m)
Cw	Damping co-eff. of road wheel rubber with track pad (for SWS AFV model) (N.S/m)
Kwf	Stiffness/ spring const. of virtual road wheel (front) rubber with track pad (for TWS AFV model) (N/m)
Kwr	Stiffness/ spring const. of virtual road wheel (front) rubber with track pad (for TWS AFV model) (N/m)
Cwf	Damping co-eff. of virtual road wheel (front) rubber with track pad (for TWS AFV model)(N.S/m)
Cwr	Damping co-eff. of virtual road wheel (rear) rubber with track pad (for TWS AFV model) (N.S/m)
K5	Stiffness/ spring const. of Crew Seat (N/m)
C5	Damping co-eff. of Crew Seat(N.S/m)
Y1, Y2, Y3&Y4	Vertical displacement of human body parts viz. head, chest & upper torso, lower torso and thigh & pelvis, respectively (m)
Y5	Vertical displacement of Crew Seat (m)
Yf&Yr	Vertical displacement of chassis mass directly above the virtual road wheels front & rear respectively (for TWS AFV model) (m)
Ywf&Ywr	Vertical displacement of wheels at virtual road wheel stations front & rear respectively(for TWS AFV model) (m)
a	Road input to wheel (for SWS AFV model) (m)
$a1$&$a2$	Road input to virtual wheels front & rear respectively(for TWS AFV model) (m)
g	Acceleration due to gravity (m/S²)

Table 3. Parameters of half plane AFV model as adopted from AMCP [12] & Saayan Banerjee et. al. [6].

Parameter	Value
m6	37,000 kg
m5	10 kg
mwf = mwr	2012.5 kg (each)
I	1.94×10^5 (kg.m²)
Kf=Kr	0.51905×10^5 N/m
K5	18000 N/m
Cf=Cr	1.043658×10^6 N.S/m
C5	200N.S/m
Kwf=Kwr	15750000 N/m
Cwf=Cwr	20275.5 N.S/m
$a = a1$	0.00264 m (for
$a2$	- 0.00264 m
g	9.81 m/S²

"a" is the road input at wheel station such that: a=A.sin ωt; ('A' is the amplitude of sine wave road profile with the value of 0.150m). For a typical vehicle speed of 40 km/hr, the value is arrived such that a = 0.00264 m, for SWS AFV-Crew model]

Similarly, "$a1$"&"$a2$" are the road inputs at rear and front virtual wheel stations such that:$a1$=A.sin ωt and$a2$ = A.sin (ωt-α). Similar to above case, for a typical vehicle speed of 40 km/hr, the values are arrived such that$a1$ = 0.00264 m & $a2$ = - 0.00264 m, for TWS AFV-Crew model.

3.2 Numerical Simulation

Both the bio-dynamic and AFV suspension parameters are implemented during the simulation of the two Simscape models formulated. Vibration response outputs of selected lumped masses, for the idealized road inputs are obtained and given in results section.

4. Results and Discussion

Screenshots of vibration response outputs obtained from the7 dof SWS AFV – Crew integrated Simscape model are given in Fig. 5 to Fig. 8. Similarly those of 8 dof TWS half plane AFV-Crew integrated Simscape model are illustrated in Fig. 9 to Fig. 12.

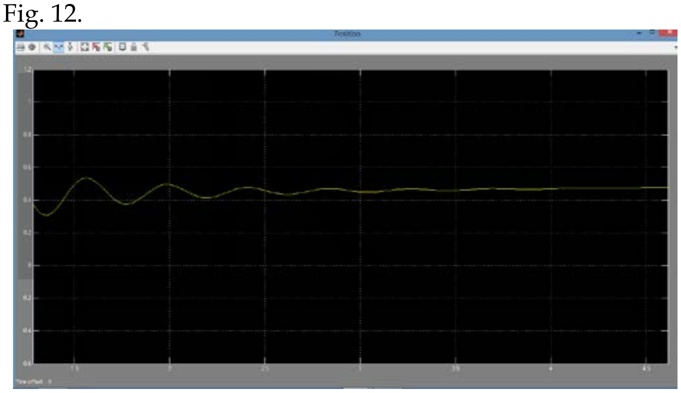

Fig. 5 - Vibration response output at head level for 7 dof Simscape model

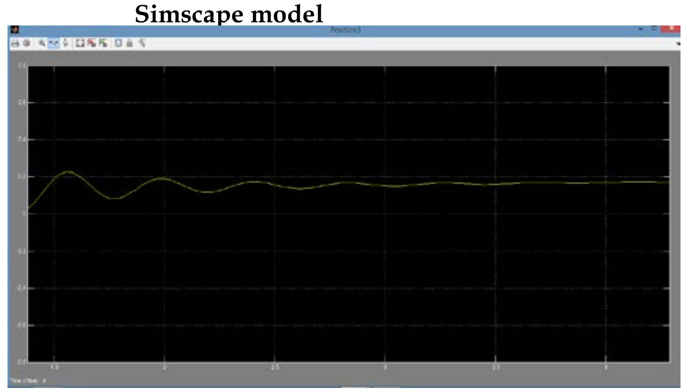

Fig. 6 - Vibration response output at thigh & pelvis level for 7 dof Simscape model

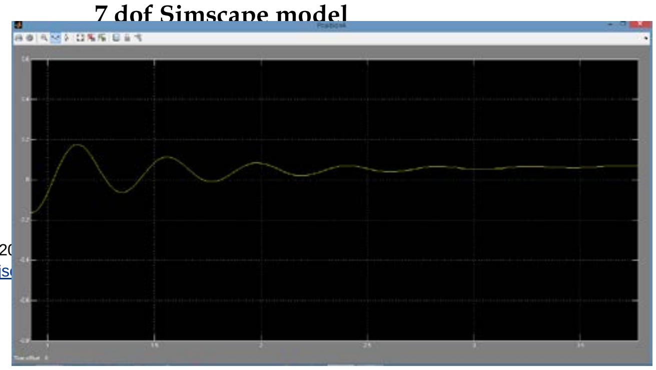

Fig. 7 - Vibration response output at seat level for 7 dof Simscape model

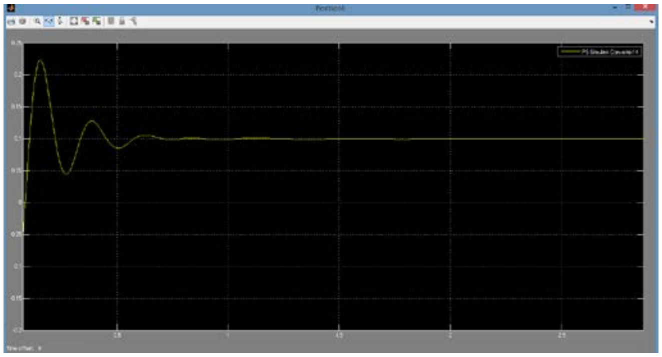

Fig. 8 - Vibration response output at chassis level for 7 dof Simscape model

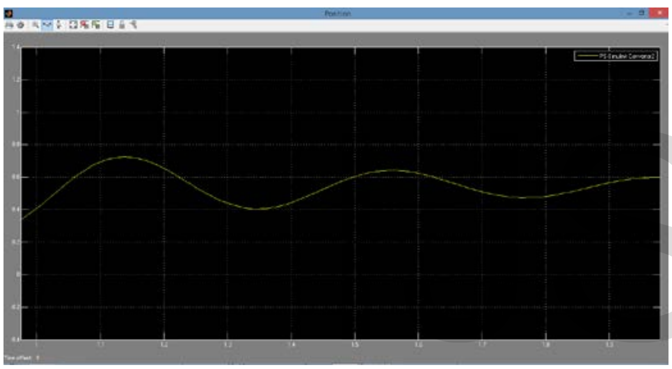

Fig. 9 -Vibration response output at head level for 8 dof Simscape model

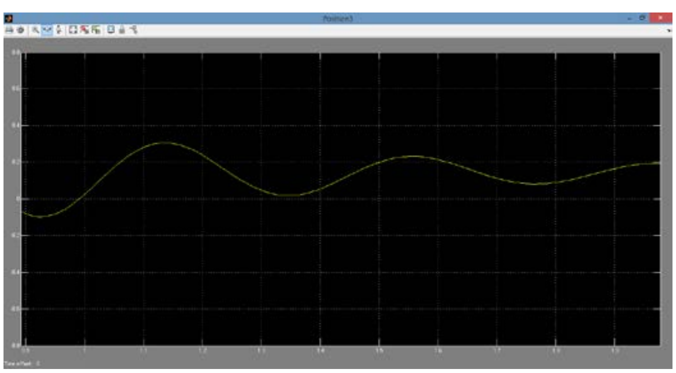

Fig. 10 -Vibration response output at thigh & pelvis level for 8 dof Simscape model

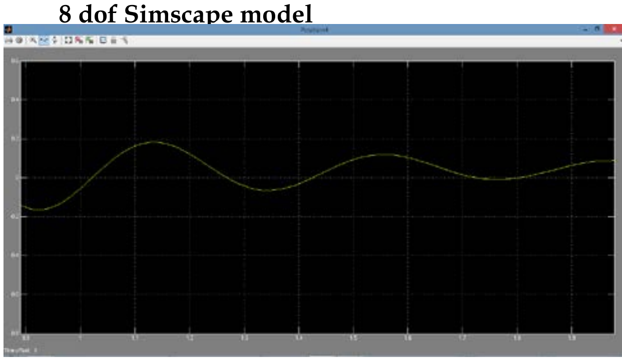

Fig. 11 -Vibration response output at seat level for 8 dof Simscape model

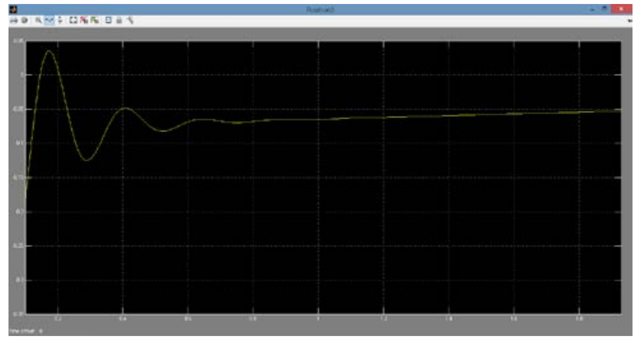

Fig. 12 -Vibration response output at Chassis level for 8 dof Simscape model

From the results, it is apparent that maximum displacement i.e vibration response is experienced not at vehicle level but by human body parts, which once again confirm the opinion of previous researchers [4], through this Simscape modeling and simulation study.

5. Conclusions and Recommendation

Simscape models have been formulated for two AFV- Crew integrated configurations and output responses for idealized road inputs are obtained. Necessity of such man-machine integrated model study has been supported by the reports of National Institute of Agricultural Engineering, U.K [4]. From the results, it is concluded that Simscape modeling cum simulation study carried out for integrated vehicle-crew configuration also is in support of the argument that maximum displacement i.e vibration response is experienced not at vehicle level but by human body parts, as concluded in earlier research [4]. Also it may be noted that in all cases, more vibration response is experienced by human body parts than the vehicle portion. It is a valid input to be accounted while designing seat suspension system for AFV crew aiming at their comfort level enhancement.

Detailed Simscape AFV- Crew integrated model can be formulated representing all the 7 wheel stations of AFV in lieu of the virtual i.e equivalent wheel stations considered here and simulation cum analysis study can be carried out as future work.

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