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Vibration Transmissibility in Seated Subjects

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Vertical vibration transmission from seat t shoulder is maximum in the frequency ran 4.5—7.0Hz for subjects varying in weight in t range 41.5—80 Kgs. Transmissibility and fr quency of maximum vibration transmissi depends on the vibration intensity input.

Vibration transmissibility at the thigh lev shows a maximum in the frequency range 5 Hz and there is an inverse relationship betwe the body weight and maximum vibration tra mission.

Compressible cushion and fibre glass se pad diminish the vibration intensity. There i considerable amount of vibration dampi in the human body in seated vertical postu There is no evidence to indicate amplificati of input vibration intensity and vibratio transmissibility is more often less than one

Introduction

The human body is routinely subjected to variety of vibrating environments. In aviati vibration represents one of the inescapable physi stresses which either in isolation or in combinati with other stresses like heat, noise etc. has so bearing on the psychophysiological functioni With modern aircraft design many of the proble pertaining to vibration have faded away. Still the are areas in military flying such as low level hi speed flying and helicopter operations which po definite problems to human operators.

Vibration enters the human body from the sour through point of contact such as seat pan or equipment in an aircraft. Vibrations generated in aircraft are either due to the interaction of aircr with outside environment or of structural mo from airframe, engines etc. Vibrations thus reachi the occupants of an aircraft, has a broad ba spectrum with respect to frequency and ener contents.[1,8,9] The vibration intensity reaching vari body organs depends on the inherent biodyna response as well as vibration isolation systems use

The human body is a complex mechanical syst

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having viscoelastic properties and capable of dynamic response to imposed short duration and long duration forces. Imposed vibrations generate damped vibrations in the human system. Various body parts are coupled by bones, muscles and ligaments and vibration intensity reaching any particular site is related to the actual point of entry and total overall damping on the way.

Deformations or displacements can occur in the human body due to differential displacements of various body organs under uniaxial[8] and multiaxial vibration.[6] Response to vibration is dependent on frequency, magnitude and phase in different axis.

In aircraft operation, vibrations are generally random in nature but the vertical component is quite predominant for a seated person. It is difficult to correlate human body response with random vibrations and usually unidirectional Z-axis (vertical) sinusoidal vibration are employed for laboratory studies. Results of such studies have been employed to predict or interpret the effects of actual vibrations, buffeting and shocks on human performance.[13]

Vibration transmissibility is taken as the ratio of the displacement or acceleration amplitude at some particular location on the human body and vibration amplitude at the point of entry. The reference vibration amplitude is usually taken on the floor of the aircraft or on the seat if the seat is heavy or on the seat in case of light weight seat. Vibration transmissibility is maximum when the vibration environment contains frequencies near the human body natural frequency. For seated human beings first two modes of resonances are said to occur at around 5 Hz and 12 Hz respectively.[9] At or around the resonance frequencies, maximum energy transmission occurs and magnitudes of vibration at any location depends critically on the damping offered by the system. Various laboratory based studies have shown that vibration transmissibility at the head and shoulder level is much greater than the input vibration intensity at or around resonance. The vibration transmission causes performance decrement in human operators.

In the present study vibration transmissibility at shoulder and thigh levels in upright, relaxed, seated subjects has been determined with respect to seat vibration. Compressible cushion, fibre glass pad and fibre glass back rests have been used to determine their effect on vibration transmission.

Materials and Method

An electrohydraulic vibrator, developed at IAM, was employed in the present study. The vibrator is capable of simulating frequencies in the range of 2-20 Hz which can be varied at intervals of 0.1 Hz. Intensity or amplitude of vibration can be maintained at any desired levels, though at the lowest frequency of 2 Hz a maximum of 0.6 g amplitude can be obtained. Details and working of the vibrator have been given in earlier work.[12]

An aircraft seat suitably modified to provide a bucket-type contour was mounted firmly on the vibrating platform so that it receives the same vibrations as those of the platform. The seat is incorporated with shoulder harness, lap strap belts and a quick release system (QRS). The bucket of the seat was 2.5" deep which can be filled completely by putting compresible and non compresible fibre glass pad in it.

A double layered thermally insulated cockpit made of Aluminium has been built around the platform. The cockpit structure has a door with attached perpexed window. The cockpit structure around the vertically vibrating platform helps in simulating the closed environment of aircraft cockpit.

Piezo electric accelerometers (type KD-35 and KD-35A) were used in the study to measure the vibration intensity and frequency. One accelerometer was mounted firmly on the seat whereas the other was attached firmly on the shoulder or thigh of subject. These accelerometers have flat frequency response upto 20KHz and a sensitivity of 5 Mv/ms.[2] A vibration meter type RFT model SM 211 was used to measure vibration amplitudes and vibration frequencies. Accelerometers were joined to the vibration meter. The vibration meter has a flat response from 2Hz to 15 KHz. Output of the vibration meter was fed to a two channel encardiorite pen recorder to determine the vibration frequencies.

Method

Equipment calibration

The accelerometers and the vibration meter were calibrated with the help of a standard electromagnetic shake table. (available at GTRE Bangalore) oscilloscope and a pen recorder. The output of the accelerometers for various vibration amplitudes (in g's) from 0.2 g—1.0 g at low frequencies in the range 3-12 Hz was standardized on the oscilloscope, the vibration meter and the pen recorder. Details of various calibrations and standardizations are given elsewhere.[15]

Constancy of the vibration simulator in respect of frequency and amplitude with respect to time was established to ensure that physical parameters of vibration environment did not change during course of experiments.

Subject details

Thirteen, healthy, adult, motivated, volunt consisting of 11 males and 2 females participat the study. Of these eight individuals took par most of the experiments. Their details in respect age, height and weight are placed in table 1.

Table I

Details of subjects

Subject	Sex	Age years	Height cms	Weight kgs
MKV	M	37	168.5	80.0
EMI	M	39	171.0	65.0
DTS	F	26	161.0	41.5
BR	M	28	173.0	54.0
NRC	M	42	166.0	62.5
SRK	F	42	161.0	59.0
NCM	M	26	163.0	66.0
NSB	M	39	174.0	67.0

Experimental procedure

Shoulder level vibration transmissibility

For determining vibration transmission from seat to shoulder, subject sat upright on the seat in a relaxed posture always maintaining contact with the seat back. Accelerometer was attached on the shoulder with the help of double sided self adhesive tape. Care was taken to ensure that accelerometer was fitting snugly and held in vertical position. Thus, readings of vibration intensity measurements were for the vertical axis vibration alone. Vibration frequencies in the range 4—8 Hz at amplitudes of 0.4g and 0.5 g were administered. Readings for frequency of 3 Hz and above 8 Hz were also taken in one set of experiments but discontinued in other experiments since the transmission was found to be very small.

Four sets of experiments were carried out nam ly, subject sitting directly on the seat (SD), sitti on a compressible cushion (CC); sitting on a fi glass pad (FGC) and sitting on fibre glass pad alo with fibre glass back rest (FGC + BR). Vibrati transmission was measured and vibration transmis bility determined. Fibre glass pad was made su that it filled the seat completely. Similarly fibre gla back pad was contoured to fit completely on t seat back and subject maintained a constant tou with it.

For the SD case and vibration amplitudes of 0. and 0.5g at the seat level, 10 and 13 subjects re pectively took part for transmissibility measuremen In the case of experimental conditions of CC, FG and FGC + BR number of subjects who participa in the experiments for 0.4g and 0.5g amplitud

Table II

Mean values of vibration transmissibility at the shoulder level for different experimental conditions

$$\text{Transmissibility} = \frac{\text{Shoulder level — vibration amplitude}}{\text{Seat level — vibration amplitude}}$$

Frequency Hz	Transmissibility values for							
	Vibration amplitude at the seat = 0.4g				Vibration amplitude at the seat = 0.5g			
	SD	CC	FGC	FGC+BR	SD	CC	FGC	PGC+BR
4.0	.63 ± .09	.62 ± .08	.63 ± .08	.68 ± .11	.61 — .15	.58 — .07	.60 × .08	.60 — .09
4.5	—	.70 ± .13	.71 ± .83	*.77 ± .16	.71	.66 — .11	.64 — .08	.69 — .09
5.0	.77 ± .11	.78 ± .19	*.75 ± .10	.74 ± .20	*.95 — .23	.77 — .17	.75 — .17	.82 — .13
5.5	—	*.83 ± .17	.72 ± .09	.76 ± .17	.82	*.81 — .18	.77 — .17	.82 — .15
6.0	*.81 ± .20	*.83 ± .13	.70 ± .19	.73 ± .13	.85 ± .19	.79 ± .11	*.83 ± .19	.76 ± .09
7.0	.70 ± .13	.72 ± .21	.70 ± .26	.72 ± .12	.66 ± .12	.70 ± .17	.66 ± .23	.72 ± .10
8.0	.60 ± .08	.51 ± .14	.50 ± .16	.59 ± .20	.50 ± .13	.47 ± .16	.48 ± .17	.56 ± .15

*indicates the maximum value; SD : Sitting directiy on the seat

CC : Sitting on the compressible cushion

FGC : Sitting on fibre glass pad

FGC+BR : Sitting on fibre glass pad together with fibre glass back rest were 6, 8, 8 and 7, 8, 8 respectively. Mean values of shoulder level vibration transmissibility are tabulated in table 2.

Thigh level vibration transmissibility

It was difficult to fix the accelerometer on the thigh directly as in the case of shoulder due to large flesh content. Therefore, a thin metal strap was made and velcro straps were attached to its ends. This metal strap could be fixed on the thigh and with the help of velcro tapes adjustment could be dr to fit different thigh thicknesses. Acceleromet was fixed on the metal plate with the help of dou sided tape. Vibration amplitudes at the thigh le were measured for the experimental conditions SD, CC and FGC for 0.5 g seat level amplitude in t frequency range of 4.0—8.0 Hz. Seven subje volunteered for these sets of experiments. Me values of thigh level vibration transmissibility w tabulated in table 3.

Table III

Mean values of thigh level vibration transmissibility

Vibration amplitude = 0.5g

Frequency Hz	Transmissibility = Thigh level vibration amp / Seat level vibration amp		
	SD	CC	FGC
4.0	.61 ± .12	.48 ± .03	.48 ± ,04
4.5	.64 ± .12	.65 ± .09	.56 ± .06
5,0	.72 ± .14	.67 ± .15	.68 ± ,10
5.5	*.74 ± .12	.71 ± .13	.72 ± .10
6.0	.71 ± .09	*.72 ± .09	.71 ± .09
7.0	.71 ± .17	.71 ± .08	*.75 ± .15
8.0	.66 ± .14	.69 ± .10	.63 ± .11

*denotes maximum valve : SD—Sitting directly on the seat
CC—Sitting on the compressible cushion
FGC—Sitting on a fibre glass pad

Results

Tables 2 and 3 give the mean values of vibration transmissibility at shoulder level and thigh level for different experimental conditions.

Table 4 gives maximum shoulder level vibration transmissibility values alongwith the frequency of maximum transmission for shoulder level measurements in respect of six subjects who participated in all series of experiments.

In table 5, maximum thigh level vibration transmissibility values have been tabulated for seven subjects along with the frequency of maximum tra mission.

Tables 6 and 7 correlation coefficients betw body weight and transmissibility/frequency are ta loted for shoulder level and thigh level maxim transmissibility values

Discussion

The mean values of shoulder level vibration tra missibilty show a maximum in the frequency ra 4.5 — 6.0Hz for 0.4g seat amplitude and in the f quency range 5—6.0Hz for 0.5g seat level amplitu

Table IV

Maximum vibration transmissibility at the shoulder level versus body weight

Subject	Body weight Kgs	Maximum shoulder level vibration transmissibility and frequency Seat amplitude = 0.4g				Seat amplitude = 0.5g			
		SD	CC	FGC	FGC+BR	SD	CC	FGC	FGC+BR
MKV	80.0	.92(6.0)	1.15(5.5)	1.04(6.0)	1.0 (5.0)	1.28(5.0)	1.14(5.0)	1.14(6.0)	1.02(5.0)
EMI	65.0	.77(5.0)	.80(5.0)	.82(4.5)	.86(5.5)	.88(5.5)	.74(4.5)	.72(5.0)	1.0 (6.0)
DTS	41.5	1.22(6.0)	.85(6.0)	.75(5.0)	.84(5.5)	.84(6.0)	.84(6.0)	.80(6.0)	.75(4.5)
SRK	59.5	.96(5.0)	.89(7.0)	1.28(7.0)	1.8 (5.5)	.80(5.5)	.90(7.0)	1.01(6.0)	.86(5.5)
BR	54.0	1.02(6.0)	.95(6.0)	.77(6.0)	.68(4.5)	.84(5.0)	.98(5.0)	.90(6.0)	.80(4.5)
NRC	66.0	.80(5.0)	.65(6.0)	.65(4.5)	.80(7.0)	.90(7.0)	.76(7.0)	.66(5.0)	.84(7.0)
Mean		.95	.88	.89	.80	1.02	.89	.87	.88
± Sd		.16	.17	.23	.12	.26	.15	.18	.11

( ) Value is frequency of maximum vibration transmission.

Table V

Maximum thigh level vibration transmissibility—Versus body weight

Vibration amplitude at the seat = 0.6g

Subject	Body weight Kgs	Maximum thigh level transmissibility and frequency		
		SD	CC	FGC
MKV	80.0	.85 (6.0)	.79 (5.5)	.88 (5.5)
EMI	65.0	.83 (5.5)	.80 (5.5)	.75 (7.0)
DTS	41.5	1.01 (7.0)	.83 (5.5)	.88 (7.0)
BR	54.0	.74 (5.5)	.67 (7.0)	.70 (7.0)
NRC	62.5	.68 (5.6)	.74 (5.0)	.78 (5.6)
SRK	59.5	1.02 (5.0)	.82 (5.0)	1.00 (7.5)
NCM	66.0	.58 (5.0)	.70 (7.0)	.72 (7.0)
Mean		.81	.76	.82
± SD		.17	.06	.11

(   ) values are frequency of maximum transmission.

Table VI

Correlation coefficient 'r' between body weight and Transmissibility/frequency

(Shoulder level vibration transmissibility maximum)

Amplitude	'r' values							
	0.4g				0.5g			
Experimental situation	SD	CC	FGC	FGC+BR	SD	CC	FGC	FGC+
Body weight and Frequency	—0.21	—0.35	0.07	—0.09	—0.07	—0.21	—0.27	0.4
Body weight and Transmissibility	—0.76	+0.35	0.29	0.48	—0.12	0.40	0.38	0.0

Table VII

Correlation coefficient 'r' between body weight and transmissibility/frequency

(Thigh level vibration transmissibility maximum)

	'r' values		
Amplitude	0.5g		
Experimental situation	SD	CC	FGC
Body weight and frequency	—0.44	—0.06	—0.58
Body weight and transmissibility	—0.38	—0.05	—0.04

Excepting the compressible cushion case, vibration transmission is more for 0.5g seat amplitude compared to 0.4g. This indicates that more the level of input vibration intensity higher is the vibration transmission. This is corroborated by other workers too.[8,11,17] However, nowhere the vibration transmissibility values exceed unity showing thereby that there is a considerable amount of resistance or damping in the path between buttocks and shoulders. Involuntary muscle tensing and postural adjustments cannot be ruled out but constancy in the values for different subjects lend support to the fact that indeed there is a great degree of vibration damping in seated upright subjects. Transmissibility values are constantly less at 4 and 8 Hz compared to the values between the frequency range of 4.5—7.0 Hz. This shows that, by and large human body natural frequency must lie in this range only for sitting posture. Fully compressed cushions underneath do not in any way amplify the vibration. In fact, the vibration transmission values for CC case are somewhat less than or equal to the SD case showing some amount of damping within the cushion. Vibration transmission for the FGC and BR is more than the FGC case which indicates that if a constant contact is forcibly ensured more vibratory energy reaches various body parts. However, higher values of vibration transmissibility for the SD case suggests that fully compressed cushions or fibre glass pads may help in reducing the vibration intensity to some marginal extent.

The vibration transmissibility at the thigh level is less than the shoulder level and the maximum values are seen in the frequency range 5.5—7Hz. However, transmissibility values in the frequency range 4.5—7Hz are comparable for different experimental conditions. It is seen that transmissibility values at 8Hz are more than the 4Hz values whereas for shoulder level reverse was the case. In the case of vibration amplitude measurements at the thigh level the path of vibration transmission was from vibrating platform, to soles, legs and thigh. There is considerable amount of vibration isolation in legs,[10] but their frequency response is much different than the upper torso due to difference in mass and elasticity. Thus, even at thigh level vibration intensity available at higher frequencies may be considerable whereas, at the shoulder level it will go on diminishing at higher frequencies. Vibration intensity found maximum at thigh level is less in CC compared to SD and FGC indicating some vibration damping in the cushion material.

From tables 4 and 5 which give maximum vibration transmissibility values, against weight of subjects it is seen that maximum values lie in the range 4.5—7.0 Hz and 5.0—7.0Hz for shoulder level and thigh level vibration transmission respectively. It is clear that vibration transmissibility at shoulder level for SD both for 0.4g and 0.5g seat amplitudes, are higher than for CC, FGC and FGC + BR. The values being approximately similar. However, here again the vibration transmission is no where very much in excess of one. Infact, in most cases the values are around .85 indicating that only 85 percent of the vibratory energy present at the seat level reaches the shoulder level. Similarly for the thigh level vibration transmissibility maximum values are around .8 only. Transmissibility values for CC are somewhat less than SD and FGC where values are similar. Body weight is inversely related to maximum vibration transmissibility at the thigh and also to the frequency (table 7). Thus, higher the weight, lower is the vibration transmission and lower is the frequency of maximum vibration transmission. Although no such generalised relationship can be elucidated for shoulder level vibration transmissibility, excepting the SD, body weight is directly proportional to maximum transmissibility which is in agreement with works of Siedel et al.[12] Griffin et al[9] have shown a negative correlation between the body weight and the frequencies of maximum vibration transmission which is similar to SD of the present study (table 6). If elastic components of human body be taken to be constant more weight would imply a lower natural frequency and vice versa. Thus a contrary result would suggest the elastic components to be different for different body weights. This in combination with variable damping in different human beings points in fact to uniqueness of every individual as far as vibration transmission through his system is concerned.

The study shows that vibration intensity at thigh and shoulder levels of a seated upright individual is less than that at the seat. There is no amplification of the vibratory energy even at frequencies of maximum transmissibility which are in the range of 4.5Hz—7.0Hz, as suggested by many other laboratory based studies.[3,4,6,9]. Performance decrement under vibration environment cannot therefore be wholly blamed on the resonance frequency alone since there is considerable vibration damping in the human body. Higher levels of input vibration intensity result in higher transmissibility and, therefore, perhaps the displacement levels rather than the acceleration levels at frequencies concerned should be correlated with performance evaluation under vibration environments.

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