FINAL TECHNICAL REPORT

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PROJECT N°:

ACRONYM: VIBSEAT

TITLE:

Evaluation and improvement of suspension seat vibration isolation performance

PROJECT CO-ORDINATOR:

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PARTNERS:

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Grammer AG (GRAMMER)	**(D)**
Isringhausen GmbH & Co. KG (ISRI)	**(D)**
Institute of Materials and Machine Mechanics, Slovak Academy of Sciences (IMMM)	**(SK)**
Federal Institute for Occupational Safety and Health (FIOSH)	**(D)**
Société Nationale des Chemines De Fer Français (SNCF)	**(F)**
Institut National de Researche et de Sécurité (INRS)	**(F)**
Federal Institute of Agricultural Engineering (BLT)	**(A)**
National Institute for Working Life (NIWL)	**(S)**

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Contents

1 EXECUTIVE PUBLISHABLE SUMMARY

The objectives of the VIBSEAT project were to develop a test protocol for the evaluation of the dynamic performance of suspension seats in axes other than the vertical, to improve understanding of the dynamic behaviour of suspension seats in response to translational and rotational motions, and to develop theoretical and physical suspension systems capable of improving seat performance in these axes.

The project began in September 2002 and ran for three years, with a no-cost extension to December 2005. During the first year of the project, measurements were made of the translational and rotational motions in off-road and on-road vehicles, rail vehicles and small marine craft. The acquired acceleration time histories were selected to be typical of the inputs to the seats and suitable for testing seat dynamic performance. The second year involved the analysis of these data to extract motions for use in the laboratory and in the development of the laboratory test code for the assessment of the performance of existing horizontal seat suspension designs.

The experience of the VIBSEAT partners in the development and use of standards, and the knowledge of the leading manufacturers of suspension seats in Europe, facilitated the development of a laboratory test protocol for assessing the performance of suspension seats in attenuating vibration and shocks in horizontal axes. The development of the protocol required an advance in understanding of the performance of seats in horizontal directions. The protocol was tested to ensure that it is clearly defined, repeatable and valid.

The dynamic performance of representative suspension seats in the fore-and-aft and lateral directions were assessed in the laboratory and mathematical models were developed to simulate the seat-person system dynamic performance in both horizontal directions. Seat component dynamic properties were determined and, during the second part of the project, the mathematical models were used to guide the development of improved horizontal seat suspension systems.

Modified seat suspension systems were produced by the seat manufacturers. The dynamic performance of current production seats and modified off-road, on-road and rail vehicle seats were compared in both field and laboratory tests. The improvement with the prototype truck seat was less than expected in both the field and the laboratory tests; the modified suspension bearing design resulted in a reduction in friction to a much lower level than proposed, resulting in not only the intended reduction in high frequency vibration but also an increase in low frequency vibration motion.

The results increased experience of the factors influencing the transmission of horizontal vibration to the drivers of vehicles and indicate areas for further improvement of the design of seat suspension systems.

In a simulation of a train-driving environment, a seat horizontal suspension provided a significant beneficial effect: the reduction of lateral accelerations had a beneficial influence on comfort and the performance of manual and visual tasks. Laboratory studies were performed to increase understanding of the subjective and biodynamic responses of seated persons to fore-and-aft, lateral, roll and pitch motions of low frequency. The studies advanced knowledge of the effects of frequency, magnitude and direction on human responses and helped to identify the motions that need to be isolated by seats. The results indicate qualitative effects of some variables and quantitative effects of others on the perceived intensity of vibration, discomfort, effort and driver control. Of particular interest was the comparison of responses to horizontal and rotation oscillation, since the effects of these two motions are not usually separated when motion is measured in vehicles. Laboratory studies found differences in both comfort and apparent mass in response to lateral oscillation as compared to roll oscillation and in response to fore-and-aft oscillation as compared to pitch oscillation, with a clear influence of the seat backrest. It is anticipated that the various laboratory experiments will lead to improved methods for the evaluation of the severity of these motions. The experiments show that this improvement is necessary before horizontal seat suspension systems can be optimised. The results of all the laboratory studies contributed to the development of the mathematical models and the formulation of the seat test protocol.

The mathematical modelling of seat suspension increased understanding of seat dynamic behaviour, giving better predictions of seat responses that could result in the quicker and cheaper development of seats and improved seat performance. It was concluded that the highest priority was to develop passive models and increase experience of passive models of horizontal seat suspensions before developing active models. The passive models developed in the project could form the basis for future active or semi-active models if such systems are needed to meet future exposure limits. The fore-and-aft and lateral models improved predictions of seat response, but the results of the biodynamic studies show that responses are complex (e.g. non-linear and influenced by the contact with the seat back), and so further development of models remains possible. Among the specific contributions in the project, the development of a dry friction model is considered a new and valuable addition to the methods of modelling the performance of seat suspensions.

The combined findings of the field studies, the laboratory studies and the modelling work show that the dynamic performance of suspension seats in fore-and-aft and lateral directions can have a significant effect on the exposure of workers to vibration in many occupations – a finding particularly relevant in view of the new EU Physical Agents (Vibration) Directive.

The test code developed during the project is a significant first step towards a future standard for the testing of seats designed to reduce exposures to horizontal whole-body vibration. After further experience in the use of the method by industry, test houses and academic institutions, it may be expected to form the basis for a new International Standard.

2 OBJECTIVES

Suspension seats are used to isolate the operators of off-road vehicles, on-road vehicles, trains and some small marine craft from vibration. Considerable research has been devoted to understanding and improving the vertical performance of suspension seats. International standards and European standards exist, or are in development, to evaluate the performance of vertical suspension systems in seats (78/764/EEC, ISO 7096, ISO 10326-2 and others). The EU Framework 4 TESTOPS project provided new techniques to assess the performance of suspension seats when exposed to high magnitude vertical motions. However, the motions to which operators are exposed are not restricted to the vertical direction – there has been little research into the performance of suspension seats exposed to other axes of motion or the potential to design seat suspensions to isolate vibration in these axes.

The objectives of the VIBSEAT project were to develop a test method to evaluate the performance of suspension seats in axes other than the vertical, to improve understanding of the dynamic behaviour of suspension seats in response to translational and rotational motions, and to develop theoretical and physical suspension systems capable of improved seat performance in these axes.

It was intended that the project would have a positive impact on the European Community through three main dissemination paths:

- The working conditions of vehicle operators would be improved through the advancement of seat suspension by the three major European seat manufacturers involved in the project;
- A laboratory test method and other results of the project would be disseminated through relevant European standardization committees;
- The results of scientific studies carried out during the project would be published at conferences and in scientific journals.

The project also facilitated and encouraged the exchange of information and experience between industry, academia and health and safety institutions.

3 SCIENTIFIC AND TECHNICAL PERFORMANCE BY WORKPACKAGE

3.1 Workpackage 1 – Seats and field testing led by BLT

3.1.1 Provision of seats, standard methodology for field trials, and data analysis

Provision of seats

Current production suspension seats were provided by the seat manufacturers (GRAMMER, ISRI, KAB). The seats had vertical vibration isolation systems and included fore-and-aft isolators. The seat characteristics (spring rate, resonance frequency, damper characteristic, etc.) were measured. After undergoing laboratory tests to determine the seat characteristics, good seat and test vehicle combinations were found. The seats were of types and configurations relevant to the test vehicle to which the seat was fitted.

Measurements taken on the seats by the manufacturer ISRI

Initial measurements

The vertical spring characteristics and the dynamic forces of the shock absorber of the vertical suspension system of each suspension seat were measured. The vertical hysteresis curve provided information about static friction and the static spring characteristic.

Second run-in process

The seat was installed on the hydro pulse system, a vertical vibration measuring test rig. Standard measurements were performed in accord with ISRI internal standards. The transmissibility and SEAT factors were determined after a run-in time of about five hours. After this, the run-in process was continued for a further five hours until no changes in the shape of the transmissibility curve or in the SEAT value were observed. A similar run-in process was conducted for the horizontal suspension system.

After the run-in process, the parameters of the seats were determined as an input for Workpackage 3 (Objective Factors) and the seats were delivered to the partners. The installation of sensors for the field measurements was discussed and agreed on.

Field trials with production seats (Field test phase I)

Field studies in vehicles were conducted by vehicle manufacturers, operators and vehicle test houses to obtain measurements of the translational and rotational vehicle motions at the seat and of the performance of existing seats in response to these motions. Procedures for the field trials were discussed and agreed on.

Field trials were performed in articulated trucks (NIWL), agricultural and industrial off-road vehicles (BLT), rail vehicles (SNCF) and small marine craft (ISVR). The vehicles were fitted with the current production seats and underwent a series of field trials with varying conditions (terrain, vehicle speed). The vehicle acceleration at the base of the seat and on the seat surface was digitally recorded. The performance of the seat fitted to the vehicle was assessed.

The vehicle motions were passed to the other VIBSEAT partners for reproduction in the laboratory, as inputs to the mathematical models, and to define the range of test conditions applicable to the development of a testing method.

Analysis of selected data

For the different vehicles (on-road, off-road, railway and marine craft), the institutes undertaking the field tests selected some characteristic test rides and results from a large number of test rides and motion measurements. Analysis of the selected data from the field trials was conducted by the ISVR. The analysis was carried out to assess the performance of the seats fitted to all vehicles used in the field trails in response to selected vehicle motions. A report was prepared and distributed.

Provision of modified seats

In the light of results from laboratory and theoretical modelling activities, modified suspension seats were provided by the seat manufacturers GRAMMER and ISRI. Unfortunately, KAB Seating was unable to undertake seat modifications and supplied instead alternative components for laboratory tests and for field tests.

Field trials with modified seats (field tests phase II)

A second series of field trials was carried out using the modified seats. The objective was to test the seats with optimised suspension characteristics. To aid comparison of the results, the same type of vehicle, tracks and conditions were used, with limited variable parameters, for the Phase I and Phase II field tests. The results of the Phase II field tests were submitted to the partners.

3.1.2 On-road vehicle – articulated truck field motion measurements

NIWL conducted measurements in an on-road articulated truck.

Phase I field tests

The first set of measurements were conducted in a two-axled articulated on-road truck, type Volvo FH 12 (Figure 3.1.1). The selection of the test vehicle was made in collaboration with ISRI. The truck was used for on-road and off-road test conditions. During the tests, the truck was equipped with a three axled semi-trailer, type Briab Kilafors.

Figure 3.1.1 The Volvo FH 12 truck with semi-trailer used for on-road vehicle trials

Six typical vehicle activities producing driver-seat motion were selected by collaboration between the seat manufacturer, project partners, vehicle manufacturer and vehicle drivers, as well as by field studies. The selected activities were driving at constant speed of 70 km/h on road; acceleration from 0 to 70 km/h; braking from 70 to 0 km/h; left-right-left manoeuvre at a speed of 20 km/h; constant speed of 10 km/h over obstacles; and start (acceleration) from 0 to 20 km/h over obstacles.

Test seat labelled “Truck seat #2”, with suspension in the vertical and horizontal (fore-and-aft) direction, was tested with and without the fore-and-aft suspension enabled. The test was repeated with the vertical suspension stiffness on maximum and on minimum. Most of the tests were conducted on a highway, but due to security reasons, the left-right-left manoeuvre test and the over-obstacles test were conducted on a special test area that had no other traffic. An experienced driver was hired for the field tests.

Measurements were performed according to the protocol defined in the work package. Acceleration in the three orthogonal directions (x, y and z) were simultaneously recorded at the base of the seat fundament, on the seat plate at the top of the suspension mechanism and on the surface of the seat cushion. Measurements of the rotational motion (roll and pitch) in two directions (x, y) on the vehicle floor were performed. Displacement in the vertical (z) and horizontal (x) direction of seat suspension mechanisms was measured simultaneously with the air pressure of the air suspension mechanism of the seat and the speed of the vehicle.

Videos of the tests showing the seat and driver and the interaction with the controls were recorded during the data acquisitions. During each test, the driver provided responses to a questionnaire on the vehicle seat and on the vehicle operation.

Recorded data were analyzed and the results were stored as ASCII-files. A report, data and video files were sent to the project partners.

The results show that the frequency response for the measured acceleration was very similar for the different vibration directions. The highest acceleration occurred over the frequency range 1 to 4 Hz in the z-direction. The fore-and-aft suspension reduced the acceleration at the seat by approximately 15%. The *z*-axis acceleration at the surface of the seat cushion varied by about 20 - 30 % with different suspension stiffness. With different test conditions and seat adjustments, the frequency-weighted acceleration varied between 0.10 and 0.64 m/s^2. The highest acceleration was measured during vehicle acceleration from 0 to 20 km/h over obstacles.

Phase II field tests

Measurements were made during two test series conducted in March and May 2005. Unmodified and modified seats provided by Isringhausen and labelled “Truck seat #2” were used. For the first series, measurements were conducted on both the old unmodified truck seat and the new modified seat. During the tests, both seats were equipped with the same type of unmodified springs. During the second series, measurements were made on the new modified seat with both the unmodified and modified springs.

For the first test series, a three-axled articulated on-road truck, type Volvo FH 16, with a three axled semi-trailer, type Schmitz, was chosen as the test vehicle (Figure 3.1.2). During the tests, the semi-trailer was loaded with rigid fixed concrete blocks (dimension 0.5 x 0.6 x 0.4 m) with a total weight of 22 tons.

For the second series, a three-axled articulated on-road truck, type Volvo FH 12 6x2, was used as the test vehicle (Figure 3.1.3). The truck was used for on-road and off-road test conditions. During the tests, the truck was loaded with 12 tons of gravel.

Figure 3.1.2 Test vehicle series 1:
Volvo FH 16 and semi trailer Schmitz

Figure 3.1.3 Test vehicle occasion 2:
Volvo FH 12.

The seats were tested with and without the fore-and-aft suspension enabled and with the suspension stiffness in the vertical direction adjusted to maximum. The seat settings were the same as in the first field trials and the same driver was used.

The tests were conducted on an asphalt main road close to Umeå. The two test conditions were (i) a constant velocity of 70 km/h and (ii) acceleration from 0 to 50 km/h, followed by constant velocity then braking to 0 km/h.

Measurements were conducted according to a test protocol that had been modified in collaboration with ISRI and IMMM after the first field trials. Acceleration in the three orthogonal directions (x, y, z) was simultaneously recorded at the base of the seat fundament, on seat plate at the top of the suspension mechanism and on the surface of the seat cushion. Acceleration was measured in the x-direction (fore-and aft) on the backrest and on the seat base. The displacement of seat suspension mechanisms was measured in the vertical (z) and horizontal (x) directions. The speed of the vehicle was also recorded. The data was analyzed and the results were sent to the project partner IMMM.

The results show that during different test conditions and seat adjustments the frequency-weighted acceleration was found to vary between 0.09 and 1.94 ms^{-2}. The highest acceleration occurred in the *x*-direction (fore-and-aft), particularly during the braking phase. The lowest acceleration occurred in the y-direction (lateral). Acceleration in the x-direction was lower for the unmodified seat with the horizontal system enabled, compared to when the system was disabled. For the modified seat with the modified springs, the opposite was observed. The modified seat with the unmodified springs showed a large reduction in the acceleration at the seat compared to the unmodified seat with the unmodified springs. The lowest acceleration was measured in the x-direction for the modified seat with the modified springs. Further details are provided in Annex WP1-1.

3.1.3 Agricultural and industrial off-road vehicle field motion measurements

Field trials on agricultural and industrial off-road vehicles were conducted by BLT. KAB Seating provided a current production suspension seat that had a vertical vibration isolation system and fore-and-aft isolators. The off-road vehicles, an articulated agricultural tractor and an industrial wheel loader, were fitted with the KAB seat and underwent a series of field trials under different test conditions. The performance of the seat fitted to the vehicle was assessed.

Field tests phase I

In Spring 2003, BLT started a first series of field tests with agricultural and industrial off-road vehicles. BLT conducted field tests with an agricultural tractor Steyr CVT 170 with the KAB seat (KAB seat model number 800) (Figure 3.1.4). Test tracks simulating different road conditions were used and parameters, including front-axle and cab suspension, were varied.

Figure 3.1.4 The agricultural tractor Steyr CVT 170 on the 35 m test track

Figure 3.1.5 The industrial loader Volvo L70C moving soil

Field tests were conducted with an industrial loader, type Volvo L70C (Figure 3.1.5). Measurements were made during loading cycles and when running on test tracks simulating different conditions with varying parameters. A report, data and video files were provided to the project partners and the results were discussed. Motion data characteristic of both types of off-road vehicles were selected.

Shock and vibration measurements in cooperation INRS and BLT

Shock and vibration measurements were performed on a wheel loader by BLT in collaboration with INRS. BLT supplied the manpower, vehicle and infrastructures; INRS supplied manpower and the measurement systems. Tests were performed in Austria over three days.

Fore-and-aft acceleration was recorded at the base of the seat frame to obtain measurements of vibration and shocks to which the driver was exposed during working conditions (Figure 3.1.6). The cab was fitted with cameras to observe the driver-vehicle interaction.

The wheel-loader driver was exposed to low frequency vibration resulting from regular pitching motions of the vehicle while riding on uneven surfaces. Therefore, analysis was performed on a normalized NIAE wood track. A representative fore-and-aft acceleration signal of the carrying operation of a wheel loader was selected for laboratory reproduction to assess seat performance. Spectral analysis of the signal showed that peak energy occurred at a frequency of around 1.6 Hz.

During specific tasks, like filling the bucket, the operator was exposed to instantaneous shocks with high peak magnitudes. Bucket-loading tests were performed in order to characterize these shocks. Shock signals may be typified by a triangle signal, where the acceleration reaches a maximum value of 4.5 ms^{-1} at 0.1 second and decreases in a second phase to reach 0 at 0.9 second.

Figure 3.1.6 The industrial loader Volvo L70C at work

Figure 3.1.7 The four views recorded in the cab: hands location, contact area back/backrest, fore-and-aft suspension, feet position

Three cameras were used to film the driver's posture and movements by focusing on the feet, hands and contact area between the back and the backrest (Figure 3.1.7). A fourth camera, mounted inside the cab, recorded the relative displacement of the fore-and-aft suspension. The fifth camera filmed the motion of the loader. Video footage was synchronised to the measured motion to facilitate detailed analysis. The loader Volvo L70C underwent tests on different test tracks, asphalt roads and field roads with loading cycles with soil and gravel. Further details are provided in Annex WP1-2.

<u>Field tests phase II</u>

In Spring 2005 BLT began a second series of field tests, repeating tests with agricultural tractors (Figure 3.1.8) and industrial loaders (Figure 3.1.9) with a modified KAB seat. The same vehicles, test tracks and conditions to enable comparison of the results with those of

Figure 3.1.8 The agricultural tractor **Steyr CVT 135 at the 100 m test track**

Figure 3.1.9 The industrial loader **Volvo L70C on the 35 m test track**

the first test series.

Most of the tests were conducted on standardised test tracks which enabled the reproduction of the test motion in all weather conditions. The test tracks were formed from slats of wood mounted on steel beams. A 100 m long bumpy test truck was used to simulate rough driving conditions on field roads. A 35 m long very bumpy test track was used to simulate the driving conditions on rough field roads or on the field. The left and right sides of the 35 m test track were different, producing different lateral motions of the vehicle.

BLT received alternative KAB seat components to modify the KAB 85 /E1 seat. During the tests, comments from the driver on the seat and operation of the vehicle were recorded. A second field test report was conducted. A test report, data and video files were prepared.

Results of the field tests with off-road vehicles

The frequency weighted r.m.s. (root-mean-square) values of the accelerations in the x, y and z direction on the surface of the seat cushion were calculated and analysed for a series of field tests for both types of vehicles.

For the agricultural tractor, there was little difference in the results for the unmodified compared with the modified seat for low driving speeds and good road conditions. With increasing driving speeds and more bumpy tracks, the vibration in each translational axis on the seat cushion of the modified seat was lower than for the unmodified seat. For tests on the 35 m track with the modified seat with a suspension system in the lateral direction (y-axis), the r.m.s. values were higher than the values of the unmodified seat. This may have been because of hard end-stop impacts in the lateral direction.

For the industrial loader, the modified seat performed generally better than the unmodified seat. For increasing speeds, in all translational axes, the performance of the modified seat was increasingly better than for the unmodified one. However, there was no improvement in the results of the modified seat as against the unmodified seat for loading cycles when loading soil at the site. This may have been due to the very flat terrain at the site, which did not produce any lateral motion. The driver of the loader reported improved seat comfort when using the modified seat on the test tracks, especially at increased driving speeds.

It was concluded that at low driving speeds or very good track conditions the lateral suspension did not improve ride. In some conditions, discomfort was caused by seat displacement in the lateral direction. For these conditions, the lateral suspension may be disabled or locked by the driver. However, when driving on bumpy or very bumpy tracks with increasing speeds, the modified seat produced lower accelerations and therefore increased seat comfort. Further details are provided in Annex WP1-3.

3.1.4 Railway vehicle field motion measurements

Field tests were conducted on a railway vehicle by SNCF.

Field tests phase I

The first field tests were conducted on a railway vehicle in December 2002. The tests were conducted with a GRAMMER seat, labelled "DRIVER SEAT MSG 95AL/741", equipped with 3-D axial suspension device: pneumatic (air spring) in the vertical direction and mechanical (damper and spring) in longitudinal and transversal directions. The seat was installed in a cabin of a SNCF locomotive BB 8700 type for the purpose of the test. The old locomotive, which was used in a double unit on the Chambery-Modane line, was chosen for its capacity to generate vibrations of high magnitudes.

Figure 3.1.10 SNCF locomotive on the rail track

Figure 3.1.11 Vibration behaviour tests on the SNCF locomotive

The results were reported in a technical report. The main document describes the test conditions: seat, vehicles and track characteristics; measurement device; configuration evaluated (speed, suspension stiffness setting, driver mass, track quality) and the data processing; calculation of comfort (according to ISO and SNCF railways standards and UIC 513 leaflet), evaluation of the vibration effects on health (according to ISO 2631 and NF E 90401-2), calculation of seat transmissibility (according to ISO 10326-2) and the results obtained, indicating the zones of interest for further analyses. A CD-ROM was prepared which contains about 3h 40min of data acquisitions shared in eight different tests and a selection of ten 5-minute video acquisitions recorded during the measurements. Full details of the Phase I field tests are provided in Annex WP1-5.

Phase II field tests

A further similar set of field tests were conducted on a railway vehicle in March 2005. The objective was to test a seat with suspension characteristics proposed as a result of work conducted under WP5.

The same vehicle as used for Phase I was not available for the Phase II tests. Therefore, to enable comparison of the original and optimised seats, tests were conducted with both seats on the same locomotive (BB17000 type) and with the same driver. The track, which ran between Épernay and Rethel, was the same for both the seat tests. Full details of the Phase II field tests are provided in Annex WP1-6.

The measurements obtained were analysed by IMMM in the context of WP5.

3.1.5 Marine craft field motion measurements

Field tests on small marine craft were carried out by ISVR.

The participation of ISVR in WP1 involved two main activities. The first activity was field tests on small marine craft.

Field tests - activity I

The marine craft field motion measurements for the VIBSEAT project took place during April 2003 on a Royal National Lifeboat Institution (RNLI) prototype FSB2 lifeboat (Figure 3.1.12 and 3.1.13). Situations that caused discomfort or resulted in difficulty in operating the controls were identified from discussion with boat crews. Measurements of the motion of the deck and the seat were obtained during these conditions.

Figure 3.1.12 The marine craft FSB2 on sea trials

Figure 3.1.13 Coxswain's position showing steering joystick

Discussions with RNLI crewmembers identified the condition where the boat was travelling directly into the waves ('head into sea') as the condition most likely to cause discomfort or difficulty operating the boat. Motion measurements were obtained for two test conditions including the 'head into sea' condition. The vibration isolation performance of the helmsman's seat was summarised and the time histories and video were converted into ASCII and MPEG format respectively. A report, video and data files was distributed to the project partners.

Analysis - activity II

The second activity was to assess the performance of the seats fitted to all the vehicles used in the field trails in response to selected vehicle motions identified by the partners responsible for running the field tests.

The power spectral density (PSD), frequency-weighted root-mean-square (r.m.s.) acceleration and the vibration dose value (VDV) were determined for the vibration at the base of the seat in each vehicle in each translational axis. The peak and r.m.s. roll and pitch acceleration were estimated.

The performance of the suspension mechanism, cushion and complete seat fitted to each vehicle was evaluated in each translational axis in terms of the complex transfer function and the seat effective amplitude transmissibility (SEAT) value calculated from the frequency-weighted r.m.s. acceleration and the VDV.

It was observed that the marine craft showed negligible difference in *z*-axis SEAT value in terms of r.m.s. acceleration, but a reduction in *z*-axis SEAT value in terms of the VDV. This is consistent with the manner in which the marine craft operators were using the seat; the seat was set to the maximum driver weight adjustment at all times to allow maximum downward displacement to absorb occasional shocks and avoid bottom-stop impacts, rather than to isolate vibration. The marine craft results indicate that both accelerometer arrays and rotational velocity sensors may be used to estimate rotation over a specified bandwidth. However, careful attention should be paid to the signal processing and numerical integration methods used to estimate the vehicle roll and pitch.

Further details are provided in Annex WP1-4.

3.1.6 Summary table of field test results

Table 3.1.1 is a summary table of the field test results with the different types of unmodified and modified seats (Grammer, Isringhausen and KAB) and different kinds of vehicles.

Frequency weighted r.m.s. acceleration at the seat cushion

test vehicle and conditions		kind of seat	x direction (fore-and-aft) [m/s^2]	y direction (lateral) [m/s^2]	z direction (vertical) [m/s^2]
Truck Volvo FH 16 and semi trailer Schmitz, seat Isringhausen					
constant speed 70 km/h on road		seat	1.72	0.12	0.35
		modified seat	0.23	0.14	0.4
acceleration from 0 to 50 km/h, constant speed and braking to 0 km/h on road		seat	1.94	0.09	0.25
		modified seat	0.26	0.10	0.29
Agricultural tractor Steyr CVT 135, seat KAB					
100 m test track	10 km/h	seat [1]	0.43	0.83	0.95
		modified seat [2]	0.48	0.77	0.95
	24 km/h	seat [1]	1.19	1.31	5.14
		modified seat [2]	1.07	1.17	3.81
35 m test track	3 km/h	seat [1]	0.59	0.82	0.60
		modified seat [2]	0.61	0.93	0.55
	5 km/h	seat [1]	0.92	1.61	1.38
		modified seat [2]	0.97	1.80	1.12

[1] seat with x, y suspension plate / x suspension active, y suspension locked

[2] seat with x, y suspension plate / x, y suspension active

test vehicle and conditions		kind of seat	x direction (fore-and-aft) [m/s^2]	y direction (lateral) [m/s^2]	z direction (vertical) [m/s^2]
Industrial loader Volvo L70 C, seat KAB					
100 m test track	8 km/h	seat [1]	0.76	0.92	1.14
		modified seat [2]	0.57	0.95	0.9
	14 km/h	seat [1]	1.52	1.06	3.08
		modified seat [2]	1.41	0.95	2.19
35 m test track	4 km/h	seat [1]	1.00	2.06	1.48
		modified seat [2]	0.76	1.64	1.01
loading cycle	- km/h	seat [1]	0.60	0.36	0.54
		modified seat [2]	0.64	0.39	0.57

test vehicle and conditions		kind of seat	x direction (fore-and-aft) [m/s^2]	y direction (lateral) [m/s^2]	z direction (vertical) [m/s^2]
SNCF railway vehicle - BB 17000 locomotive, seat Grammer					
Épernay – Rethel line (n°M1A1)	90 km/h	seat	0.50	0.23	0.15
Kilometric point 143 (n°M3A1)	90 km/h	modified seat [3]	0.41	0.22	0.12
Épernay – Rethel line (n°M9A1)	50 km/h	modified seat [3]	0.33	0.22	0.11
Kilometric point 143 (n°M5A1)	90 km/h	modified seat [4]	0.48	0.22	0.11
Épernay – Rethel line (n°M9A1)	50 km/h	modified seat [3]	0.33	0.22	0.11
Kilometric point 143 (n°M7A1)	? km/h	modified seat [5]	0.39	0.22	0.13

[3] vertical suspension setting: minimum stiffness / x, y, z suspensions active

[4] vertical suspension setting: medium stiffness / x, y, z suspensions active

[5] vertical suspension setting: minimum stiffness / x, y suspensions locked

test vehicle and conditions		kind of seat	x direction (fore-and-aft) [m/s^2]	y direction (lateral) [m/s^2]	z direction (vertical) [m/s^2]
Marine craft RNLI prototype FSB2 lifeboat, seat KAB					
head into sea condition		seat	-	-	-
		modified seat	no similar sea conditions – no tests – no results		

Table 3.1.1 Summary table of field test results

3.1.7 Workpackage 1 Conclusions

Current production seats with known dynamic characteristics have been provided for use in field trials and laboratory studies.

WP1 successfully provided digitised time histories of the translational and rotational motions of off-road and on-road vehicles, rail vehicles and small marine craft that were typical of the input to the seats and suitable for dynamic seat performance tests.

Partner experience has enabled the provision of summary information on measurements within typical vehicles with typical motions.

Digitised and summary measurements of the performance of current production and modified seats in each vehicle have been provided in individual reports. Technical reports summarizing the main results and analyses of field testing and comparing unmodified and modified seats have been provided and are included as annexes to this report.

A summary table of field test results with unmodified and modified seats has been provided.

3.2 Workpackage 2 – Subjective factors led by FIOSH

3.2.1 Aim of workpackage 2 and partners

The aim of Workpackage 2 was to assess the effect of lateral/rotational motions on subjective discomfort and the ability to perform relevant tasks. Three partners participated in this workpackage – FIOSH, ISVR, and SNCF.

3.2.2 FIOSH activities

3.2.2.1 Objectives

The optimal design of driver seats with horizontal suspension requires knowledge of human response with respect to the perception of the vibration intensity and seat comfort and of the performance in motor tasks.

Investigations were conducted to determine whether magnitude and direction of horizontal whole-body vibration, and the relative motion between the operator seat and the horizontal suspension control elements, influence the judgement of the vibration intensity, comfort, effort or performance (motor task) during the operating task.

3.2.2.2 Methods

Experimental studies using Seat 1 (Isringhausen, suspension in x-direction)

An investigation was conducted with Seat 1 (Isringhausen, suspension in x-direction). The test signal was a reproduction of motion measured on a modified Volvo Truck seat. The signal consisted of vibration in the x-direction at three magnitudes with a duration of 166 s. The stimuli were presented in a balanced order with a biaxial xy reference signal. The test was conducted with the suspension in the x-direction both locked and activated and with the suspension in the z-direction always fixed.

Experimental studies using Seat 2 (Grammer, suspension in x- and y-direction)

An investigation was conducted with Seat 2 (Grammer, suspension in the x- and y-direction). The test signal was a reproduction of motion measured on a modified Tractor Deutz 150 seat. The signal consisted of vibration in the x- and y-direction at three magnitudes with a duration of 166 s. The stimuli were presented in a balanced order with a biaxial xy reference signal. The test was conducted with the suspension in the x- and y-direction both locked and activated and with the suspension in the z-direction always fixed. Figure 3.2.1 shows the mean, maximum and minimum of the acceleration for excitation in the x- and combined xy-axes for seat 2.

Measurements

Translational accelerations (x,y,z) was measured at the seat base, seat frame below the seat cushion and above the suspension, and on the seat cushion and backrest. The relative motions between the body parts (head, hand, right foot, right knee, left hip, including different angles) and platform, seat, pedals (motion analyses) were determined. Subjective judgements were recorded. Responses were obtained from questions on the length of a line, vibration intensity, seat comfort and the effort to carry out the reaction test. Reaction times were determined for eight breaking periods and eight acceleration periods presented in a randomised order (for time points see Section 3.2.2.3).

Subjects and posture

Twelve healthy, male university or advanced technical college students participated in the investigation. The body mass of the subjects ranged from 59.0 kg to 97.3 kg and the body height from 163.7 cm to 197 cm. The subjects adopted an upright relaxed posture using the backrest and the hand support. The right foot was placed between the brake and the accelerator for the first 60 seconds of the exposure. The angles between parts of the body were typical for bus and coach drivers as given in the literature.

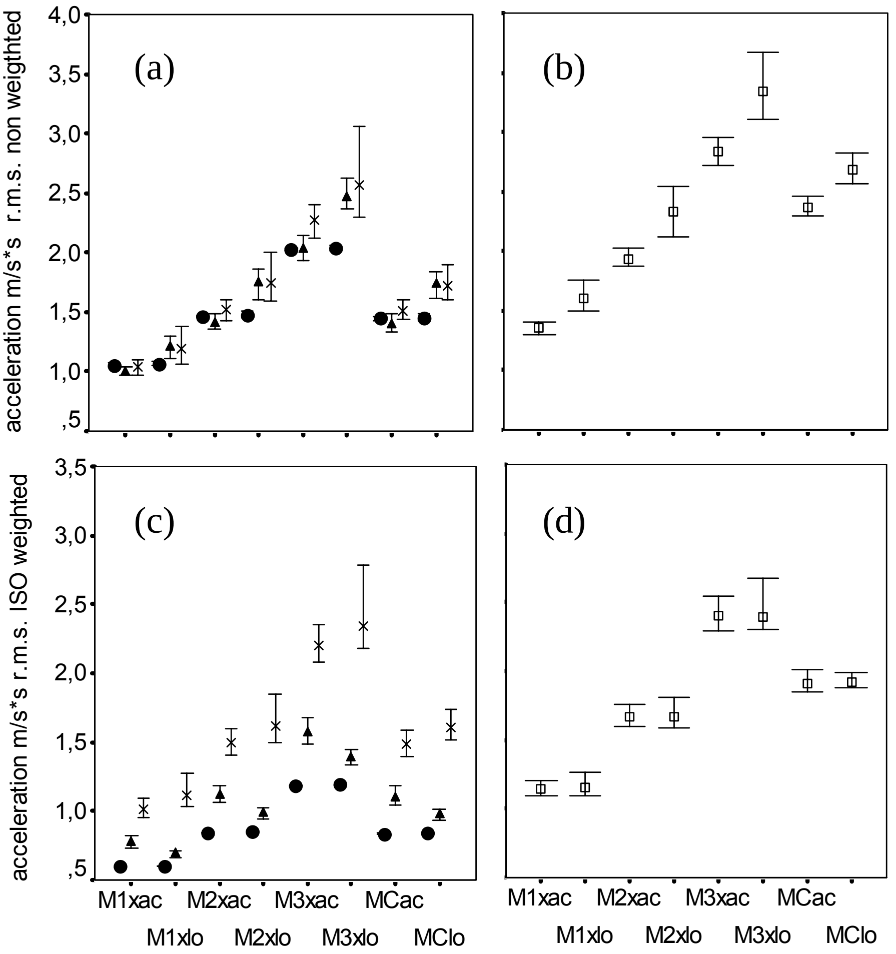


Figure 3.2.1 Seat 2, Mean value, maximum and minimum of the acceleration (r.m.s., 2.-25. s of exposure). Excitation in the x- and combined xy-axes. Vibration magnitudes M1, M2, M3 and MC. Suspension ac = activated, lo = locked. (a), (b): non weighted values (c), (d): w_k-, w_d- and w_c-weighted values according to ISO 2631-1. (a), (c): measuring points (measured in x-direction) ● platform, ▲ cushion, × backrest. (b), (d): overall vibration total value according to ISO 2631-1, but (b) calculated with non weighted values.

3.2.2.3 Results

The intensity judgements increased significantly with increasing vibration magnitude. They were higher for the locked suspension (Seat 1 insignificant, $p = 0.066$, Seat 2 significant $p < 0.037$). For example, Figure 3.2.2 shows the mean values of judgements of the vibration intensity for the experiment with Seat 2. With only some exceptions, the judgements of the seat comfort decreased significantly with increasing magnitude and time with locked suspension. The effort judgements increased significantly with increasing magnitude and time and revealed a tendency towards a lower effort with activated suspension. The reaction times showed no significant influences of vibration magnitude, suspension or time, but higher demands seemed to be compensated by enhanced effort. The w_d-weighting did not adequately reflect the perceptions for the frequency spectra applied in this study in the x-axis. Further analyses of data obtained from Seat 2 revealed that a modified overall vibration total value determined from the unweighted accelerations instead of the weighted ones (ISO 2631-1) was correlated with the subjective judgements in the case of exposure in the x- and xy-directions.

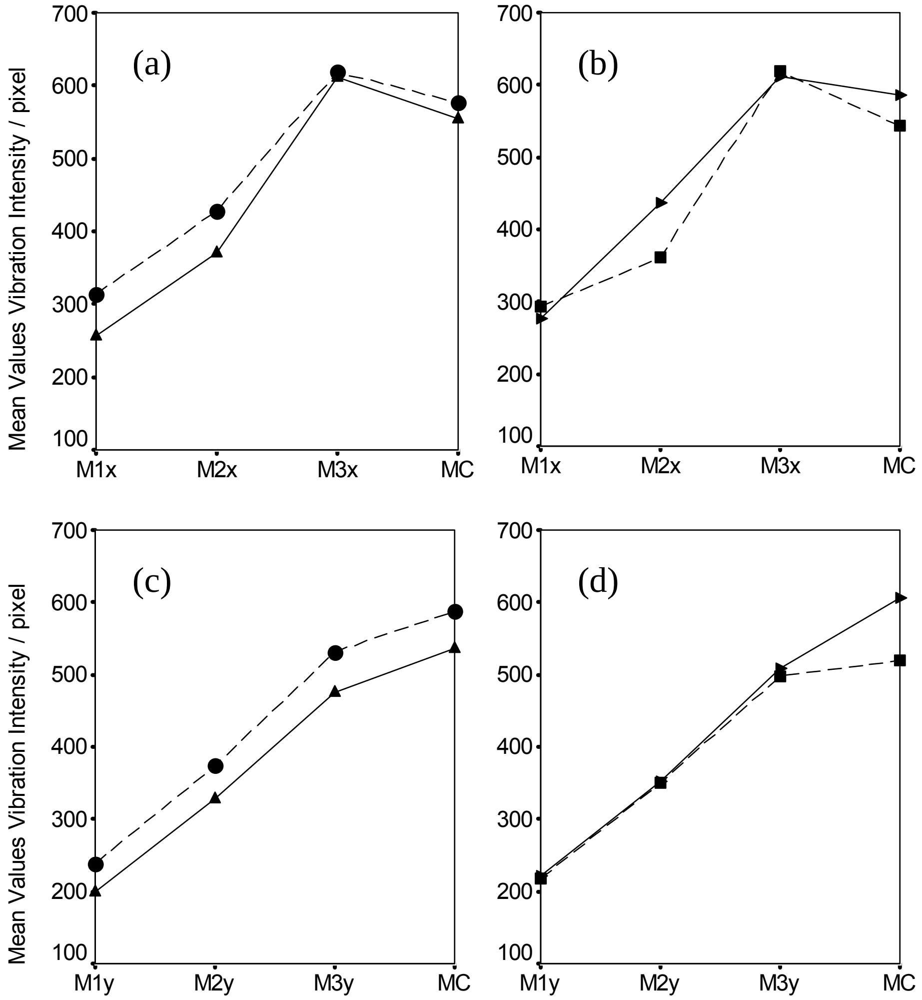


Figure 3.2.2. Seat 2, Mean values of judgements of the vibration intensity (length of a line in pixel). Vibration magnitudes M1, M2, M3 and MC. (a), (b): Excitation in the x- and xy-axes. (c), (d): Excitation in the y- and xy-axes. (a), (c): ● suspension locked, ▲ suspension activated. (b), (d): ■ repetition 1, ► repetition 2.

3.2.2.4 Conclusions:

W_d-weighting may inadequately reflect the perception of vibration intensity, seat comfort and effort. Further development of the frequency weighting is required. For excitations in the x- and xy-directions similar to those tested with Seat 2, an overall vibration total value calculated with the unweighted accelerations seems to be the most appropriate method for the evaluation of the perceptions investigated in the present study. In general, a clear definition of vibration ‘comfort’ and/or ‘discomfort’ is recommended with consideration of different psychological dimensions associated with these terms and with regard to the large variety of semantic terms that are employed in Europe. Subjective judgements concerning ‘vibration intensity’ probably deliver more precise results, maybe, because ‘intensity’ is a less ambiguous wording and exists presumably in any language. The performance of simple choice reaction tasks can remain stable, even with a somewhat increased mechanical interference caused by a horizontal seat suspension. The potential compensation of higher demands with enhanced effort to carry out motor tasks should be considered with prolonged exposure times.

A full description of the activities of FIOSH can be found in Annexes WP2-1 and WP2-2.

3.2.3 ISVR activities

3.2.3.1 Objectives and research structure

A study was designed to determine the rate of growth of discomfort, the absolute level of discomfort, and the principal locations of discomfort arising from exposure to roll, lateral, pitch and fore-and-aft oscillation of subjects seated on a flat rigid seat and on a rigid seat with a backrest. The study also tested whether exposure to rotational and translational stimuli in the same plane, with matched accelerations in the plane of the seat, results in similar rates of growth of discomfort and similar absolute discomfort. The study design is shown in outline in Figure 3.2.3.

3.2.3.2 Overview of methods, stimuli, equipment and procedure

Methods and stimuli

Throughout this investigation the method of magnitude estimation, in which subjects judged the discomfort caused by exposure to a test motion relative to a fixed reference motion, was used to establish the rate of growth of discomfort arising from exposure to motion. Full descriptions of the methods used can be found in Annex WP2-3. Sinusoidal stimuli 30 seconds in duration were used in all experiments.

Motion was produced using facilities at the Human Factors Research unit in the Institute of Sound and Vibration Research. Single frequency experiments comparing the discomfort arising from exposure to roll and lateral, and pitch and fore-and-aft oscillation were conducted using a 12-metre long-stroke simulator as shown in Figure 3.2.4 (a). Translational motion for all other conditions was generated using a 1-metre horizontal electro-hydraulic vibrator which has a maximum stroke of 1 m peak-to-peak. Rotational motions were obtained with a rotation simulator which was driven via a crank by the 1 m horizontal vibrator (Figure 3.2.4b). In all motion conditions, subjects were seated on a rigid seat with or without a backrest and harness (Figure 3.2.4). The seat surface was 420 mm above the simulator platform, and in rotational conditions subjects were seated at the centre of rotation. The acceleration in the plane of the seat was measured using appropriate transducers.

Subjects were instructed to maintain a comfortably upright posture throughout the experiments and to make judgments of the discomfort caused by the motions. The studies were approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research.

All subjects who participated in this research were aged between 18 and 30 years and were staff or students at the University of Southampton.

Results

When subjects were exposed to translational and rotational oscillations with matched accelerations in the plane of the seat they experienced approximately equal discomfort at frequencies between 0.2 and 0.4 Hz. At higher frequencies, subjects were more sensitive to rotational than to translational motion.

The presence of a backrest increased the discomfort experienced during exposure to rotational motion at frequencies greater than 0.5 Hz. However, during exposure to lateral oscillation the presence of a backrest reduced the discomfort experienced by subjects at frequencies between 0.25 and 0.4 Hz.

The results showed that the discomfort arising from rotational and translational motions has a broadly similar character below 0.5 Hz, while above 0.5 Hz subjects were more sensitive to rotational than to translational oscillation (Figure 3.2.5). Full details are provided in Annex WP2-3.

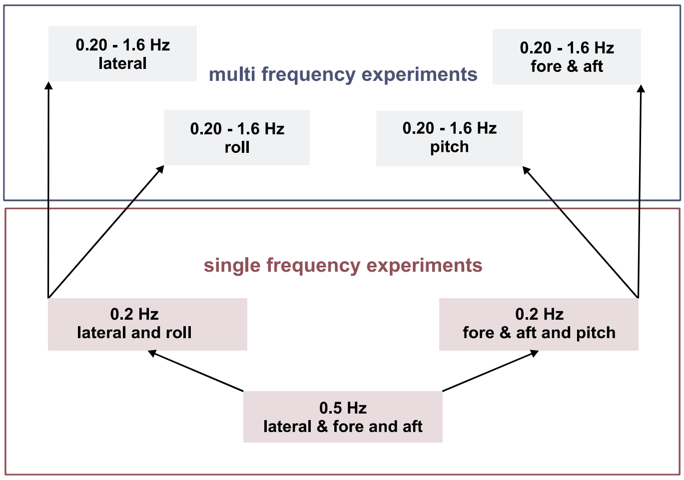


Figure 3.2.3 Structure of the research described in this report

Conclusions

For accurate prediction of the discomfort occurring when persons are exposed to acceleration in the plane of the seat, it is necessary at frequencies greater than 0.4 Hz to know how much of the acceleration in the plane of the seat is due to rotation and how much is due to translation.

The presence of a backrest increases the sensitivity of exposed persons to rotational oscillations at frequencies greater than 0.4 Hz. However, during exposure to lateral oscillation the opposite effect occurred between 0.25 and 0.4 Hz. The utility of a backrest therefore depends critically on the operator environment.

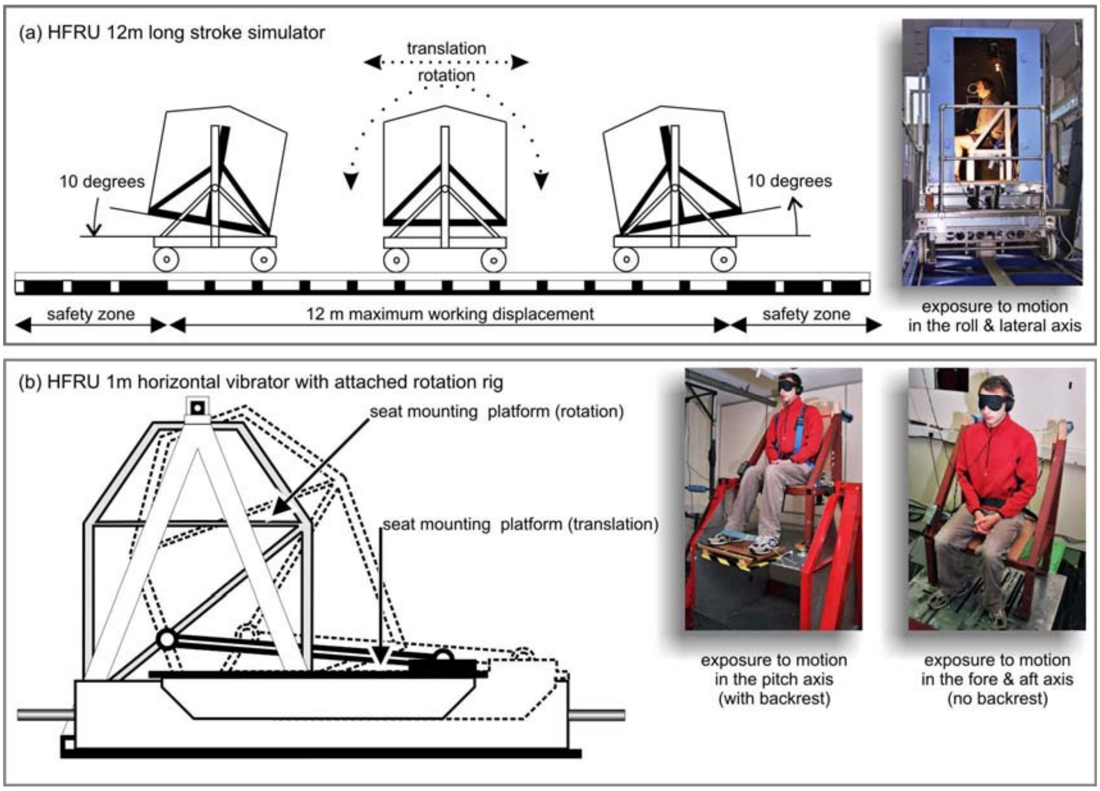


Figure 3.2.4. The equipment used to generate motions during the experiments described in this report.

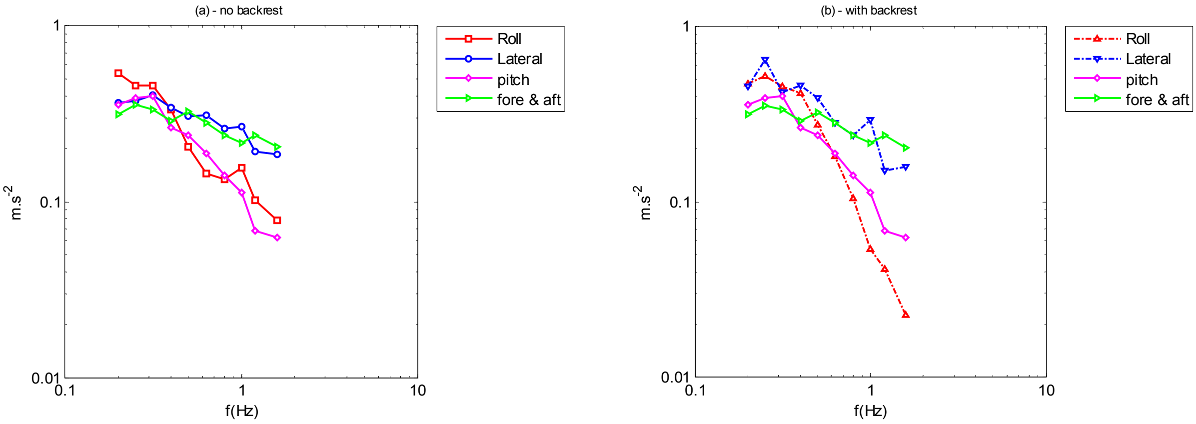


Figure 3.2.5 Combined results showing the variation in the level of the equivalent comfort contours resulting from exposure to roll, pitch, lateral, and fore-and-aft oscillation on a flat rigid seat (a), and on a rigid seat with backrest (b).

3.2.4 SNCF activities

3.2.4.1 Aims and Objectives

SNCF conducted experiments with the aim of designing a test procedure for a rail cab simulator (SIMUFER) which was used for tests aimed at improving of the efficiency of seat suspension systems. The objective was to evaluate the effects of vibration and displacement on the driver's capacity to control the vehicle.

A review was completed of the small number of studies which have been conducted of a drivers' capacity to control his vehicle in a vibratory environment.

In order to be able to build a realistic test protocol on the railway simulator, preliminary studies were conducted. Field working conditions on eight different kinds of locomotives were examined by an ergonomics specialist. Perturbations of a driving task due to vibration were recorded. Interviews were conducted with drivers, doctors and experts in ergonomics and human factors.

The test procedure was devised on the assumption that lateral displacements and accelerations have a significant effect on postural stability, reading tasks and driver movements.

Accelerations perturb driving tasks. However, the magnitude-dependence of the effect on various tasks performed by a driver are not precisely known. The use of a suspension to limit acceleration levels introduces horizontal displacements. The positive and negative effects of these displacements on the ability of the driver to control his vehicle have never been studied.

3.2.4.2 Methods

Test conditions

Nine different drivers aged between 34 and 47 years participated in the study. The drivers had a driving experience of between 6 and 25 years. The participants completed driving tasks of 50 minutes duration, consisting of 15 reading tasks and 15 handling tasks, accomplished with and without vibration. For each driver, the tasks were repeated with motion simulation of the same railway line and the same floor vibration but with three different seat suspension characteristics: free (d_y=±40mm), damped (d_y=±20mm) and locked (d_y=±0mm).

For each driver, the tests took place over two days, during which time each driver completed four runs on the simulator. The drivers completed one training session. Before the first run, the drivers were provided with an explanation of the objectives of the study. The training session was used as a reference, allowing the drivers to familiarise themselves with the simulator. During this session, which lasted about 20 minutes, the drivers experienced all the actions that were going to be carried out during the other three sessions, but without vibration. After the training session, the driver drove three times on the virtual line created for this study. Each of the three sessions lasted about 50 minutes and the order of sessions changed for each driver.

The tuning of the transversal suspension of the seat varied for each session. During Session 1, the shock absorber of the transversal suspension of the seat was removed, the maximal transversal displacement of the seat was ± 40mm (the suspension works only with a spring);

In Session 2, the transversal suspension of the seat was active (spring + shock absorber). The maximal transversal displacement of the seat was ± 20mm.

In Session 3, the transversal suspension of the seat was locked, the transversal displacement of the seat was 0 mm.

For each session, the vibration on the floor was the same and alternated regularly between periods of high and low vibration magnitude.

Test measurements

The following information was recorded:

- Video acquisitions of all 27 sessions;
- Verbalisation of actions (with required reading tasks) and driver responses;
- An interview after each session,
- Events and driver actions on the simulator,

- x-,y- and z-axis acceleration at the floor and seat and lateral suspension displacement.

Analysed parameters

Various data on the effect of accelerations and displacements on driver's activities were reported during the tests. This information was classified according to the following ergonomics methods:

- Behaviour indicators (collateral activities) using video acquisitions and questionnaires;
- Posture using video acquisitions;
- Reading tasks using verbalisation during the test;
- Professional gestures and security devices using simulation data acquisition.

Along the 61 kilometres of travel, different events were introduced, requiring the driver to make decisions, actions and gestures. Thus, it was possible to observe a large number of actions.

In addition to verbalisations during the journey, semi-directive interviews after each run on the simulator and videos of the driving were conducted in order to determine the influence of the different relative vibratory conditions on the driving activities.

Test organisation

A description of the purpose of the test was presented to the drivers. All the necessary documents used by a driver to accomplish his tasks according to a specific line were completed, including the train schedule, technical information and a line description.

3.2.4.3 Results

After all the tests, six drivers out of nine estimated that the driving sensation on the simulator was "rather realistic" and the three others estimated that the sensation was "very realistic".

Seven drivers out of nine estimated that the quality of vibrations felt in the cabin were either "rather realistic" or "very realistic".

The discomfort felt on the seat when driving

The data analysis provided the following results:

The lock of the transversal suspension (Session 3) increased significantly the discomfort felt by drivers, especially at the level of the trunk (neck, shoulders, back, lumbar) and of the upper members.

The lack of transversal suspension absorber (Session 1) generated some important movements of the seat in relation to the cabin, which increased the discomfort felt at lower members, especially at the feet.

The transversal suspension (Session 2) had a tendency to equalise the different levels of discomfort, which led to better overall comfort during the drive.

There is a clear difference in the discomfort felt between Session 3 and the two other sessions. When the transverse suspension was locked, drivers felt more stressed by the transversal vibrations and all drivers felt that the drive was more tiring.

When the shock absorber of the transversal suspension was removed (Session 1), drivers expressed that it was more often necessary to reposition themselves on the seat in order to keep the correct position for the drive.

A similarity between the three sessions was noticed, since maximum discomfort was felt at the level of hips.

The different affected tasks

The *inside* visual controls:

It appeared that the precise reading of certain indications on the control desk was made more difficult when the transversal suspension of the seat was locked (Session 3), requiring the drivers to adopt different operative modes (memorisation of data, posture changing etc.).

The *outside* visual controls:

The results obtained also showed that reading of the outside visual controls was more difficult when the transversal suspension was locked (Session 3). Nevertheless, these results remain difficult to interpret because some drivers estimated that perception of distances and signalling on the simulator was altered.

Actions and gestures achieved on the control desk

When the transverse suspension was removed (Session 1), the most affected tasks were the holding of the pedals with the feet and the manipulation of the radio.

When the transversal suspension was locked (Session 3), the manipulation of the cut-out and notably, closing, was difficult because it required a precise and prolonged tactile touch of some seconds. Drivers deferred the action, waiting for a more favourable vibratory environment.

3.2.4.4 Conclusions

The transversal vibratory constraints tend to a significant increase in the general work load of the drivers (mental and physical), making some tasks more difficult.

The discomfort felt and the ability to achieve some tasks depended on the characteristics of the suspension (three were tested in this study).

Very interesting results were obtained in the study conducted on the driving simulator. However, in spite of all the measures taken, differences between simulated and real driving situations remain. In this study, it is necessary to conduct the same set of tests in real situation to confirm the conclusions.

A full description of the activities of SNCF can be found in Annex WP2-4.

3.2.5 Workpackage 2 conclusions

Studies have been conducted to investigate the effect of frequency, magnitude and direction. The results indicate a qualitative influence, and for some factors a quantitative effect, on perceived intensity, comfort, effort and driver control.

For accurate prediction of the discomfort occurring when persons are exposed to acceleration in the plane of the seat, it is necessary at frequencies greater than 0.4 Hz to know how much of the acceleration in the plane of the seat is due to rotation and how much is due to translation.

A backrest increased the sensitivity to rotational oscillations at frequencies greater than 0.4Hz; it decreased the sensitivity to lateral oscillations at frequencies between 0.25 and 0.4 Hz. Further work is required to obtain the effect of backrest in a wider range of frequencies and situations.

Performance of some tasks may be maintained by increased effort, in spite of increased mechanical interference due to horizontal suspensions.

W_d-weighting may inadequately reflect the perception of vibration intensity, seat comfort and effort. Further development of the frequency weighting is required.

Precise definitions of the terms "comfort" and "discomfort" would allow consistent interpretation of these terms in different European countries.

For certain biaxial excitations, a modified "overall vibration total value" (determined from the unweighted accelerations) might be appropriate for vibration evaluation.

In a simulation of a train driving environment, horizontal suspension had a significant beneficial effect on discomfort, experienced effort and performance of train drivers.

Observed positive effects of horizontal suspension on the well-being and performance of train drivers require confirmation in real situations.

The reduction of lateral (y-axis) accelerations had a beneficial influence on discomfort and performance of manual and visual tasks. The effect was limited by an increase in relative stroke between the seat cushion and the driver’s feet, which had a detrimental effect on tasks involving the feet.

3.3 Workpackage 3 – Objective factors led by ISVR

3.3.1 Overview

The activities planned for workpackage 3 were the measurement of the dynamic characteristics of the seat suspensions to be used during this project, the development of prototype seats, assessment of the performance of the original and prototype seats in the laboratory, and measurements of the mechanical impedance of the human body. This information is required for the development of theoretical models carried out under workpackage 5 and for the development of a testing method under workpackage 4.

This workpackage has seen close and effective co-operation between the theoretical modelling groups and laboratories involved in the measurement of the dynamic response of the seats and the seated human body. At the third project meeting it was decided to alter the project plan to allow this process to continue. The project plan anticipated a series of seat component measurements to be conducted during the first nine months of the project. However, it has proved more useful to carry out a number of specifically targeted laboratory tests as required by the current state of the mathematical models. The due dates of for this deliverable (‘D3 Measurements of seat component dynamic properties’) and the associated project Milestone (‘M3.1- Seat component measurements complete’) were therefore removed as this activity continued as required throughout the project.

Prototype suspension seat systems have been developed by ISRI and GRAMMER and laboratory testing has been completed.

Human body apparent mass measurements have been carried out. The decision was also taken to move the responsibility for the development of theoretical models of the human body from workpackage 3 to workpackage 5 to allow the seat and body models to be developed as an integrated entity.

3.3.2 ISVR Activities

The response of the body in the lateral direction has been reported in very few studies and the body response to roll motions has not been investigated. ISVR have conducted a series of studies to measure the apparent mass of the human body in response to lateral and roll motions with varying seating conditions. In the first study, the lateral apparent mass was measured at the seat surface using a rigid flat seat with no backrest. The axis of rotation of the roll motions was also at the seat surface. Tests were conducted using pseudo-random motions band-limited at 0.2 and 2 Hz reproduced with three magnitudes of seat surface lateral acceleration. The lateral apparent mass, normalised with respect to the subject sitting weight, was found to be greater in response to roll vibration than in response to lateral vibration over the frequency range investigated. Annex WP3-1 provides full details of the results.

In the second study, the influence of a back restraint on the lateral apparent mass of the seated human body in response to lateral and roll motions was investigated. The lateral apparent mass of the seated human body with and without a backrest and harness was measured using 0.2 to 2.0 Hz band-limited random motion. Force and acceleration were measured during exposure to lateral and roll oscillation of a seat surface with the axis of measurement in the plane of the seat surface. Apparent mass was determined with subjects in a comfortably upright sitting posture with no backrest contact, and in a posture with the back in contact with a wooden backrest with the upper body restrained by a four-point harness. The lateral apparent mass (in response to roll vibration and lateral vibration) was significantly greater for the ‘harnessed’ posture than for the ‘back-off’ posture at frequencies between 0.6 and 1.1 Hz. The magnitude of the difference was greater with roll vibration than with lateral vibration. Annex WP3-2 provides full details of the results.

These studies showed clear differences between the apparent mass in response to lateral motion as compared to roll motion and a clear influence of the seat backrest. These results have been made available to the consortium and presented at the 38th and 39th United Kingdom Conferences on Human Response to Vibration (Annex WP3-1 and WP3-2).

A seat component measurement rig has been developed and has been used to provide seat component dynamic information for use in the mathematical models. A series of tests to measure vertical seat suspension response required for the model development have also been carried out to a specification developed in collaboration with IMMM.

Laboratory evaluations of the performance of prototype seats have been conducted. Three laboratory tests have been conducted on ISRI truck seats: (a) original, unmodified seat (b) seat with a shock absorber and (c) seat with a prototype spring. Test reports has been made available (see Annex WP3-3 and WP3-4). The expected improvement with the prototype truck seat was not shown in the laboratory measurements. A modified GRAMMER seat, which was initially provided to FIOSH to use during assessment of the workpackage 4 test protocol, has been assessed by the ISVR and a test report has been provided (Annex WP3-5). One KAB seat fitted with vertical, fore-and-aft and lateral suspensions was tested in the fore-and-aft and lateral directions by the ISVR and a test report has been provided (Annex WP3-6).

The following observations were made during the laboratory evaluations:

Checking that the r.m.s values of the acceleration at the seat alone are correct can be misleading. The experimenter must check that the power spectral density of the measured signal is 'the same as' the power spectral density of the specified signal;

The r.m.s error is a sensitive measure of errors in reproducing the desired acceleration time history;

The use of a rigid mass in situations involving end-stop impacts in the fore-and aft suspension can cause the mass to slide off the front of the seat. It is necessary to secure the mass to the seat;

Some subjects suspected loss of contact between the lower backrest and the back during some tests, particularly with the loader and marine craft motions.

3.3.3 INRS Activities

3.3.3.1 Laboratory testing to characterize fore-and-aft suspension features

Tests conditions

One seat and two additional fore-and-aft suspensions were supplied to INRS by KAB-Seating. The seat is made up of several parts including the seat cushion, the backrest, the vertical and the fore-and-aft suspension. The fore-and-aft suspension features were investigated to estimate the fore-and-aft vibration isolation performance of the seat.

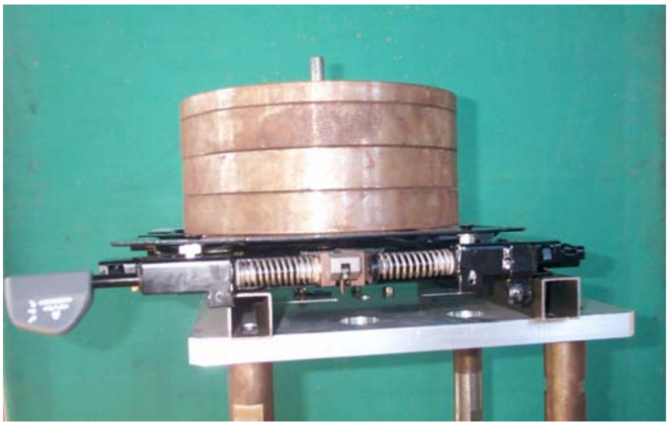


Fig. 3.3.1 Device mounted on a shaker to identify the mechanical features for each suspension component

The fore-and-aft suspension was dismantled in order to test separately each component including the springs, damper, end-stop buffers and glide system. Each spring has a stiffness of about 5000 Nm^{-1}. The damping coefficient of the damper was measured at 600 Nms^{-1}. The friction coefficient for the glide system was estimated at 0.07, the suspension stroke to ± 13 mm and the end stop buffers stiffness was measured at 38000 Nm^{-1}. A numerical model was built to predict the behaviour of the whole suspension, using the measured component characteristics as input values. Additional tests were performed with the whole suspension; a rigid mass of 70 kg was bolted to the upper part of the suspension and the lower part was vibrated with random acceleration signals. The transmissibility of the suspension was measured and compared to the model prediction. Good agreements were found.

3.3.3.2 Laboratory testing to characterize the behaviour of a seated subject exposed to fore-and-aft random vibration

Tests conditions

The assessment of fore-and-aft suspension performance using numerical tools requires the development of a model to describe the dynamical behaviour of a seated subject exposed to fore-and-aft vibration. Model parameters were identified by fitting experimental data. Thus, the apparent mass frequency response function of one seated subject was measured in the fore-and-aft direction using random vibration of r.m.s. acceleration 1.2 ms^{-2} in the frequency range 0.5 to 8 Hz. The tests procedures and all results are reported in Fleury (2004). The seat used for testing in the laboratory was dismantled and the vertical suspension was removed. The seat cushion, backrest and fore-and-aft suspension were mounted to a frame bolted on a hydraulic shaker (see Fig. 3.3.2).

Fig. 3.3.2 Seat mounted on a shaker to measure the apparent mass of a seated subject.

All tests were performed with the same male subject. His whole mass was 87 kg and his sitting mass, which does not include the mass ratio of his lower limbs directly supported by the shaker while sitting, was 65 kg. A force sensor was attached to the seat frame in order to measure the force transmitted by the suspension to the seated subject. Acceleration of the subject was measured by means of a pad placed between the seat cushion and the driver's buttocks. Acquisition and post-treatment were conducted using the data acquisition software LMS. The complex transfer function between both the measured force and acceleration was computed. Measurements with an unoccupied seat were performed to obtain the response of the seat itself. The real and imaginary parts of the seat function were subtracted from the real and imaginary parts of the seat-subject function in order to obtain the apparent mass frequency function of the subject.

Several test conditions were applied in order to investigate the effect of hands and feet positions. The subject either had the hands on the lap or gripping the steering wheel. The feet were either directly supported by the moving floor of the shaker or placed on a footrest fixed to the seat frame in order to avoid force transmission through the feet. The fore-and-aft suspension could easily be locked or unlocked. The backrest could easily be reclined from vertical to horizontal positions. Tests with the following seat settings were of particular interest:

- fully reclined backrest and suspension locked
- 10° backward reclined backrest and suspension locked
- 10° backward reclined backrest and suspension unlocked

Results

- Influence of frequency

The influence of frequency was first analysed. All apparent mass frequency functions exhibited the same shape (Fig. 3.3.3). The apparent mass remained nearly constant, slightly decreasing in some cases, at frequencies lower than 1 Hz. With increased frequency, the apparent mass tended to increase, reaching a maximum in the frequency range 2 to 5 Hz, depending on test conditions, and finally decreasing to reach a value lower than 10 kg at 8 Hz. In order to investigate accurately the effect of frequency on the seated subject's response, additional tests with seat settings “fully reclined backrest and suspension locked” were conducted at constant frequencies with sinusoidal input at a r.m.s. acceleration of 1.2 ms^{-2}. The subject's movements due to vibration were filmed. For the test at frequency 0.7 Hz, a pitching motion of the subject's upper body around a transverse axis approximately located in the pelvis area was observed. This type of behaviour has already been reported by Fairley and Griffin (1990). The rotational motion vanishes with increasing frequencies. Hence, it is emphasised that the human body may be modelled with two interconnected rigid bodies. The connector is assumed to be a hinge with an axis located in the pelvis area and perpendicular to the sagittal plane. The rotational degree of freedom is assumed to have stiffness and damping.

At a higher frequency of around 2.25 Hz, videos showed that the most obvious motion is not pitching of the subject's upper body but a purely fore-and-aft pelvis translation with respect to the seat pan. This out-of-phase motion caused a peak in the apparent mass and a 90° phase angle. This was the main resonance of the seated subject exposed to fore-and-aft vibration.

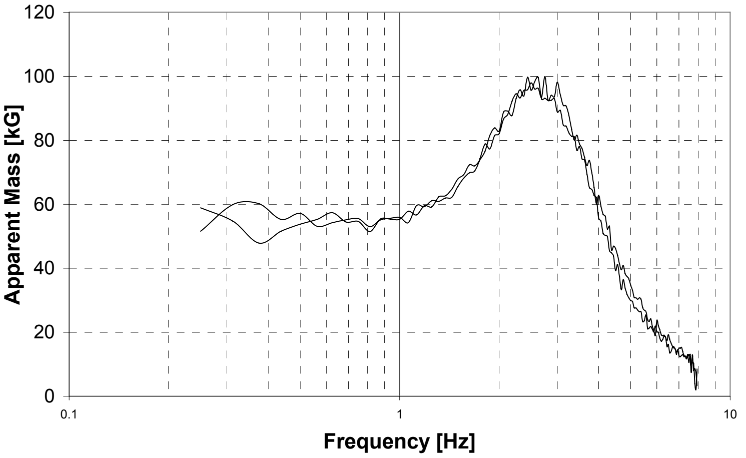


Fig. 3.3.3 Apparent mass frequency response function of a seated subject.

- Influence of the backrest

Apparent mass values measured when the subject was leaning against the backrest were considerably higher than those measured without backrest support. Therefore, the backrest and the manner in which it was used by the operator should be considered in assessing the fore-and-aft suspension performance. Their effects were analysed and are described below. The resonance frequency measured when the subject was leaning against the backrest was about 0.5 Hz higher than the resonance frequency obtained without a backrest (Fig. 3.3.5). If the subject did not use the backrest, interaction forces were only transmitted through the sitting surface. In the case involving the subject leaning against the backrest, additional forces were transmitted from the seat to the operator through the backrest. Thus, an additional stiffness was required to model the interaction between the seat and the subject. There was greater experimental scatter of the peak apparent mass values measured with the subject leaning against the backrest (Fig. 3.3.6). Additional tests were conducted to reduce the experimental scatter. Efforts were devoted to define and report with more precision the initial position of the subject's back with respect to the backrest. Two initial postures were specified: i) the contact surface between the subject's back and the backrest was limited to the lumbar area; ii) the contact surface between the subject's back and the backrest was extended to the whole back surface. The latter posture led to apparent mass peaks higher than those measured when contact was limited to the lumbar area.

- Influence of fore-and-aft suspension

The fore-and-aft suspension could easily be manually locked or unlocked. When unlocked, the fore-and-aft suspension transmitted vibration at lower frequencies (<1 Hz) but attenuation occurred at frequencies higher than 1.5 Hz. The attenuation factor was about equal to one third. The resonance frequency of the apparent mass measured during tests with unlocked suspension was about 0.5 Hz higher than the resonance frequency measured when the suspension was locked (Fig. 3.3.5). The increase of the resonance frequency due to the use of the suspension resulted from the attenuation of the input signal by the suspension and the fact that the dynamical response of the seated human body is non-linear. Additional tests carried out with locked suspension and a random input signal with acceleration of 0.44 ms^{-2} r.m.s. (i.e. 1.2 ms^{-2} multiplied by the attenuation factor of the suspension) produce the same apparent mass response function as when the tests were carried out with the unlocked suspension and with an input signal of 1.2 ms^{-2} r.m.s.. A linear model for the apparent mass of the sitting human cannot reproduce this feature.

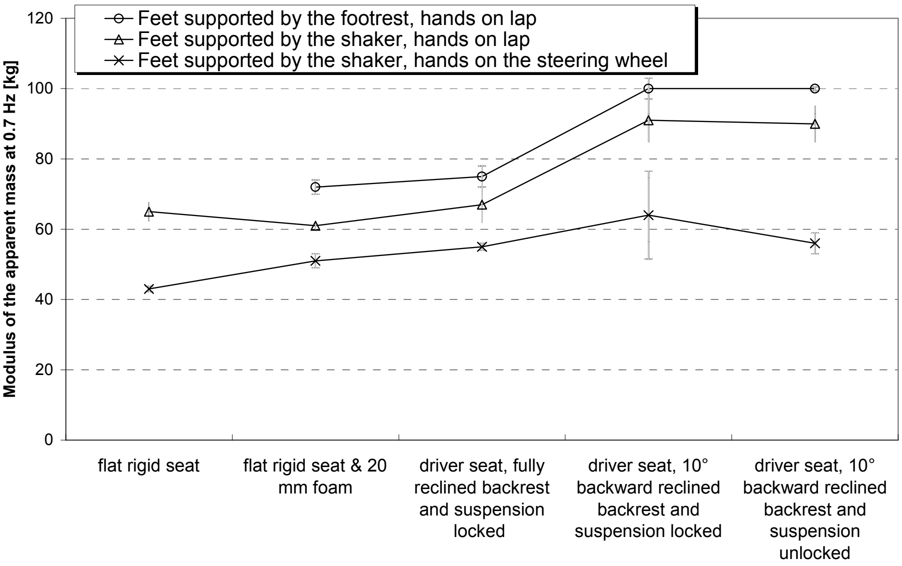


Fig. 3.3.4 Modulus of the apparent mass at 0.7 Hz for each test condition.

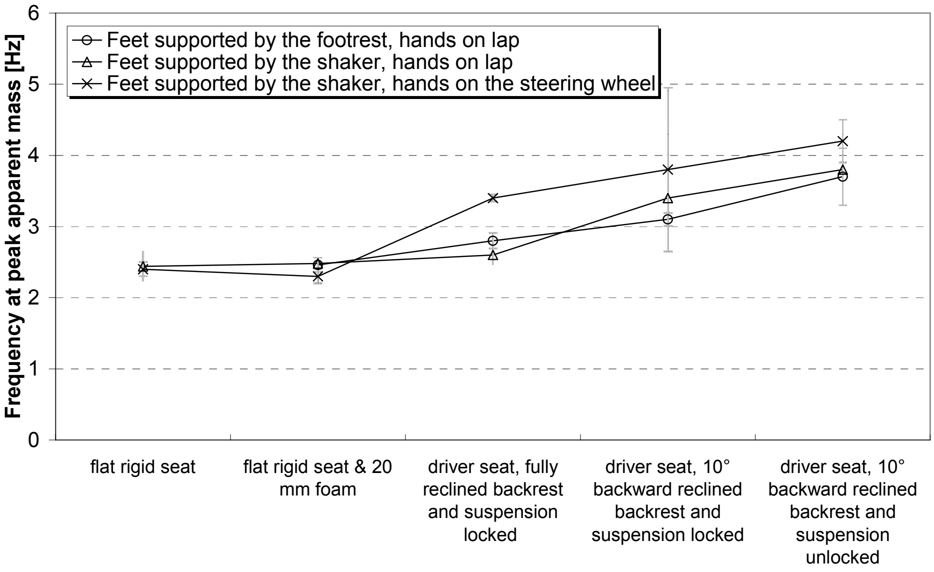


Fig. 3.3.5 Frequency at peak apparent mass for each test condition.

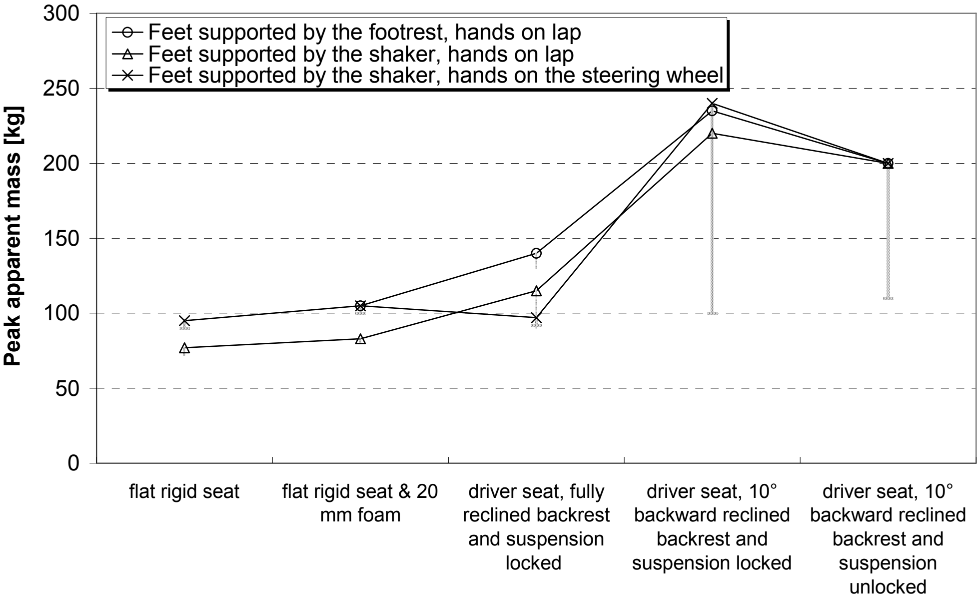


Fig. 3.3.6 Peak apparent mass for each test condition.

3.3.4 FIOSH Activities

The task of Partner 6 (FIOSH) was to perform laboratory measurements of the impedance of the human body in response to horizontal motions. The experimental design presented by FIOSH contained the determination of the impedance or apparent mass of the seated human body measured in the laboratory in response to horizontal motions over a suitable range of frequencies during exposure to magnitudes of motions determined during WP1. To measure the impedance and/or the apparent mass, a rigid seat should be used in the experimental studies. During the 3rd Meeting for Consortium partners it was agreed that the mathematical modelling of the human body would be moved from a WP3 to a WP5 activity. The initial task was adapted to the requirements of WP5. These requirements aimed at modelling the human body sitting on a soft seat cushion. In agreement with the partners in WP3 and WP5, FIOSH changed the experimental design and performed the experimental study with an upper part of a truck seat, to meet the requirements of a more practical relevance. The ethical commission was asked to give their approval for this experimental study. The laboratory equipment was extended and adapted to the tasks of the WP3.

FIOSH completed laboratory studies of the impedance of the human body – upper-part truck-seat complex in response to x- and y-axis horizontal vibration. Thirteen male subjects were chosen for the tests. They sat on an upper part of a truck seat (mounted on a Kistler force plate) with the hands on a support. There was backrest contact in the lumbar region only. The exposures in the x- and y-direction, generated by a hexapod simulator, were white noise signals in the frequency range 0.3 to 30 Hz with unweighted vibration magnitudes of 0.3, 1.0 and 2.0 ms^{-2} r.m.s. (cf. Annex WP3-7). The forces and accelerations were measured beneath the upper part of the truck seat in the two horizontal directions. The individual posture was determined by motion analysis, which registered the movements of joint points during the vibration exposure. To quantify the intensity of the backrest contact, the pressure distributions at the backrest were registered by a pliance system (Novel gmbh) during the exposures. The apparent mass is defined as the complex relation of force amplitude (F) and acceleration amplitude (a) in the same direction. The apparent mass AM was calculated using a MatLab routine. For each data file of the pressure distributions, a frame with mean values (MVP) of all sensors and a frame of maximum values (MPP) of each sensor were calculated. For both frames, the forces, loaded areas and maximum pressure values were determined.

The apparent mass functions of the subject/seat combination showed an individual coupling between the subject and the seat i.e., the effects of the subject and the unrigid upper part of the driver seat – both located above the force plate – were inseparably mixed. Due to this coupling, the apparent masses of the subject could not be separated from the apparent mass of the seat. The data basis created can be used for the modelling of the seat/subject system in the range between 0.5 and 20 Hz. The use of this data basis is not suitable for the modelling of the human body. Details of the results can be found in Annex WP3-8.

In the x-direction, the peak frequencies of the apparent mass functions occurred between 3.13 and 6.75 Hz, with the lower values during the higher intensities (Annex WP3-7, Table 1 to 3). The maximum moduli remained nearly constant during the vibration intensities tested (Annex WP3-7, Figure 9 top)).

In the y-direction, the peak frequencies of the apparent mass functions occurred between 1.13 Hz and 4.25 Hz, with the lower values during the higher intensities (Annex 3-7, Table 1 to 3). The maximum moduli remained nearly constant during the vibration intensities tested (Annex WP3-7, Figure 9 bottom).

The pressure distributions can be characterized by the mean and maximum values of the parameters force, loaded area and peak pressure. The mean values of forces remained nearly constant during the vibration intensities tested in both excitation directions, whereas the maximum forces increased with the intensity. The mean values of the loaded areas remained nearly constant when the intensity changed from i1 to i2. The mean values of the loaded areas were higher during the vibration intensity i3. The maximum values of the loaded areas and the peak pressure values increased clearly with the vibration intensity (Annex WP3-7, Figures 11 to 16). The data were delivered to WP5 for the mathematical modelling.

3.3.5 ISRI Activities

In cooperation with Partner 1 (ISVR), the measurements of the seat components were defined in detail. All parameters which have a significant influence on the dynamic behaviour of a suspension seat, whether in the vertical direction or in the horizontal direction, were considered. The following parameters were measured:

Spring Characteristic

The spring characteristic is most important for the resonance frequency of a suspension seat. The test was carried out on a vertical load-deflection test rig (see Figure 3.3.7 below). Data were recorded in digital format and transferred to the partners. The seat was adjusted to a reference height position and filled with air (an air suspension system is used in this type of truck seats) in relation to specific driver weights. The air spring was closed and the

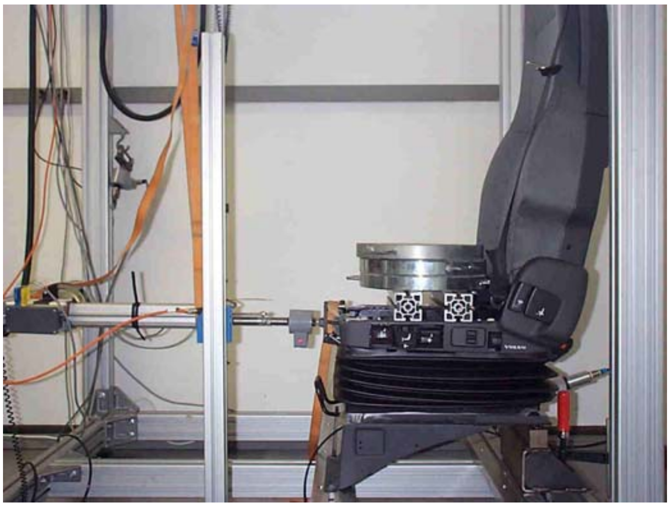


Figure 3.3.7 Experimental set-up

measurement started at the up-most position of the suspension system. Removed masses were taken into account. The suspension system was compressed down into the lower end-stop buffers and moved back to the start position. Force and displacement was measured continuously and the data were stored. The test speed was adjusted to 50mm/min to get the static spring characteristic. An example of a measured spring characteristic curve, called "hysteresis-curve" is shown in Figure 3.3.8 below.

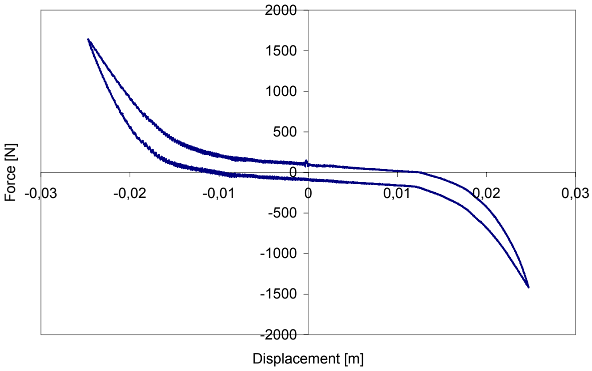


Figure 3.3.8 Horizontal spring characteristic

Static Friction

The static friction was determined during the same measurement as for the static spring characteristic. The system was compressed against the friction force downwards and moved against the friction force upwards. Due to the fact that the overall force acting on the movable loading device of the test rig dictates the direction, the graph shows twice the friction between the two parts (compressing/removing). This is shown also in Figure 3.3.8.

Shock Absorber Forces

Besides the spring characteristic, the shock absorber, as it was used in the project, was the most important component determining the vibration behaviour of a standard suspension system. The forces of a shock absorber are dependent on velocity, but often in a non-linear way. For that reason, the shock absorbers were measured over the whole range of possible velocities. The data was used to calculate the shock absorber forces in relation to the suspension travel.

Additional Data

Additional geometric information about the seats, in particular the suspension system, was provided. For example, the relation between suspension travel and shock absorber stroke was needed to calculate the shock absorber forces and also to calculate their influence on the moving masses. Data was provided to Partner 5 (IMMM), who was responsible for the mathematical modelling of the truck seat under workpackage 5.

3.3.6 Work package 3 conclusions

Laboratory studies have shown clear differences between the apparent mass in response to lateral motion as compared to roll motion and a clear influence of the seat backrest.

Seat component dynamic properties have been determined.

The improvement with the prototype truck seat was less than expected in both the field and the laboratory tests; the modified suspension bearing design resulted in a reduction in friction to a much lower level than proposed, resulting in not only the intended reduction in high frequency vibration but also an increase in low frequency vibration motion.

The results open the way for obtaining more specific knowledge of the effects influencing horizontal vibration in these types of vehicles and give possibilities for further improvement of the design of such systems.

3.3.7 Deliverables due and achieved

D3: Measurement of the seat component dynamic properties. COMPLETE

D4: Measurements of the performance of each existing seat in response to each axis of vibration. COMPLETE

D7: Physical models (prototypes) of seat suspension systems. COMPLETE

D12: Measurement of the performance of modified/prototype seat in response to each axis of vibration. COMPLETE

3.4 Workpackage 4 – Laboratory test protocol for assessing the vibration performance of seats equipped with horizontal suspensions led by SNCF

3.4.1 Introduction

A standard procedure is required for use throughout the European Union for assessing suspension seat performance with vibration in horizontal and rotational axes. There are currently no standard methods for assessing suspension seat performance in horizontal and rotational axes, even though these motions cause distraction and discomfort, interfere with operator ability to control vehicles and present a risk to health and safety at work.

Standardised test methodologies are necessary to allow:

- Seat manufacturers to optimise and assess the performance of their products,
- Vehicle manufacturers to select suitable products for use in specific vehicles,

- Vehicle operators to minimise health risks and discomfort.

Utilising the extensive experience of the partners in the development and use of standards and involving leading European suspension seat manufacturers, the work package has developed a laboratory test protocol for assessing the performance of seats equipped with suspensions intended to attenuate shock and vibration in the fore-and-aft and lateral axes.

Rotational vibrations may be unpleasant in some circumstances, but the partners considered that more work is required before proposing a test method related to these movements.

Issues that differentiate seat assessment in response to horizontal motions from assessment in response to vertical motions have been identified and example test motions for several vehicle classes have been provided. Objective criteria which may be appropriate to the assessment of horizontal seat suspension performance have been identified.

Laboratory tests have been conducted to ensure that the method is viable. The test method was revised where necessary following laboratory testing.

Studies conducted during the project have resulted in useful conclusions and have led to proposals for future studies.

3.4.2 Information from other work packages

This work package required the following information:

- Digitised time histories and summary reports of the vehicle and seat surface motions observed during the WP1 field trials with identified relevant frequency and amplitude ranges;
- Results of the human factors research conducted under WP2 to design a test method that accounts for the comfort of the driver when assessing seat performance;
- Models of the human body impedance from WP3;
- Practical experience of horizontal suspension seats from WP3.

Some suspension seats exist with vertical, fore-and-aft and even lateral vibration isolators. Seat manufacturers conducting laboratory and field measurements for the project have provided such seats to partners.

3.4.3 Direction of studies

The preliminary considerations, started on month +9, led to a proposal that the testing method should aim to:

- Evaluate seats performances with objective criteria under a wide range of operation conditions;

- Provide information for the behaviour analysis of the seat, suspensions and cushion.

A draft test method was prepared by the WP4 leader and circulated to the partners for comment. The WP4 leader has continuously revised the document in response to partners' comments.

Discussions at VIBSEAT meetings have led to agreement on the expected content of the chapters. The chapters have been determined by common agreement between the partners from experience acquired during the project and by application of the test method.

The test method includes sections on each of the following:

- Test rig, seats, persons and posture : requirements and precautions;
- Excitation signals : input vibrations for eight vibration classes, each class consisting of recorded cabin floor *x*-axis and *y*-axis time histories for a particular vehicle performing a specific operation (according to the experience acquired in WP1), tolerances;
- Measurements: directions, positions of the sensors, instrumentation, integrity check;
- Test progress;
- Criteria: to evaluate the dynamic performances, i.e., the capacity of the seat (or parts of it) to minimise the effects of vibrations;
- Report content: information to be reported to guarantee the traceability of the results and relevance for the evaluation of the seat performances;
- Uncertainty estimation in measurements;
- Seat behaviour analysis guide: analysis of the seat elements behaviour in the comfort, health and ergonomics domains.

A draft test method (version 8) was supplied at beginning of April 2005 taking into account some preliminary conclusions of application of the test protocol version 6.

The method was reviewed in the light of comments of the completed laboratory evaluations. Draft 9 of the test protocol was circulated for comment. A final version of the test protocol was produced in December 2005 (Annex WP4-1).

3.4.4 Laboratory evaluations of the test method (FIOSH and ISVR contributions)

The test protocol draft 6 was submitted for an operational evaluation by ISVR in December 2004 and a test report with comments was produced (Annex WP3-3). Evaluation of test protocol draft 8 was conducted by ISVR in November 2005 and test reports with comments were produced (Annexes WP3-4, WP3-5 and WP3-6).

FIOSH, who is not involved in the method development, conducted laboratory testing to ensure that the method is viable. For the laboratory evaluation, the Draft 7 of the test protocol, dated January 2005, was used. A report on the evaluation of the test method (Annex WP4-2) and editorial comments on Draft 6 were presented at the 6th VIBSEAT meeting and published. Nine subjects with different body mass (three light, three medium, three heavy) participated in the experiments. One seat was tested with three exposure conditions: band-limited random test motion, agriculture tractor test motion 2, and articulated truck) in x- and y-axis, combined (x- and y-directions simultaneously) random exposures were additionally tested. The evaluation considered:

- the application of the draft test protocol in practice and the derivation of proposals for a possible revision with respect to methodical aspects,
- the suitability of results obtained with two test persons as criterion for quality and criterion for the comparison of different seats,
- the possibility of simultaneous exposure in x- and y-axes,
- editorial comments.

One issue agreed within the research group of FIOSH was the examination of three groups with three subjects in each group of body mass (low, medium and high), instead of only two subjects, one with a low, and one with a high body mass. The tests were conducted with three female subjects of body mass of 52.4 - 54.6 kg, three male subjects of body mass 75.5 - 77.1 kg and three male subjects of body mass 98 - 100.7 kg.

The FIOSH-Hexapod simulator with FCS control system and FCS manager software was used for the tests. A Grammer seat type MSG 95 AL/741 was fixed on the platform of the simulator.

The accelerations in all three directions (x, y, z) were measured at the platform, on the seat cushion, on the backrest and additionally on the frame of the seat.

The main conclusions were:

- The necessity to test and to consider the very low frequencies between 0.2 and 0.5 Hz for the transfer function of suspended seats should be explained in a revised test code.
- The definition of the signs of acceleration in relation to the displacement should be unequivocal, duly considering the prehistory in the time domain.
- The present general limits for the maximal error of the excitations in time and frequency domain do not consider differences of the usual control quality that can arise from different signal qualities.

- A note might be added to the draft: “Bi- or multi-axial excitations could be more appropriate for a more realistic simulation of field conditions, if the development is going on. A preliminary study has shown that SEAT-values may be different from those obtained by single axis tests.”
- As the results with three subjects in each of three groups with nearly the same body mass demonstrated, the test results of only two persons are not suitable as quality criterion for the comparison of different seats, because the correlation of SEAT-values with body mass is weak and the differences of SEAT-values between subjects with the same body mass can be very great. The anthropometric characteristics body mass and body height cannot explain between-subject differences. It is necessary to find a test method without these shortcomings.

3.4.5 Other partners contributions

3.4.5.1 ISRI

Under the leadership of Partner 7 (SNCF), a test method for horizontal suspension system had been developed.

Experience of more than 15 years in tests of vertical and horizontal suspension systems played a significant part. Experiences in previous projects, in which different test laboratories were involved in comparative seat tests, has been extremely valuable.

Due to the fact, that horizontal suspension systems have a limited stroke, the knowledge of the European Project TESTOP - a project dealing with vertical end-stops of suspension systems - was very helpful.

The experience of national (German) round-robin tests played a part by the writing of a standard with a view of usage and practicability.

The results of very cooperative work and discussions are shown in the final test protocol.

Specific Work Items: The test protocol was divided into several parts. Although all the partners of this work package gave their contribution to the entire document, each partner worked more intensively on a specific part. The work of ISRI was on Part 5: Safety requirements, test rig, seats and test persons. As mentioned above, all results are integrated into the entire test protocol.

3.4.5.2 INRS

INRS focused its activity in the frame of the VIBSEAT project on fore-and-aft suspension seats for wheel loaders. Mechanical specifications were identified for a fore-and-aft suspended seat in a wheel loader. Typical input signals measured on a wheel loader were made available to assess fore-and-aft suspended seat performance with regard to shock absorption and vibration attenuation. Secondly, tests were performed in the laboratory with a suspension prototype. Details are provided in Annex WP4-3.

3.4.6 Deliverables due and achieved

M4.1: (Month 24) Draft test methodology completed and submitted to Partner 6 for assessment: realised (with 6 month delay).

M4.2: (Month 30) Laboratory evaluation complete and results accepted by WP4 partners (on time):

- ISVR report: Gunston, T.P. and Griffin, M.J. (2005) Seat performance laboratory test – unmodified and prototype truck seats tested in the x-axis according to VIBSEAT test protocol Draft 6-28Dec04 (Annex WP3-3).
- FIOSH report: Blüthner, R., Seidel, H., Gericke, L. and Keital, J. (2005) Laboratory Evaluation of the test method for driver seats with suspension in x- and/or y-direction (Annex WP4-2).

M4.3: (Month 36) Test method was finalised and accepted by the partnership.

D10 (Month +36): SNCF report (final version of test protocol): Clément, P. (2005) Laboratory test protocol for assessing the vibration performance of seats equipped with horizontal suspensions (Annex WP4-1).

3.4.7 Workpackage 4 Conclusions

The extensive experience of the VIBSEAT partners in the development and use of standards and the knowledge of leading European suspension seat manufacturers have facilitated the development of a laboratory test protocol for assessing the performance of seats equipped with suspensions for the attenuation of shocks and vibrations in horizontal axes. The development of the protocol has led to significant progress in the understanding of methods of testing the performance of seats in horizontal directions. The proposed test protocol has been evaluated by the partners in laboratory tests to ensure that the test method is viable.

Discussions of field and laboratory studies undertaken for the project have led to the provision of a relevant protocol, leading the way to appropriate future studies.

3.4.8 Future work

Future development of the test protocol is proposed on the following areas:

Criteria

One of the essential parts of an evaluation of seat performances is the availability of objective criteria.

Shock excitations

It is important to be in a position to evaluate the behaviour of seats subjected to shocks. A first step in the definition of a shock signal and seat response evaluation has been made (industrial loader). The results identified isolated shocks rather than continuous vibration as the dominant source of vibration for the tasks typically performed by this vehicle.

As the performance of the seat in reaction to shocks could have a relatively greater importance compared to its behaviour when submitted to random vibrations, this subject is worth being developed in future works, for example, shock measurements, laboratory reproduction and isolation performance evaluation.

Rotational vibrations

Rotational vibrations may be unpleasant in some circumstances, but more work is required to propose a test method related to these movements.

Multi-axis excitations and analysis

For practical reasons, studies have been limited to separate axes analysis. Combined axes excitations are a large domain to explore in future work.

Though test rigs capable of generating 6 degrees of freedom excitations exist, knowledge of the way to analyse results from multi-axis excitations is insufficient at present.

Continuous motion – ergonomics criteria

In some circumstances, the driver is subjected to continuous or low-frequency vibration in horizontal directions, interfering with the horizontal suspension (e.g. circulation on a non-flat surface, pressure on the foot pedals of some vehicles or action on the steering wheel).

Quasi-static force-deflection measurements for the suspension systems are therefore considered useful for characterising the suspension under test to provide some guidance on the resistance of the seat to quasi-static loads.

Laboratory tests should measure the relative displacement of the horizontal suspension system. The collection of data will allow the usefulness of the suspension displacement as a test criterion to be investigated.

This area of investigation is linked to ergonomic studies of the effects of displacements on the ability of a driver to control his vehicle.

Test persons and posture

Differences in response to vibration exist between and within light and heavy subjects. Therefore, future developments might consider the merits of using more than two subjects or the use of a rigid mass or a dummy.

The results of WP 1, WP 3 and WP 5 showed that the test position with the hands on the lap and seat back as defined in the test protocol provides more reproducible and reliable results than the position the with hands on a mock-up steering wheel and the seat back as defined in EN 30326-2.

Range of signal

This project was not expected to provide the amount of machine-specific data required to select sufficiently representative test motions and acceptance values for all the types of vehicles under investigation.

A large amount of further work is needed to enable the provision of representative test motions.

3.5 Workpackage 5 – Theoretical modelling led by INRS

The aim of workpackage 5 is to useh numerical tools with the aim of enabling seat manufacturers to design seats with improved performance with respect to the reduction of horizontal vibrations transferred to seated operators in mobile machines.

3.5.1 INRS activities

3.5.1.1 Introduction

The work of INRS in the project aimed at proposing a numerical method to design fore-and-aft suspensions for wheel loader seats. Several types of data are required to implement such a method:

- Input acceleration signals measured on the wheel loader floor during working conditions (cooperation with partner N°9 in the frame of WP1 and WP1 report);
- A validated model to predict the suspension behaviour (measurements in laboratory of seat component properties were performed in the frame of WP3);
- A validated model to describe the dynamical response of the seated subject (measurements of the apparent mass of a seated subject were performed in the frame of WP3);

- Criteria to assess the suspension performance.

Based on the loading conditions measured in the field, on models developed and on criteria selected, simulations were performed and a modified suspension with improved performance was proposed. Suspensions prototypes were produced and tested in laboratory design orientations resulting from numerical simulations. This section aims to report modelling efforts by INRS. More information concerning investigations of input signal measured on the wheel loader is provided in the work package 1 report (Section 3.1). Details of the experimental results obtained in the laboratory to identify model parameters are provided in the work package 3 report (Section 3.3) and Fleury (2004). Further details concerning the models are provided in Annex WP5-1.

3.5.1.2 The model of the dynamical behaviour of the seated driver

The dynamic behaviour of a seated subject was first modelled for the cases “hands on lap”, “feet on the shaker” and “backrest off” (see Fig. 3.5.1). This two-dimensional base model connects two rigid bodies, where the lower body represents lower limbs and pelvis and the upper body includes the trunk, upper limbs and head of the seated human body. The lower body is connected to a rigid seat by means of a spring and a damper, both oriented in the fore-and-aft direction. The upper body is connected to the lower body by means of a hinge with rotational stiffness and damping. The upper rigid body is assumed to be rectangular and the position of its centre of gravity with respect to the hinge rotation point is required to defined its moment of inertia. The model has two degrees of freedom: the fore-and-aft

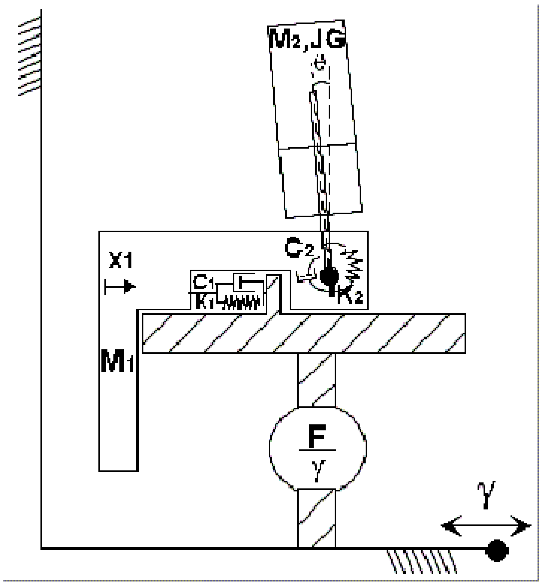


Figure 3.5.1 A two rigid body model to describe the apparent mass of the seated subject exposed to fore-and-aft vibration (hands on lap, feet supported by the moving floor, backrest off).

relative translation of the lower body with respect to the seat and the rotation of the upper body about the hinge axis. Seven parameters are required to define the model response: the two masses of both rigid bodies, stiffness and damping coefficient for the connection between the lower body and the seat, rotational stiffness and damping coefficient applied to the hinge and the distance between the centre of gravity of the upper body to the hinge axis.

Model equations are reported with assumption of small rotations, i.e.

For $\sin(\theta) = \frac{x_1 - x_2}{L} \approx \theta$:

$$m_1 \ddot{x}_1 + K_1(x_1 - x_0) + C_1\left(\dot{x}_1 - \dot{x}_0\right) + m_2 \ddot{x}_2 = 0 \qquad \text{Eq. 1}$$

$$J_G\left(\ddot{x}_1 - \ddot{x}_2\right) - m_2 L^2 \ddot{x}_2 + K_2(x_1 - x_2) + C_2\left(\dot{x}_1 - \dot{x}_2\right) = 0 \qquad \text{Eq. 2}$$

$$M = m_1 \frac{x_1}{x_0} + m_2 \frac{x_2}{x_0} \qquad \text{Eq. 3}$$

where:

m_1 , m_2: Mass of the lower and upper rigid body, respectively

θ Rotation angle in the hinge

x_0, x_1, x_2: Complex fore-and-aft displacement of excitation point of the lower and upper rigid body, respectively

L: Distance between the hinge axis and the centre of gravity of the upper rigid body

J_g: Moment of inertia of the upper rigid body with respect to its centre of gravity

K_1, C_1: Stiffness and damping coefficient of the connector between the lower rigid body and the excitation point

K_2, C_2: Rotational stiffness and damping coefficient applied to the hinge.

3.5.1.3 Parameter identification

The masses of the lower and upper body are given by Plagenhoef (1983), where each body segment's weight is given as a percentage of total body weight. The distance between the centre of gravity of the upper body to the hinge axis is assumed to be equal to the realistic value of 0.4 m. Properties of the connection between the lower body and the seat are assumed to be correlated with the point of peak apparent mass. The stiffness respectively and the damping coefficients are defined by the frequency corresponding to the peak apparent mass. The rotational damping coefficient applied to the hinge is correlated to the apparent mass value at 0.7 Hz and the rotational stiffness is fixed to a value which tends to give good agreement in the lower frequency range between the model and the experimental curves.

Model extensions were proposed to include postural effects on the apparent mass. Effects resulting from setting feet on a footrest were modelled by adding a mass of 7 kg to the lower body. Effects resulting from holding the steering wheel in the hand were modelled by constraining the fore-and-aft translation at the upper extremity of the upper body.

The experimental results indicate that the use of the backrest, and the manner by which the driver uses the backrest, modify considerably the apparent mass response function. Effects resulting from leaning against the backrest were modelled by adding a spring and a damper between the lower rigid body and the rigid seat (see Fig. 3.5.2). If the driver leant against the backrest only in the lumbar area, a weight ratio was transferred from the upper to the lower rigid body. If the driver leans against the backrest on his whole back surface, the whole mass of the upper rigid body was transferred to the lower rigid body and consequently the rotational degree of freedom of the model vanishes for this case. Therefore, only three parameters are required to model the backrest effects: the mass Mi transferred from upper to lower rigid body, the stiffness and the damping coefficient of the connection between the lower rigid body and the backrest.

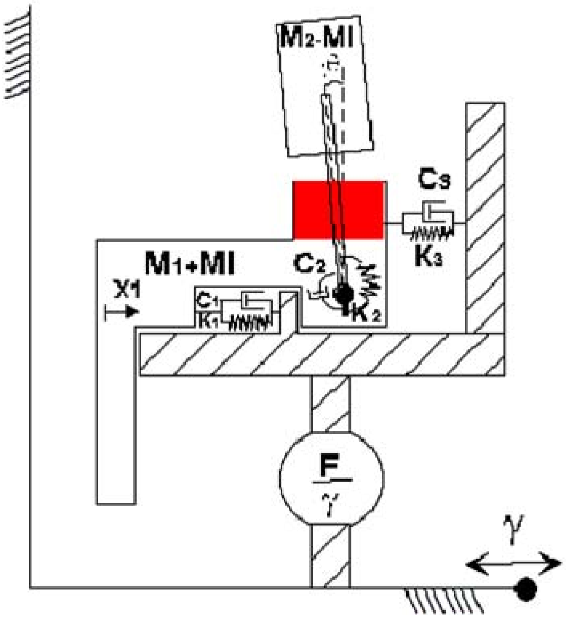


Fig. 3.5.2 Model extension to describe the effect of backrest

The Table 3.5.1 reports parameter values for a flat rigid surface, a flat rigid surface covered with 20 mm foam and the industrial seat equipped with a backrest.

		Flat rigid surface	Flat rigid surface with 20 mm foam	Industrial seat
Parameter set for the basis model	M1 [kg]	31	31	31
	K1 [Nm-1]	9585	9125	13605
	C1 [Nm-1s]	306	272	258
	M2 [kg]	49	49	49
	K2 [Nm]	50	50	50
	C2 [Nms]	32	28	37
	L [m]	0.4	0.4	0.4
Model extension to include the backrest	Mi [kg]			32
	K3 [Nm-1]			14760
	C3 [Nm-1s]			340

Table 3.5.1 Model parameters identified for two sitting surfaces and an industrial seat

The Figure 3.5.3 shows the comparison between calculated and measured apparent mass values while taking into account the effect of the backrest. The model is able to reproduce with a good agreement the apparent mass frequency response for the three postures: i) backrest off; ii) backrest on, contact in lumbar area; iii) backrest on, contact over the whole back.

3.5.1.4 The seat model

The seat model is restricted to the suspension, which consists of two pre-constrained steel springs, a damper, two end stop buffers and a glide system with friction. Features for each component are characterised by means of component tests. Springs stiffness was evaluated as 5000 N/m, the damping coefficient of the damper was equal to 600 N/ms-1, the end stop buffers had a stiffness of about 38000 N/m and the friction coefficient in the glide system was evaluated as 0.07. The suspension stroke was equal to +/- 13 mm and the pre-constrained force was equal to 350 N. The suspension model was based on all suspension component models with their own features.

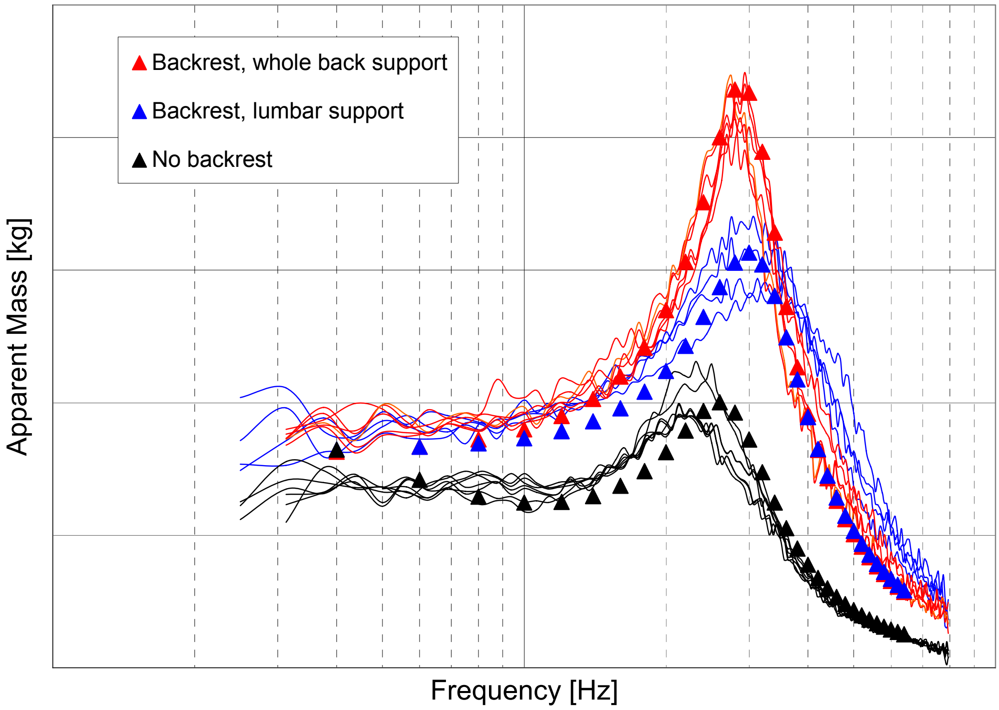


Fig. 3.5.3 Comparison between calculated and measured apparent mass frequency response with effect of the backrest.

3.5.1.5 The man/seat system model

The man/seat system model was built by coupling the man model to the seat model. Equations of the man/seat system become:

$$m_0 \ddot{x}_0 + K_1 (x_0 - x_1) + C_1 \left(\dot{x}_0 - \dot{x}_1 \right) + K_s (x_0 - x_s) + C_s \left(\dot{x}_0 - \dot{x}_s \right) = 0 \qquad \text{Eq. 4}$$

$$m_1 \ddot{x}_1 + K_1 (x_1 - x_0) + C_1 \left(\dot{x}_1 - \dot{x}_0 \right) + m_2 \ddot{x}_2 = 0 \qquad \text{Eq. 5}$$

$$J_G \left(\ddot{x}_1 - \ddot{x}_2 \right) - m_2 L^2 \ddot{x}_2 + K_2 (x_1 - x_2) + C_2 \left(\dot{x}_1 - \dot{x}_2 \right) = 0 \qquad \text{Eq. 6}$$

where:

m_0 is the seat mass attached to the mobile part of the suspension,

x_0, x_s are the complex displacement of the seat pan respectively the excitation point prior the suspension,

K_s, C_s are the stiffness and damping coefficient characteristic of the suspension.

Figure 3.5.4 shows the comparison between calculated and measured apparent mass frequency function for the case involving whole back support and unlocked suspension. Some discrepancies appear concerning the peak apparent mass and the corresponding resonance frequency. The disagreement results from the fact that the model assumes a linear behaviour while the response of the subject is non-linear. These discrepancies may be significant for research works but they are assumed to be acceptable for design purposes.

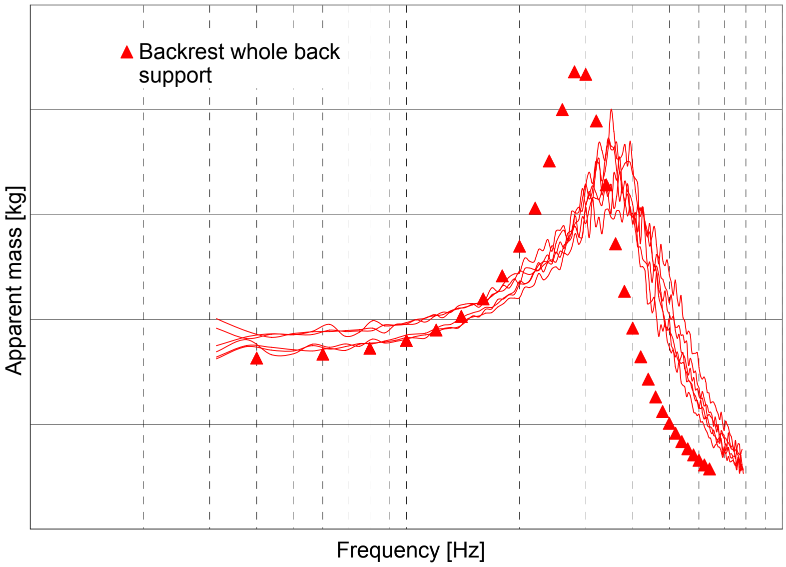


Fig. 3.5.4 Comparison between measured and predicted apparent mass curves with unlocked suspension

3.5.1.6 A numerical method to design fore-and-aft suspensions

Designing technical solutions require the determination of technical specifications. This is achieved for the fore-and-aft suspension by measurements and observations made during field tests carried out with the wheel loader (see Workpackage 1, Section 3.1). Consequently, it is concluded that a fore-and-aft suspension performance should be assessed by taking into account three main mechanical features: static strength, shock absorption and vibration attenuation.

Static strength is described by the force slowly and progressively applied to the suspension to produce relative displacement. During driving operations, like pushing on pedals or gripping the steering wheel, the driver exerts force on the seat. If the suspension responds by producing large relative displacements, the operator has difficulties to control his actions and feels uncomfortable. A technical solution consisted of using stiff springs to limit relative displacements or in limiting the suspension stroke.

The second mechanical feature selected to assess mechanical performance of a fore-and-aft suspension was instantaneous shocks occurring while bucket loading. Shock absorption was not fully handled in the frame of this work. It is emphasized that shocks and vibration must be handled separately. Shocks are asymmetric and produce high relative displacements of the suspension only in the fore direction. The suspension used in this work has not been designed to consider this aspect.

The third mechanical feature selected was fore-and-aft acceleration resulting from the pitching motion of the vehicle riding on uneven tracks. Typical acceleration signals were measured and the frequency analysis of these signals showed the energy to be mainly concentrated in a narrow frequency band centred around 1.6 Hz. Hence, a preliminary study of the permanent model response was carried out with a sinusoidal excitation set at frequency 1.6 Hz. Four criteria were processed to quantify the suspension performance with respect to vibration.

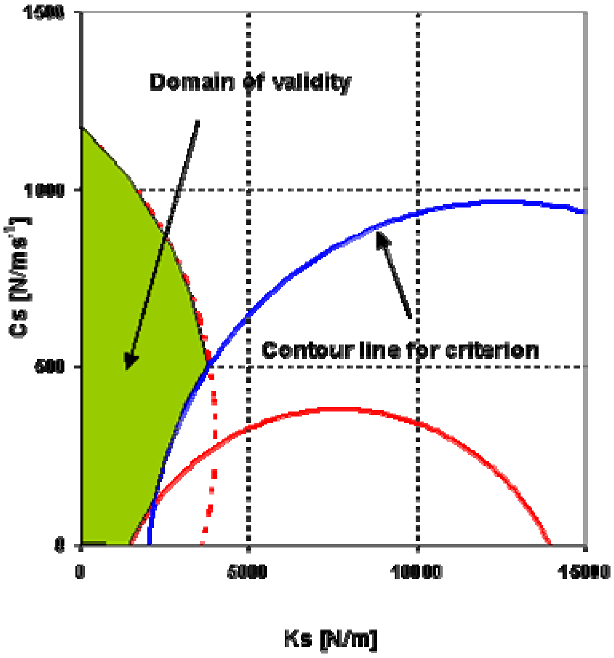


Fig. 3.5.5 Example for a design diagram

The suspension stiffness K_s and the damping coefficient C_s of the suspension were selected to be optimised and results were reported in a K_s/C_s diagram as shown in Figure 3.5.5. One point on this diagram represents one suspension. For each criterion, values of K_s and C_s are located and the corresponding contour lines are drawn in the K_s/C_s diagram. A contour line divides the diagram surface into two areas: the domain of validity for the criterion and the domain for which the criterion is not fulfilled.

The four computed criteria are: transmissibility between lower rigid body and shaker, transmissibility between upper rigid body and shaker. They were assumed to be equal to unity, i.e. the cut-off frequency of the transfer function is the excitation frequency. Solutions which fulfil these criteria are solutions which do not amplify vibration measured on both rigid bodies of the man model. The suspension displacement was also computed and should remain lower than the maximal suspension stroke in order to avoid bottoming. Preliminary calculations with a suspension stroke of +/- 13 mm showed that this criterion is too restrictive. No suspension can be designed to fulfil these criteria; therefore the suspension stroke was increased from +/- 13 mm to +/-20 mm to obtain some solutions. The fourth criterion was the interaction force between the back and the backrest. K_s and C_s were selected to obtain interaction force equal to 100 N.

The validity domain for the suspension is the intersection of the four validity domains for each criterion. Figure 3.5.4 shows the resulting validity domain and consequently the following characteristics were proposed for a new design: i) the stroke may be increased from +/- 13 mm to +/- 20 mm, ii) spring stiffness may be reduced from 5000 N/m to 1700 N/m, iii) damping coefficient remains unmodified.

In order to estimate the performance of a seat with such characteristics, numerical simulations were performed by using the input signal recorded on the wheel loader during field tests and the resulting accelerations were post-treated and weighted according to the ISO 2631 (1997). Calculations were made for both the existing suspension and the optimised one. The results show that the optimised suspension leads to a SEAT value which is approximately one-half the value calculated for the existing suspension.

3.5.2 IMMM activities

3.5.2.1 Truck test seat 1st Phase results

At the beginning of the project, the seat manufacturer ISRI undertook a set of laboratory measurements, which were passed to Partner No. 5 (IMMM) for analysis. The main results, extensively reported in Stein, Zahoranský and Chmúrny (2003), are summarised below.

When the seat base was excited at a constant acceleration, there was a limiting r.m.s. value (approximately $a_{\mathrm{eff}} = 0.70\ \mathrm{m/s^2}$), below which the inertial forces would not overcome the static friction forces; the seat would not move and so did not act as a vibration isolator. The acceleration transmissibility was around unity, so no vibration reduction was feasible.

For excitation at a larger r.m.s. acceleration, there was a certain cut-off frequency above which the vibration isolation system started to reduce the vibration. However, at higher frequencies, the system became stuck and again no vibration reduction occurred. However, if a certain excitation level was exceeded, the rubber end-stops slipped into action, making the system stiffness a non-linear one and resulting in an increase in the natural frequency.

These findings were verified by analysis of signals gathered on road tests conducted by NIWL (Partner No. 10) and extensively analysed by IMMM and reported in Stein and Múčka (2003). The seat performance in field conditions is best described by the seat transfer

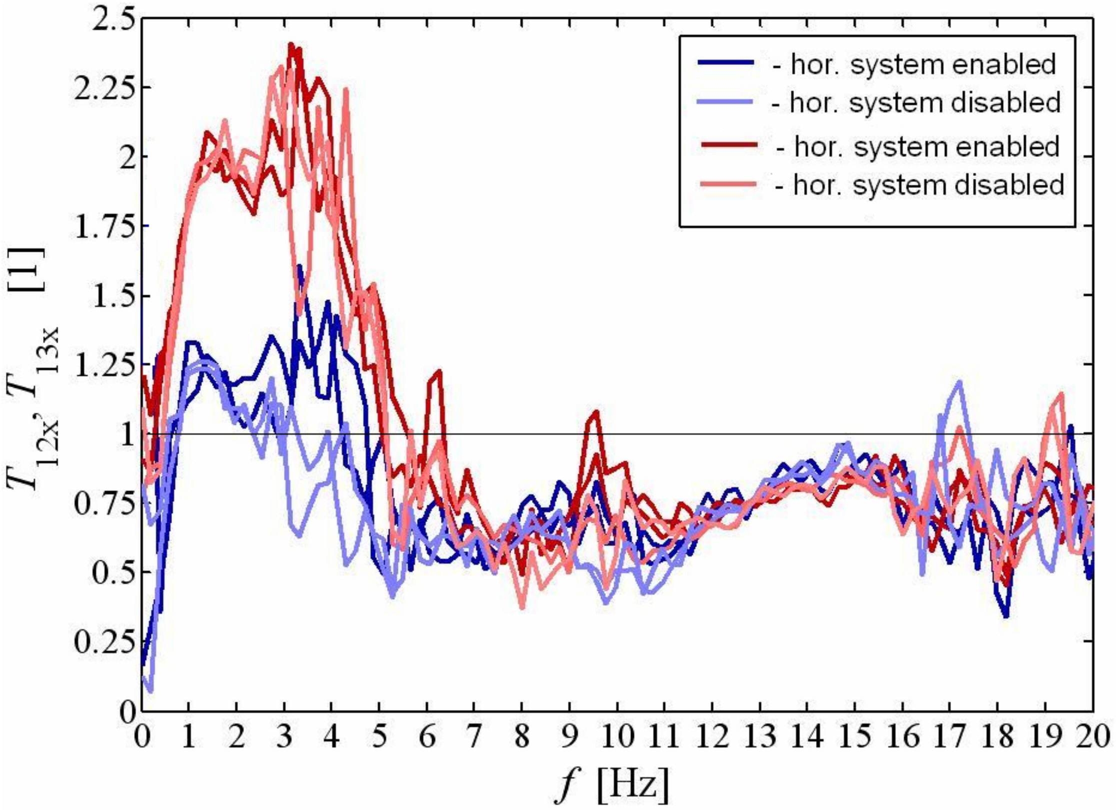


Figure 3.5.6 x-axis seat transfer function estimate.

function estimate (TFE) *T* in both *x*-axis and *y*-axis for two situations – the horizontal (*x*-axis) suspension enabled and disabled, as depicted in Figures 3.5.6 and 3.5.7. The bluish colours are for the seat frame vibration, the reddish colours for vibration at the seat/driver interface, measured by test disk as defined in EN ISO 30326.

From the figures, it can be seen that the vibration isolation system had no marked effect on the vibration intensity to which the seated driver was exposed, since the light red and dark red curves are virtually the same. As expected, there was no difference in the *y*-direction in the respective courses of transfer function estimate. The absence of vibration reduction above about 7 Hz is attributed to high friction in the seat, as seen in Fig. 3.5.11. Investigations by FIOSH (Partner No. 6) arrived at similar results.

The high friction force posed some difficulties in seat modelling. However, these difficulties, as well as the pitch influence that was present in the field data, were overcome. A mechano-mathematical model of the horizontal seat suspension system was set up and two different simulation approaches were developed:

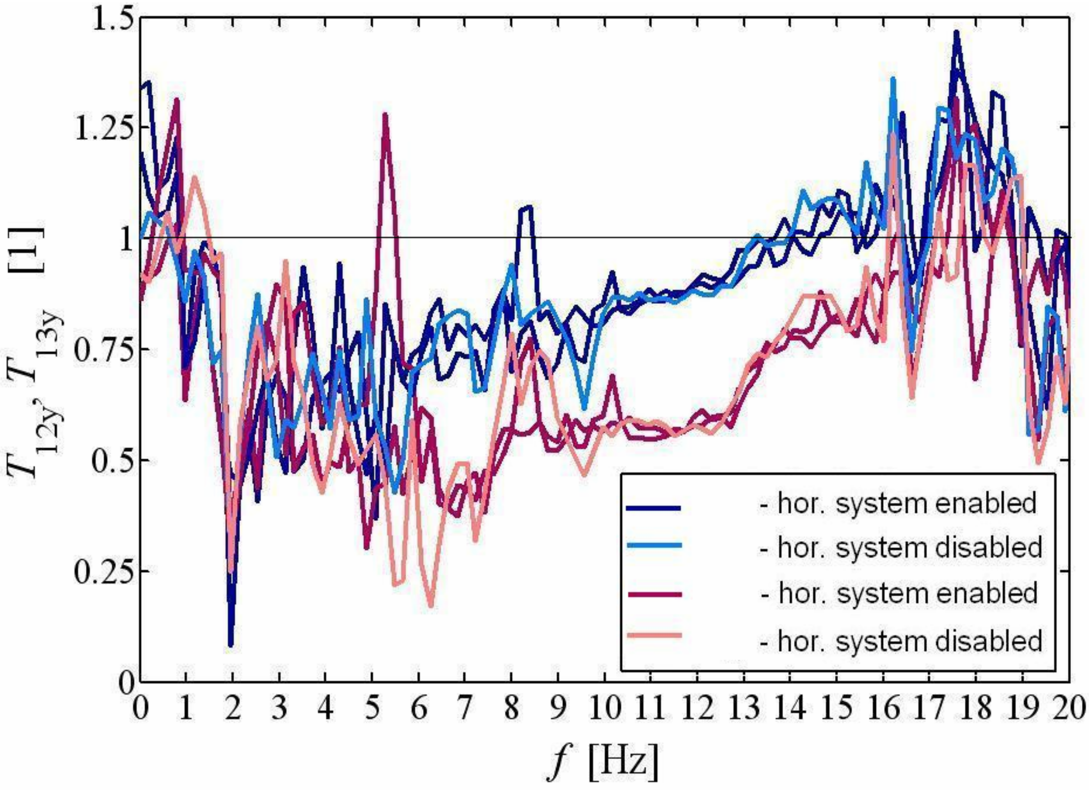


Figure 3.5.7 y-axis seat transfer function estimate.

- Friction modelled by the signum function, value estimated by "phenomenological optimisation", no correction for pitch influence build in, as reported in Stein, Zahoranský, Múčka, Chmúrny and Meyer (2004).

- Friction modelled by a physically correct slip-stick system, as detailed in Annex WP5-4.

In analogy to the SEAT factor used in seat research, a similar measure was introduced which was related to the seat frame, rather than to the seat/driver interface, termed pseudo SEAT factor (PSF), with indices indicating the axis to which it is related. A reasonable agreement between the measured and simulated PSD courses for the 2nd approach was obtained, as well as a rather high identified dry friction force value of about 60 to 80 N. As indicated above, this virtually prohibits vibration reduction. These findings were passed on to the respective seat manufacturer in September 2004 for improvement of prototype seats for the 2nd Phase tests, which would theoretically bring about a 5 % improvement in PSF_x. In this way, the requirements of milestone M5.1 for this particular seat were fulfilled.

3.5.2.2 Rail test seat 1st Phase results

After becoming familiar with the seat suspension systems layout and internal dynamics from documentation supplied by the seat manufacturer Grammer (Partner No. 3), the field measurements, supplied by SNCF (Partner No. 7) in August 2003 were extensively analysed and reported in Stein and Múčka (2004). The vertical and transversal vibration isolation system of the rail test seat were thoroughly analysed. Comparisons of manufacturer's data, laboratory and field measurements were undertaken. Corresponding suspension system models were developed and parameters optimised.

The transversal suspension system in its linear range can be modelled as a standard single-degree-of-freedom oscillatory system with negligible dry-friction. In the measured PSD, three peaks were distinguishable – first at about 0.5 Hz which was attributed to roll of the engine, the second at around 1.3 Hz which was attributed to the transversal vibration isolation system action and a third at about 2.5 Hz which coincided with the assumed engine pitch. The simple single-degree-of-freedom model was used for horizontal suspension "what-if" analysis for concurrent vibration reduction and relative displacement reduction (see Stein and Múčka, 2004). A further "what-if" analysis indicated that a fine-tuning of seat parameters would bring improvement in the *y*-axis SEAT factor of about 10 % and halve the transversal relative displacements. These findings were passed to the respective seat manufacturer in April 2004 for implementation in the prototype design as milestone M 5.1.

For the vertical suspension system, good agreement between theory and field measurements was also reached. The model was used for "what-if" analysis, primarily focused on simultaneous seat surface acceleration reduction and reduction of seat relative displacement by passive and semi-active means (Stein, Múčka and Clément, 2004). No real advantage of a semi-active controllable damper was demonstrated (Stein, Múčka and Clément, 2004). From the three possible damper settings, the one denoted as "medium" was singled out as that one providing the best compromise between vibration reduction and concurrently the relative displacement reduction.

The fore-and-aft (x-axis) suspension system was analysed at a later stage. First, it was observed that measurements of fore-and-aft vibrations measured at the "back" position, as defined in EN ISO 32362-2, resulted in highly non-stationary values, which cannot be evaluated. This was attributed to a changing backrest/back contact due to forward leaning of the driver. Therefore analysis was concentrated on measurements made at the seat frame or seat/driver interface, respectively where a stationary, linear approach was feasible. A "what-if" analysis was undertaken, using a single-degree-of-freedom model without dry friction influence. Results of the analysis indicated a marked improvement in the relative displacement handling capabilities of the fore-and-aft suspension system with increased damping and with increased spring stiffness. For the suggested parameter values, the PSFx deteriorated by about 7 %. However, the displacement range improved by 42 %, i.e. better vehicle handling capabilities resulted. These findings were passed to the seat manufacturer for consideration in the second phase prototype design as part of the milestone M 5.1. Also, the respective model codes were supplied to the seat manufacturer for evaluation, as required for milestone M 5.2. Descriptions of the test seat y-axis suspension system MatLab models are provided in Annex WP5-5.

3.5.2.3 Development of x-direction apparent mass model

From the very onset of the project, Partner No. 5 (IMMM SAS) was interested in a “holistic” approach, i.e. to include previous knowledge on apparent mass in the modelling process, as for the vertical direction which was reported in Stein and Múčka (2004). First available data were obtained from (INRS) Partner No. 8 in March 2003, representing the measured apparent mass of a single subject, under white noise excitation in frequency range 0-20 Hz with acceleration a_x at 1.20 m/s^2 r.m.s. The measured apparent mass with respect to a stipulated distance *d* from the steering wheel supported a single-degree-of-freedom oscillatory system model. However, a good model must be both descriptive and predictive, i.e. it must faithfully describe the apparent mass in the *x*-direction, irrespective of the fore-and-aft suspension system state (blocked or enabled) and must also enable the prediction of the acceleration transmissibility across an enabled horizontal suspension system. This was not the case here, so this model had to be discarded. After some further research, a more complicated model was designed, accounting for the steeringwheel reaction and some possible head movement as shown in Fig. 3.5.8 (see Annex WP5-3). Various model variants were tested and the predicted acceleration transmissibility in the *x*-direction was compared with the measured one for an enabled low-friction horizontal suspension system of a KAB seat. Comparison of the predicted and the measured transmissibility is shown in Fig. 3.5.9. There is a frequency shift between measured and predicted transmissibility of about 0.5 Hz which cannot be fully explained yet.

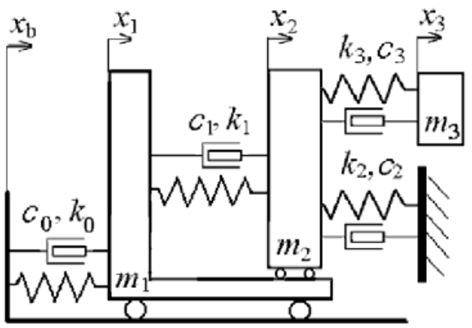


Fig. 3.5.8 Developed human body model in a cushioned suspended armchair part of a driver’s seat with a fore-and-aft suspension system described by parameters k_0, c_0.

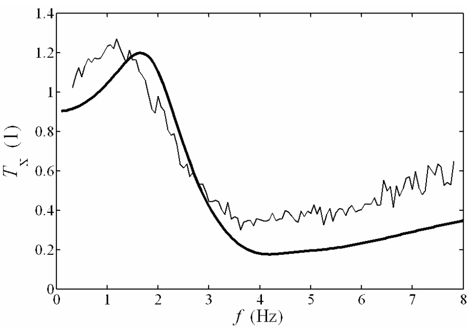


Fig. 3.5.9 Comparison of measured and simulated acceleration transmissibility across the fore-and-aft suspension system

(— measured; ▬ modelled).

A further set of apparent mass measurements was made by FIOSH (Partner No. 6) on a cohort of 13 trained volunteers. Measurements were made with a broad-band random signal in the frequency range 0.1- 30 Hz at three acceleration magnitudes: e1 = 0.28 ms^{-2} r.m.s., e2 = 0.96 ms^{-2} r.m.s., e3 = 2.03 ms^{-2} r.m.s.. The results were extensively analysed and reported in Stein, Múčka and Chmúrny (2005). The following findings were made:

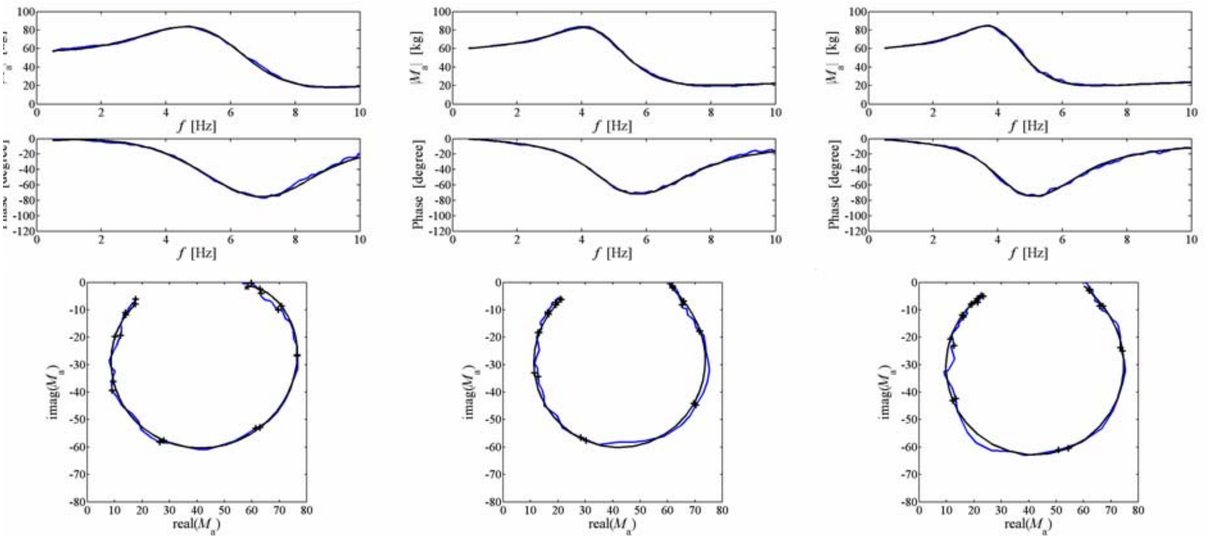
There was an unexplained peak in measured apparent mass at about 15 Hz for subjects sitting on the cushioned "armchair" part of a specific driver's seat that was not present if the same subject sat on a rigid surface under the same conditions.

If a same frequency range as above is analysed, i.e. 0.5-10 Hz, the model introduced above gives the best results in both the magnitude/phase versus frequency representation and in the Bode plots, as shown in Fig. 3.5.10. Model parameters were also estimated.

A similar approach was used for modelling of the y-direction apparent mass. A model structure as shown in Fig. 3.5.8 was arrived at but with y-axis variables and without the seat horizontal suspension system (described by parameters c_0 and k_0). A satisfactory match between the measured apparent mass and the modelled one was achieved. Model parameters were estimated for the three intensities e1, e2 and e3.

3.5.2.4 Truck test seat Phase II results

In the course of work within WP 4, a test code for laboratory assessment of driver seats was



e1 – 0.28 m/s^2 e2 – 0.96 m/s^2 e3 – 2.03 m/s^2

Fig. 3.5.10 Simulated (black) and measured (blue) apparent mass in the *x*-direction for three excitation magnitudes.

UNMODIFIED SEAT
Heavy subject horizontal system
Enabled and blocked

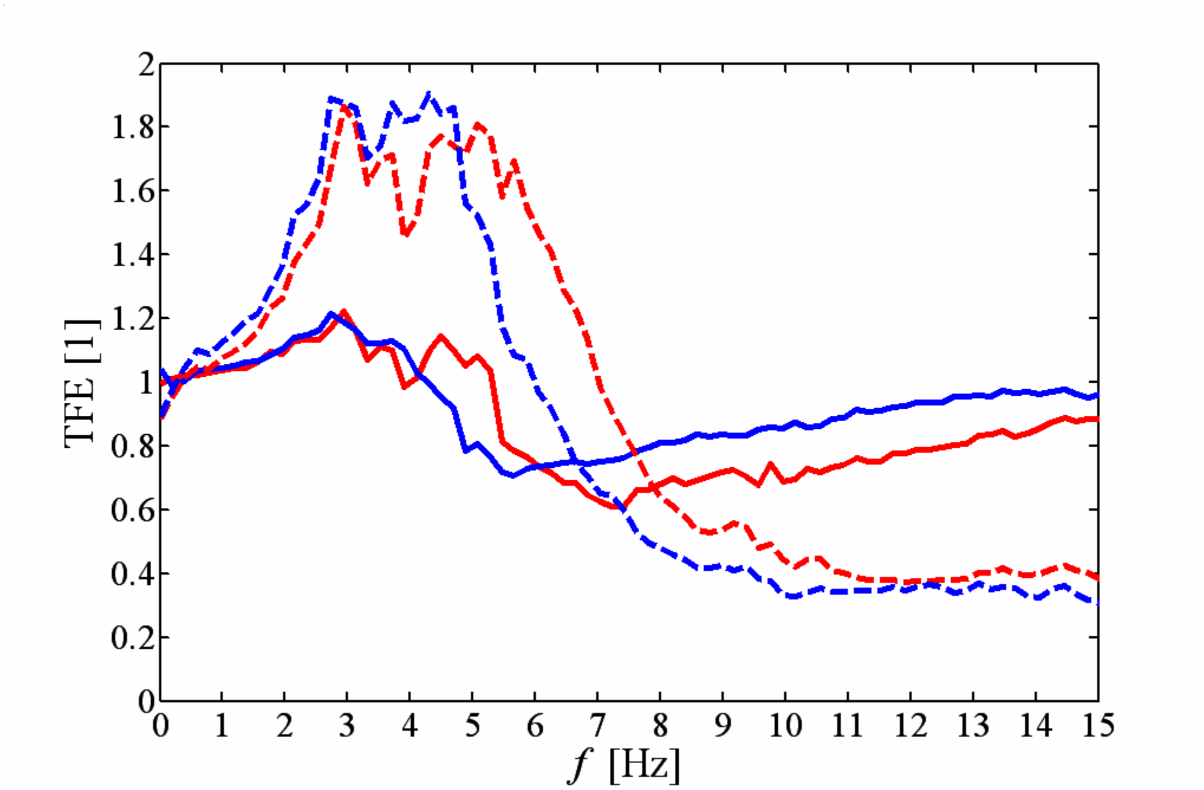


Figure 3.5.11 Transfer function estimates

Seat X - enabled —
Seat X - blocked —
Lower Back X - enabled – –
Lower Back X - blocked – –

developed. ISVR (Partner No. 1) tested the code using the truck test seat with two subjects (a light one of mass 55 kg and a heavy one of mass 106 kg) with excitation signal types representing stipulated realistic conditions (see Annex WP3-3). The horizontal (*x*-axis) seat transfer function estimates at the seat/driver interface and at the newly introduced lower back position are compared in Fig. 3.5.11 and Fig. 3.5.12. For the unmodified seat, a comparison of the results with the suspension system enabled and blocked is shown. For the modified seat, the results for the heavy and light subject are shown for an enabled suspension system.

The on-road tests were conducted with two variants of the modified truck test seat: modification “A” with a harder spring (also referred to in this report as modified seat with unmodified spring) and modification “B” with a softer spring (also referred to in this report as modified seat with modified spring). The field signals were highly non-stationary; the large peaks were probably generated by traverse road obstacles, which led to high crest factor

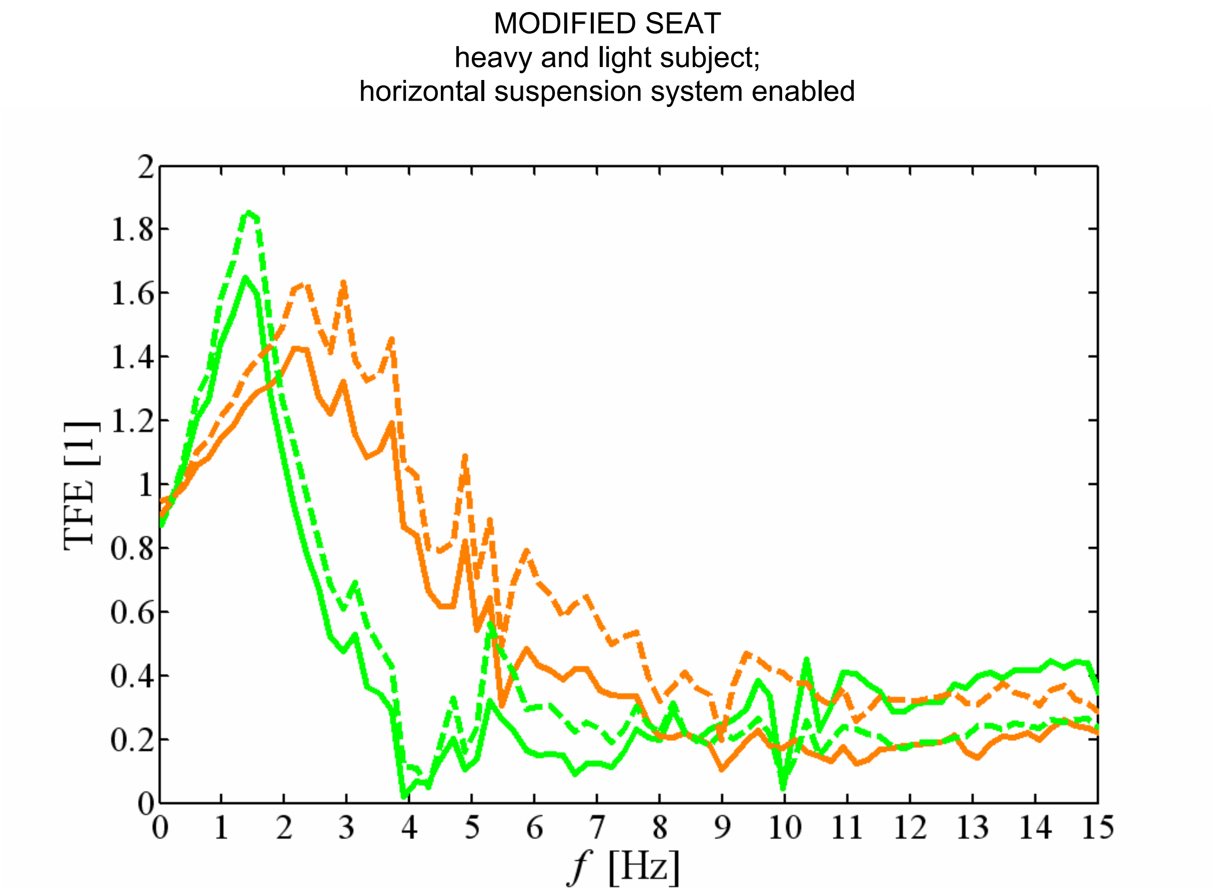

MODIFIED SEAT
heavy and light subject;
horizontal suspension system enabled

Figure 3.5.12 Transfer function estimates
Seat X - heavy subject ▬
Seat X - light subject ▬
Lower Back X - heavy subject ▬ ▬
Lower Back X - light subject ▬ ▬

values for both x- and y-directions. These are attributed to oscillations in the frequency range 10-15 Hz, as detailed analysis revealed. The most relevant data from the Phase I and Phase II tests are summarised in table below.

	VERTICAL			LONGITUDINAL		
	UNMOD SEAT	MODIF “A”	MODIF “B”	UNMOD SEAT	MODIF “A”	MODIF “B”
R.M.S. a_{base} [m/s^2]	0.451	0.502	0.526	0.320	0.284	0.293
CREST factor a_{base} [1]	5.4	6.52	6.52	4.95	12.9	13.4
R.M.S. a_{seat} [m/s^2]	0.420	0.489	0.504	0.315	0.238	0.194
CREST factor a_{seat} [1]	4.0	5.41	4.98	6.20	9.68	10.1
SEAT factor [1]	1.15	0.962	0.981	1.78	1.53	1.15
$D_{MIN-MAX}$ [mm]	5.62	8.79	9.58	3.41	10.69	17.71

If the values of the SEATx factors and crest factors are compared, modification “B” performed better than “A” and these outperform the unmodified seat, both in the *x*- and *z*-directions. The only concern was a larger relative displacement for the modification “B”, due to use of a softer spring. It can be concluded that the modified seats outperform the original one, while the modification “B” performs better than the modification “A”. Details are provided in Stein, Múčka and Zahoranský (2005). The *x*-axis suspension model gave a reasonable indication of the seat performance. However, it cannot predict the suspension performance in all situations. The model code was supplied to the seat manufacturer for evaluation, as required for milestone M 5.2. Descriptions of the test seat x-axis suspension system MatLab models are provided in Annex WP5-6.

3.5.2.5 Rail test seat Phase II results

In March 2005, SNCF conducted a second run of field measurements, from which selected sections were analysed. A selected locomotive was used; the same driver operated the vehicle at a speed of 100 km/h and traversed a specific section of track for each occasion, i.e. the excitation can be assumed to be the same. It was noted that strong electromagnetic interference was present - the signals measured at the test disk under the seated operator were of bad quality yielding unrealistic values. Therefore the SEAT factor values in *x*- and *y*-directions could not be calculated. Instead the above introduced pseudo SEAT values (PSF) were analysed and the results reported in Stein and Múčka (2005).

In the vertical direction there was an improvement by the Phase II seat – the SEAT factor was decreased by 12 %. However, the relative displacement decreased by only about 6 %.

In the transversal direction not much improvement in the PSFy factor was demonstrated. However, the seat transversal movement deteriorated, as predicted.

In the vertical direction, the “medium” vertical configuration increased the SEAT values by about 27 % in comparison with the “soft” or “minimal” setting (the SEAT value changed from 0.45 to 0.62). The relative displacement is improved by 16%.

Marked improvement in the fore-and-aft direction (*x*-direction) was observable; the PSF_x was improved by 21%, while the relative displacement range improved by 25 %. The effect is also shown in the *x*-axis PSD of Fig. 3.5.13.

To sum up, the Phase II seat was better than the Phase I seat (see Stein and Múčka, 2005). Suspension models were supplied to the seat manufacturer concerned for evaluation, as required for milestone M 5.2.

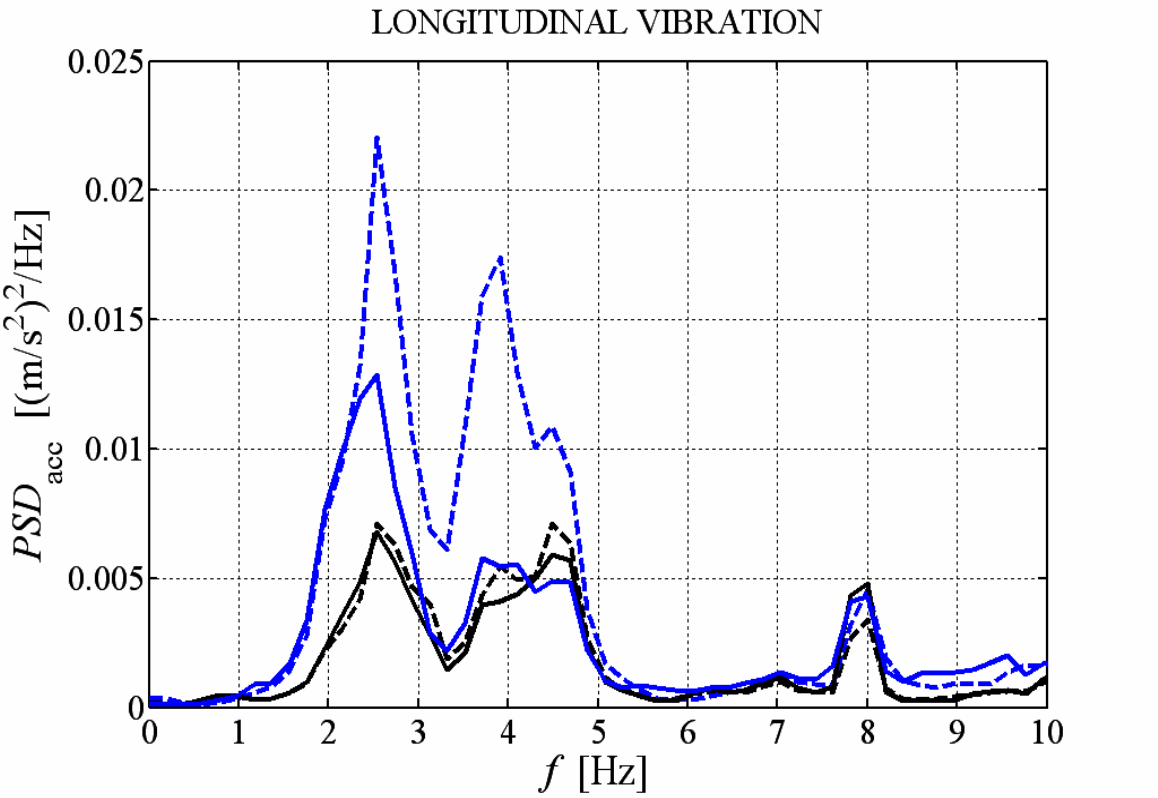


Fig. 3.5.13 PSD in the *x*-direction (a_{base} - black; a_{frame} - blue) - enabled (solid), blocked (dashed)

3.5.3 ISVR activities

ISVR has worked on a model capable of predicting the performance of lateral seat suspension systems in response to arbitrary lateral and roll motions. The structure of a lateral/vertical/roll planar model of a seat suspension system was implemented using the SimMechanics extension to the Mathworks Matlab and Simulink software as shown in Figure 3.5.14. The structure of the model is suitable for simulating non-linear passive or active seat components.

In addition to models of the biodynamic responses, there is a need to develop better models for predicting the various and complex subjective responses (comfort and performance) as revealed by the experimental results obtained in WP2.

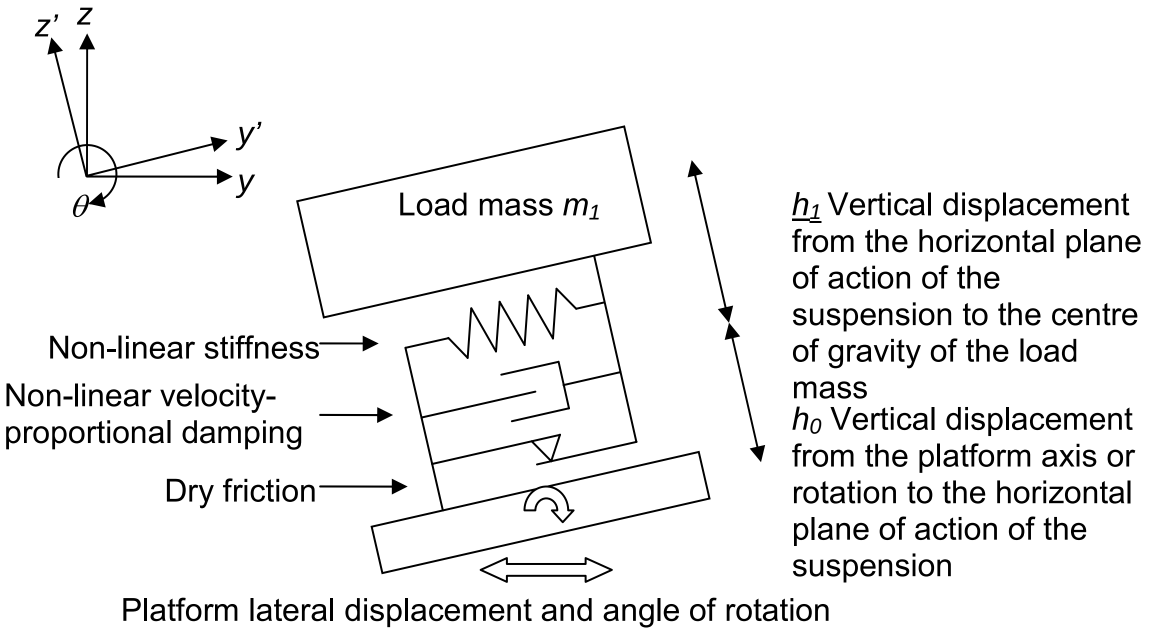


Figure 3.5.14 A schematic of the ISVR model structure.

The lateral vibration isolation system fitted to the VIBSEAT 'rail seat' was examined and the dynamic characteristics of the components were measured. The suspension has been modelled as a parallel arrangement of a three-state non-linear spring, a non-linear damper with hysteresis and a dry friction element. The performance of the dry friction model provided as part of SimMechanics was found to be insufficient, so the two-state friction model developed during the TESTOPS project has been adapted for use with this model.

The seat load motion predicted by the model in the lateral axis was compared with laboratory measurements of the seat performance. The predicted suspension displacement was observed to be in good agreement with the laboratory measurements with a simple seat load.

ISVR took measurements of the dynamic response of seated subject in response to lateral and roll motions in order to obtain a suitable model of the seated human body for use with lateral and roll seat motions. This model included the translational and inertial response of the body.

3.5.3 Workpackage 5 conclusions

It was concluded that the modelling work performed under WP5 provides an improved understanding of seat dynamic behaviour, enabling better prediction of seat responses

It was concluded that the highest priority was to develop passive models and obtain improved experience of passive models of horizontal seat suspensions before developing active models. It was also agreed that while they can sometimes be successful, active suspensions for the isolation of vertical vibration are currently too expensive for widespread use within industry. Therefore, emphasis was placed on understanding and modelling passive systems. The models could form the basis for active models in the future. The need for active systems will depend on the exposure limits, and a reduction in the exposure limits for horizontal vibration would increase the demand for active or semi-active horizontal suspensions.

The developed models in the fore-and-aft and lateral directions provide improved predictions of the biodynamic responses of the body, but the results of WP3 show that the biodynamic responses are complex (e.g. non-linear and influenced by the contact with the seat back) and so further development of models based on further experimental data will allow improved models in the future.

The dry friction model developed by Partner 10 (IMMM) is a new and valuable addition to the methods of modelling the performance of seat suspensions.

4 GENERAL CONCLUSIONS

The combined findings from the field studies in Workpackage 1, the laboratory studies in Workpackages 2 and 3, and the modelling in Workpackage 5, show that the dynamic performance of suspension seats in the fore-and-aft and lateral directions can have a significant effect on the exposure of workers to vibration in many occupations – a finding particularly relevant in view of the new EU Physical Agents (Vibration) Directive.

The test code developed in Workpackage 4 provides the first draft for a future standard method of testing seats designed to reduce exposures to horizontal whole-body vibration. After further experience in the use of the method by industry, test houses and academic institutions the test code may be expected to form the basis of a new International Standard.

Laboratory experiments conducted in Workpackage 2 and Workpackage 3 increased fundamental understanding of both subjective and biodynamic responses of the body to low frequency horizontal and rotational oscillation. The results of these studies can be expected to lead to improved methods for the evaluation of the severity of these motions. The experiments showed that improvements in the standard methods of evaluating such motions are necessary before horizontal seat isolation systems can be optimised.

The mathematical modelling performed in Workpackage 5 increased understanding of seat dynamic behaviour, allowing improved predictions of seat responses and quicker and cheaper development of seats with improved dynamic performance.

5 LIST OF DELIVERABLES AND MILESTONES

The complete list of project deliverables is shown in Table 1 and the project milestones in Table 2.

Table 1 List of deliverables

Deliverable Nr.	Delivery date (months from start)	Output from WP Nr	Nature of deliverable and brief description	Status
Internal Deliverables				
D1	+6	1	Digital time histories measured during vehicle field trials and summary reports of the conditions for each test	**COMPLETE**
D2	+9	1	Summary reports of the field trials including descriptions of the vehicles, the frequency and time / amplitude domain content of the motions at the seat base, and summary measures of the quantity of vibration and the performance of the seat in each axis and overall	**COMPLETE**
D3	N/A	3	Measurements of seat component dynamic properties	**COMPLETE**
D4	+15	3	Measurements of seat dynamic performance in each axis measured in the laboratory.	Updated to an ongoing 'on demand' task. **COMPLETE**
D5	+18	2	Report on human factors affecting seated response to horizontal and rotational oscillatory motions.	**COMPLETE**
D6	+18	3	Measurements of the mechanical impedance of the seated human body.	**COMPLETE**
D11	+33	1	Summary reports and data from the modified seat field trials.	**COMPLETE**
D12	+33	3	Prototype seat laboratory measurements.	**COMPLETE**
Key deliverables				
D7	+27	4	Physical models (prototypes) of seat suspension systems	**COMPLETE**
D8	+33	5	Theoretical models of passive seat suspension systems	**COMPLETE**
D9	+33	5	Theoretical models of active or semi-active seat suspension systems	**COMPLETE**
D10	+36	4	A methodology for testing suspension seating in the laboratory in response to horizontal and rotational vibration	**COMPLETE**

Table 2 List of milestones

OVERVIEW OF MILESTONES				
Milestone Nr.	**Due date**	**Brief description of Milestone objectives**	**Decision criteria for assessment**	**Status**
M1.1	+9	Production seat field trials complete.	Field trial reports accepted by WP2, WP3, WP4 and WP5 partners.	**COMPLETE**
M1.2	+33	Modified seat field trials complete.	Results accepted by the partnership.	**COMPLETE**
M2.1	+18	Report on human factors relevant to horizontal and rotational suspension seating complete.	Results accepted by WP4 and WP5 partners.	**COMPLETE**
M3.1	N/A	Seat component measurements complete.	Results accepted by WP3 and WP5 partners.	**COMPLETE**
M3.2	+15	Laboratory evaluation of current production seats complete.	Results accepted by manufacturers and WP5 partners.	**COMPLETE**
M3.3	+18	Measurements of the impedance of the human body complete.	Results accepted by WP4 and WP5 partners.	**COMPLETE**
M3.4	+27	Prototype seats constructed.	Prototype seats supplied to the partner responsible for WP3 laboratory testing of prototype seats.	**COMPLETE**
M3.5	+33	Laboratory evaluation of prototype seats complete.	Results accepted by he partnership.	**COMPLETE**
M4.1	+24	Draft test methodology complete.	Draft test method submitted to partner 6 for laboratory evaluation.	**COMPLETE**
M4.2	+30	Laboratory evaluation complete.	Results accepted by WP4 partners.	**COMPLETE**
M4.2	+36	Test method finalised	Results accepted by the partnership.	**COMPLETE**
M5.1	+18	Theoretical input into prototype development complete.	Results accepted by prototype manufacturers.	**COMPLETE**
M5.2	+36	Theoretical modelling complete.	Model code provided to interested partners.	**COMPLETE**
M6.1	+18	Mid term assessment milestone	M1.1, M2.1, M3.1, M3.2, M5.1 complete. Technology implementation plan initiated.	**COMPLETE**
M6.2	+36	Final report	All reports complete including the technology implementation plan and submitted to the EC.	**COMPLETE**

6 COMPARISON OF INITIALLY PLANNED ACTIVITIES AND WORK ACTUALLY ACCOMPLISHED

(Refer to Section 4)

Some activity deliverables experienced delays or were extended in the light of results obtained. The project meetings involved frank and productive discussion of difficulties and revised deadlines were proposed with the agreement of all partners to ensure that the required activities were completed within the timescales of the project.

The main areas re-scheduled were as follows:

- It was decided to prioritise measurements of the apparent mass of the seated human body (WP3) over the subjective assessments (WP2). The apparent mass data were required for the mathematical models that, in turn, provided information to the manufacturers to allow prototypes to be developed in time to be tested in the laboratory. The subjective response data were mainly required for the test method development and were therefore not essential early in the project. Milestone M2.1 was therefore moved back in favour of obtaining WP3 results.
- M3.2, the laboratory assessment of existing seat performance, was performed and presented to the partnership. It was suggested that some additional motions might be investigated, and that the laboratory seat assessments might be used to gain experience with the draft test method. These tests were therefore extended and the draft test method was used by ISVR to assess the existing and production seats in January 2005.
- The development of the test method required substantial discussion time between the partners involved in this aspect of the project. Additional meetings were scheduled for this purpose in order to prepare a useable draft of the method in time for the laboratory seat tests in early 2005. Experience of these tests was used to develop a revised draft for assessment by FIOSH.

7 MANAGEMENT AND CO-ORDINATION ASPECTS

7.1 Work program and meetings

The work was divided into six workpackages with activities within each workpackage and timescales as shown in Table 3. The project has involved substantial activity in all technical workpackages as discussed in Section 3. The Workpackage 6 involves the administration, financial and reporting aspects of the project and is ongoing throughout the project.

Project meetings were held every six months and an additional meeting relating to the test method development (WP4) was held in December 2004.

7.2 Communication and transfer of data

The primary method of communication between partners has been by e-mail. It has also proved useful to hold meetings relating to specific workpackages independently of the scheduled progress meetings.

A secure web site accessible to all members of the VIBSEAT project was established. This site allowed partners to access meeting information, technical and administrative reports, finance forms, the contact list and other relevant information. It is accessible by password and is not available to members of the public. A public page summarizing the project was set up at http://www.humanvibration.com/EU/vibseat.htm.

7.3 Consortium agreement and contract matters

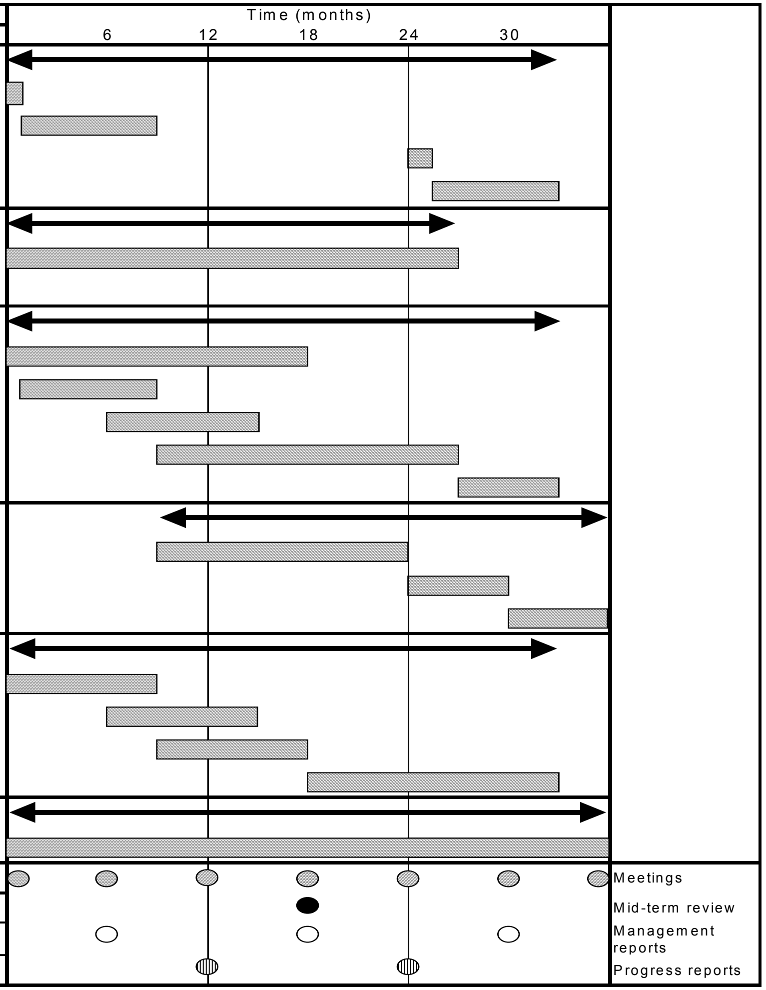
A three-month no-cost extension of the contract was requested from the EC. All partners signed an agreement to indicate consent to the three-month extension of the contract.

7.4 Contact details

The contact details for all partners may be found in Annex 1.

Table 3 The VIBSEAT project manpower bar chart

	Workpackage and Activity descriptions	Partner man months 1	2	3	4	5	6	7	8	9	10	Ttl.
WP 1	Field trials (led by partner 9)	6.0	3.0	2.0	2.0	0.0	0.0	2.0	0.0	7.0	9.0	31.0
A1.1	Provision of seats											
A1.2	Field trials with production seats											
A1.3	Provision of modified seats											
A1.4	Field trials with modified seats											
WP 2	Human factors (led by partner 6)	12.0	0.0	0.0	0.0	0.0	5.0	3.4	0.0	0.0	0.0	20.4
A2.1	Assess the effect of lateral/rotational motions on subjective discomfort and the ability to perform relevant tasks											
WP 3	Objective factors (led by partner 1)	14.0	0.0	3.0	11.5	0.0	5.0	0.0	2.0	0.0	0.0	35.5
A3.1	Quantification of the impedance of the human body											
A3.2	Laboratory measurements of seat components											
A3.3	Laboratory evaluation of seat performance											
A3.4	Development of prototype seat suspensions											
A3.5	Laboratory evaluation of prototype seat performance											
WP 4	Test method development (led by partner 7)	6.0	3.0	3.0	3.0	0.0	2.0	2.0	2.0	3.0	0.0	24.0
A4.1	Development of the test method											
A4.2	Laboratory evaluation of the test method											
A4.3	Refinement of the test method											
WP 5	Theoretical model development (led by partner 8)	3.1	0.0	0.0	0.0	51.5	0.0	0.0	8.0	0.0	0.0	62.6
A5.1	Development of model structures											
A5.2	Comparison with laboratory results											
A5.3	Theoretical studies to support prototype development											
A5.4	Further theoretical research											
WP 6	Project management (led by partner 1)	6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.75
A6.1	Administrative and technical management											
TOTAL MANMONTH		47.9	6.0	8.0	16.5	51.5	12.0	7.4	12.0	10.0	9.0	180.3
In year 1		16.0	2.0	2.0	6.3	18.6	3.0	2.4	4.0	4.5	4.0	62.8
In year 2		16.0	2.0	3.0	6.7	18.6	6.0	2.3	4.0	1.0	0.0	59.6
In year 3		16.0	2.0	3.0	3.5	14.0	3.0	2.7	4.0	4.5	5.0	57.7



8 ANNEX LIST

8.1 Work package 1 annexes

WP1-1: Burström, L., Lindberg, I., Nordström, B., (December 2005) Measurement and analysis of vehicle and seat motion in an articulated on-road truck - Results from second field trials. National Institute for Working Life, Sweden.

WP1-2: Fleury, G. (2005) Measurements and analysis of accelerations on a seat in a wheel loader during working conditions. National Research and Safety Institute, France.

WP1-3: Luger, E., Nadlinger, M. (December 2005) Agricultural and industrial off-road vehicle field test results. BLT-HBLFA Francisco Josephinum, Austria.

WP1-4: Gunston, T. and Griffin, M.J. (2004) Analysis of workpackage 1 field data obtained in 2002 / 2003 with respect to vehicle floor motions and seat performance. Institute of Sound and Vibration Research, University of Southampton, UK.

WP1-5: Clément, P. (August 2003) Grammer 3D axial suspension seat vibration behaviour on SNCF BB 8700 locomotive. SNCF – CIM, France.

WP1-6: Clément, P. (December 2005) Grammer 3D axial suspension seat vibration behaviour on SNCF BB 17000 locomotive train field test phase II. SNCF – CIM, France.

8.2 Work package 2 annexes

WP2-1: Schust, M. (2004) Measurement of subjective judgements (intensity, comfort, effort) and reaction times – a pilot study. Federal Institute for Occupational Safety and Health, Berlin, Germany

WP2-2: Schust, M., Seidel, H. and Blüthner, R. (2005) Subjective judgements and reaction times during vibration in x- or y-direction and biaxial (xy-) vibration of driver seats with locked or activated horizontal suspension - main study. Federal Institute for Occupational Safety and Health, Berlin, Germany

WP2-3: Wyllie, I.H. and Griffin, M.J. (2005) The discomfort arising from exposure to roll, lateral, pitch and fore-and-aft oscillation at frequencies between 0.2 and 1.6 Hz. Institute of Sound and Vibration Research, University of Southampton, Southampton, UK

WP2-4: Clément, P. and Mirot, L. (2005) An ergonomic study on SNCF locomotive cab simulator: Evaluation of the effects of vibrations on vehicle control performances. SNCF – CIM, France.

8.3 Work package 3 annexes

WP3-1: Gunston, T.P. (2003) The apparent mass of the seated human body in response to lateral and roll vibration. Presented at the 38th United Kingdom Conference on Human Response to Vibration, held at Institute of Naval Medicine, Alverstoke, Gosport, PO12 2DL, England, 17 - 19 September 2003. Institute of Sound and Vibration Research, University of Southampton, UK.

WP3-2: Gunston, T.P. (2004) Influence of a back restraint on the lateral apparent mass of the seated human body in response to lateral and roll motions. Paper presented at the 39th United Kingdom Group Meeting on Human Responses to Vibration, held at Ludlow, Shropshire, England, 15 - 17 September 2004. Institute of Sound and Vibration Research, University of Southampton, UK

WP3-3: Gunston, T.P. and Griffin, M.J. (2005) Seat performance laboratory test – unmodified and prototype truck seats tested in the x-axis according to VIBSEAT test protocol

Draft 6-28Dec04. HFRU 05/15, Institute of Sound and Vibration Research, University of Southampton, Southampton, UK, February 2005. Institute of Sound and Vibration Research, University of Southampton, UK

WP3-4: Nawayseh, N. and Griffin, M.J. (2005) Seat performance laboratory test –modified truck seat fitted with a prototype spring tested in the x-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/65, Institute of Sound and Vibration Research, University of Southampton, UK, October 2005.

WP3-5: Nawayseh, N. and Griffin, M.J. (2005) Seat performance laboratory test – GRAMMER seats tested in the x-axis and y-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/71, Institute of Sound and Vibration Research, University of Southampton, UK, November 2005.

WP3-6: Nawayseh, N. and Griffin, M.J. (2005) Seat performance laboratory test – KAB seat tested in the x-axis and y-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/70, Institute of Sound and Vibration Research, University of Southampton, UK, November 2005.

WP3-7 Hinz, B., Blüthner, R., Seidel, H. and Menzel, G. (2005) Apparent mass functions of the combination subject / seat - an experimental study. Federal Institute for Occupational Safety and Health, Berlin, Germany, July 2005.

WP3-8 Seidel, H. and Blüthner, R. (2005) Shared-cost RTD Control of the Hexapod. Federal Institute for Occupational Safety and Health, Berlin, German, July 2005.

8.4 Work package 4 annexes

WP4-1: Clément, P. (2005) Laboratory test protocol for assessing the vibration performance of seats equipped with horizontal suspensions. Final version December 2005. SNCF – CIM, France.

WP4-2: Blüthner, R., Seidel, H., Gericke, L. and Keital, J. (2005) Laboratory Evaluation of the test method for driver seats with suspension in x- and/or y-direction. Federal Institute for Occupational Safety and Health, Berlin, Germany

WP4-3: Fleury, G. (2005) Investigation in laboratory of testing conditions for a fore-and-aft suspended seat of a wheel loader. National Research and Safety Institute, France.

8.5 Work package 5 annexes

WP5-1 Fleury, G., (2005) Numerical assessment of fore-and-aft suspension performance to reduce whole-body vibration of wheel loader drivers, Proceedings of the 3rd International Conference on Whole-Body Vibration injuries held in Nancy in June 2005. National Research and Safety Institute, France.

WP5-2 Stein, G. J., Múčka, P., Clément, P. (2004) Vibration mitigation by intelligent control of seat suspension damper. Euro-Mech 455 Colloquium "Semi-Active Vibration Suppression", Prague, Czech Republic, July 5-7, 2004. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

WP5-3 Stein, G. J., Záhoranský, R., Múčka, P., Chmúrny, R. and Meyer, H. (2004) On dry-friction modelling in simple, kinematically excited, vibration isolation systems. Paper presented at the ISMA 2004 Intl. Conference, Leuven, Belgium Sept. 20-22nd, 2004, p. 649-663. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

WP5-4 Záhoranský, R., Stein, G. J., and Meyer, H. (2005) Modelling and simulation of kinematically excited vibration isolation systems with friction, under random and harmonic excitation. Presented at the "European Non-linear conference 2005", TU Eindhoven, the

Netherlands, August. 2005. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

WP5-5 Múčka, P. and Stein, G. J. (2005) Description of the test seat y-axis (transversal) suspension system MatLab models. Institute of Materials and Machine Mechanics Slovak Academy of Sciences, August 2005.

WP5-6 Múčka, P. and Stein, G. J. (2005) Description of the test seat x-axis suspension system MatLab models. Institute of Materials and Machine Mechanics Slovak Academy of Sciences, July 2005.

9 PUBLICATIONS AND REPORTS

9.1 Publications

Blüthner, R., Hinz, B., Menzel, G., Schust, M. and Seidel, H. (2005) On the significance of body mass and vibration magnitude for the acceleration transmission from the seat base to seats with horizontal suspension during low-frequency excitation in x- and y-directions. Paper presented at the 3rd International Conference on Whole body vibration injuries, 7-9 June 2005, Nancy.

Fleury, G. (2004) Experimentelle Untersuchung der dynamischen Masse einer sitzenden Versuchsperson bei Schwingungen in der X-Richtung zur Bildung eines Modells. Paper presented at the "Humanschwingungen" conference in Darmstadt (17 and 18 March 2004), VDI-Berichte 1821.

Fleury, G. (2005) Numerical assessment of fore-and-aft suspension performance to reduce whole-body vibration of wheel loader drivers, Proceedings of the 3rd International Conference on Whole-Body Vibration injuries held in Nancy in June 2005

Gunston, T.P. (2004) Influence of a back restraint on the lateral apparent mass of the seated human body in response to lateral and roll motions. Paper to be presented at the 39th United Kingdom Group Meeting on Human Responses to Vibration, held at Ludlow, Shropshire, England, 15 - 17 September.

Gunston, T.P. (2003) The apparent mass of the seated human body in response to lateral and roll vibration. Presented at the 38th United Kingdom Conference on Human Response to Vibration, held at Institute of Naval Medicine, Alverstoke, Gosport, PO12 2DL, England, 17 - 19 September 2003.

Schust, M., Blüthner, R. and Seidel, H. (2005) Examination of comfort and reaction times (brake and accelerator) during low-frequency vibration in x- or y-direction and biaxial (xy-) vibration of driver seats with activated and deactivated horizontal suspension. Paper presented at the 3rd International Conference on Whole body vibration injuries, 7-9 June 2005, Nancy.

Stein, G., J. (2005) On calibration uncertainty estimation in ratio-metric measurements. Measurement Science Review, Vol. 5, Sect. 1 (2005), pp. 31–34.

Stein, G., J. (2005) On calibration uncertainty estimation in ratio-metric measurements. Presented at the 2005 Measurement Conference, Bratislava – Smolenice, Slovakia, May 2005 (an ISI Proceedings entry).

Stein, G., J. (2005) On A-type (Statistical) uncertainty estimation in whole body vibration measurements. Symposium *Managing Uncertainty in Noise Measurement and Prediction* Le Mans, France, 27-29 June 2005.

Stein, J and Mucka, P. (2003) Influence of passenger's mass and posture on response to random vibration. Colloquium “Dynamics of Machines 2003”, Prague, Czech Republic Feb. 11-12th, 2003, p. 183 – 190.

Stein, G., J., Múčka, P., Chmúrny, R. (2005) Development of a x-direction apparent mass model of human body sitting in a cushioned, suspended seat. Presented at the 3rd Whole-Body Vibration Injury Conference, June 2005, Nancy, France.

Stein, GJ, Mucka, P and Clément, P. (2004) Identification and optimization of vertical seat suspension system for a railway vehicle. Paper presented at the 9th mini-conference on vehicle system dynamics, identification and anomalies in Budapest, Hungary, 8-10 November, 2004.

Stein, G.J, Múčka, P and Clément, P. (2004) Vibration mitigation by intelligent control of seat suspension damper. Paper presented at EUROMECH 455 on Semi-Active Vibration Suppression, in Prague, Czech Republic, 5-7 July 2004.

Stein, G. J., and Záhoranský, R. (2006) Modelling and simulation of simple oscillatory system with combined viscous and dry-friction damping under reality-like random excitation. Paper submitted for presentation at the 6th Intl. Conference “Recent advances in structural dynamics”, to be held at ISVR, Southampton, UK in July 2006.

Stein, J., Záhoranský, R., Múčka, P., Chmúrny, R. and Meyer, H. (2004) On dry-friction modelling in simple, kinematically excited, vibration isolation systems. Colloquium “Dynamics of Machines 2004”, Prague, Czech Republic Feb. 10-11th, 2004, p. 117-124.

Stein, G. J., Zahoranský, R., Múčka, P., Chmúrny, R. and Meyer, H. (2004) On dry-friction modelling in simple, kinematically excited, vibration isolation systems. Paper presented at the ISMA 2004 Intl. Conference, Leuven, Belgium Sept. 20-22nd, 2004, p. 649-663.

Wyllie, I.H. (2005). Discomfort from sinusoidal oscillation in the roll and lateral axes at frequencies between 0.2 and 1.6 Hz. Presented at 40th UK Group Meeting on Human Response to Vibration. HSE, Liverpool, UK.

Wyllie, I.H. (2004). Discomfort in roll oscillation at low frequencies. Presented at 39th UK Group Meeting on Human Response to Vibration. Ludlow, UK.

Wyllie, I. H. (2003). Rate of growth in discomfort with low frequency lateral and roll oscillation. Presented at 38th UK Group Meeting on Human Response to Vibration. Institute of Naval Medicine, Alverstoke, UK.

Záhoranský, R., Stein, G., .., Chmúrny, R. (2005). Dry-friction effects modelling in kinematically excited vibration isolation systems“. Colloquium “Dynamics of Machines 2005”, Prague, Czech Republic Feb. 7-9th, 2005, p. 155 – 162.

Záhoranský, R., Stein, G., J., and Meyer, H. (2005). Modelling and simulation of kinematically excited vibration isolation systems with friction, under random and harmonic excitation. Submitted to the “European Non-linear conference 2005”, TU Eindhoven, the Netherlands, August 2005.

9.2 Internal project reports produced by each workpackage

Workpackage 1:

INRS, 2005. Fleury, G. Measurements and analysis of accelerations on a seat in a wheel loader during working conditions. National Research and Safety Institute, France.

IMMM, November 2005. Stein, G. J. and Múčka, P. Analysis of the Phase II road test data for the unmodified and modified truck test seats. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

IMMM, October 2005. Stein, G. and Múčka, P. Analysis of the Phase II rail test seat performance in operating conditions. [VIBSEAT Project Internal Technical Report]. Code IMMM SAS 14.1-F, IMMM SAS, Bratislava.

SNCF, December 2005. Clément P. Grammer 3D axial suspension seat vibration behaviour on SNCF BB locomotive train field tests Phase II, SNCF, France.

NIWL, December 2005. Burström, L., Lindberg, I., Nordström, B., Measurement and analysis of vehicle and seat motion in an articulated on-road truck - Results from second field trials. National Institute for Working Life, Sweden.

NIWL, September 2005. Burström L., Lindberg L., Nordström B. VIBSEAT Seats and field-testing -Measurement and analysis of vehicle and seat motion in an articulated on-road truck - Results from second field trials. Technical Report, National Institute for Working Life, Sweden, 2005-09-28.

BLT, December 2005. Luger, E., Nadlinger, M. Agricultural and industrial off-road vehicle field test results. BLT-HBLFA Francisco Josephinum, Austria.

BLT, Spring 2005. Luger E. and Nadlinger M.. VIBSEAT – WP1 field tests – KAB suspension seat vibration behaviour on Steyr CVT 170 tractor and Volvo L70C loader – report, video & data files on two DVD-ROM's by FJ-BLT, Austria

IMMM, June 2004. Stein, G. J. and Múčka, P. Analysis of the rail test seat performance in operating conditions. [VIBSEAT Project Internal Technical Report]. Code IMMM SAS 5.1-F, IMMM SAS, Bratislava.

ISVR, February 2004. Gunston T. and Griffin MJ. Analysis of workpackage 1 field data obtained in 2002 / 2003 with respect to vehicle floor motions and seat performance. ISVR report HFRU 04/17.

IMMM, August 2003. Stein, G. J. and Múčka, P. Analysis of the road test data of the truck test seat. [VIBSEAT Project Internal Technical Report]. Code IMMM SAS 2.1-F, IMMM SAS, Bratislava.

BLT, Spring 2003. Luger E. and Nadlinger M.. VIBSEAT – WP1 field tests – KAB suspension seat vibration behaviour on Steyr CVT 170 tractor and Volvo L70C loader – report, video & data files on CD-ROM by BLT, Austria

NIWL, April 2003. Burström L, Lindberg L, Nordström B. VIBSEAT Seats and field testing - Measurement and analysis of vehicle and seat motion in an articulated on-road truck. Technical Report. National Institute for Working Life, Sweden, 2003-06-22

ISVR, 2003. Gunston, T. and Griffin, M.J. ISVR marine craft field test report. ISVR report HFRU 03/53.

NIWL, April 2003: Burström, L., Lindberg, L., Nordström. B.Measurement report: Work package 1: Seats and field testing - Measurement of vehicle and seat motion in an articulated on-road truck. Technical Report. National Institute for Working Life, Sweden.

ISVR, September 2003. Gunston, TP. and Griffin, MJ ISVR marine craft field test report. ISVR report HFRU 03/53.

BLT, September 2003. Luger, E. and Nadlinger, M.Measurement report: Work package 1: Seats and field testing - Measurement of vehicle and seat motion in off road vehicles articulated an agricultural tractor and a wheel loader.

SNCF, December 2002. Clément P.. VIBSEAT – WP1 field tests – Grammer 3D axial suspension seat vibration behaviour on SNCF BB 8700 locomotive – report, video & data acquisitions on CD-ROM.

Workpackage 2:

FIOSH, March 2005. Subjective judgements and reaction times during vibration in x- or y-direction and biaxial (xy-) vibration of driver seats with locked or activated horizontal suspension.

FIOSH, 2005. Schust, M., Seidel, H. and Blüthner, R. Subjective judgements and reaction times during vibration in x- or y-direction and biaxial (xy-) vibration of driver seats with locked or activated horizontal suspension - main study. Federal Institute for Occupational Safety and Health, Berlin, Germany

FIOSH, 2004. Schust, M. Measurement of subjective judgements (intensity, comfort, effort) and reaction times – a pilot study. Federal Institute for Occupational Safety and Health, Berlin, Germany

ISVR, 2005. Wyllie, I.H. and Griffin, M.J. The discomfort arising from exposure to roll, lateral, pitch and fore-and-aft oscillation at frequencies between 0.2 and 1.6 Hz. Institute of Sound and Vibration Research, University of Southampton, Southampton, UK

SNCF, 2005 Clément, P. and Mirot, L. An ergonomic study on SNCF locomotive cab simulator: Evaluation of the effects of vibrations on vehicle control performances. SNCF – CIM, France.

Workpackage 3:

IMMM, November 2005. Stein, GJ and Múčka, P. Modelling of the transversal (y-direction) seated human body apparent mass. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

IMMM, August 2005. Stein, G.J., Múčka, P. and Chmúrny, R. Modelling of the fore-and-aft seated human body apparent mass. Institute of Materials and Machine Mechanics Slovak Academy of Sciences.

FIOSH, July 2005. Hinz, B., Blüthner, R., Seidel, H. and Menzel, G. (2005) Apparent mass functions of the combination subject / seat - an experimental study. Federal Institute for Occupational Safety and Health, Berlin, Germany.

FIOSH, July 2005. Seidel, H. and Blüthner, R. (2005) Shared-cost RTD Control of the Hexapod. Federal Institute for Occupational Safety and Health, Berlin, German.

ISVR, October 2005. Nawayseh, N. and Griffin, M.J. Seat performance laboratory test – modified truck seat fitted with a prototype spring tested in the x-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/65, Institute of Sound and Vibration Research, University of Southampton, UK.

ISVR, November 2005. Nawayseh, N. and Griffin, M.J. Seat performance laboratory test – GRAMMER seats tested in the x-axis and y-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/71, Institute of Sound and Vibration Research, University of Southampton, UK.

ISVR, November 2005. Nawayseh, N. and Griffin, M.J. Seat performance laboratory test – KAB seat tested in the x-axis and y-axis according to VIBSEAT test protocol Draft 8-5April05. HFRU 05/70, Institute of Sound and Vibration Research, University of Southampton, UK,

ISVR, February 2005. Gunston, T. and Griffin, M.J. Seat performance laboratory test - unmodified and prototype truck seats tested in the x-axis according to VIBSEAT test protocol Draft 6-28Dec04. ISVR Technical report 05/15.

ISVR, March 2004. Gunston, TP. Dynamic cushion tests on the VIBSEAT project ‘Rail seat’.

ISVR, July 2003. Gunston, TP. Vertical suspension and cushion test on the VIBSEAT project ‘Articulated truck seat’.

ISVR, August 2003. Vertical suspension tests on the VIBSEAT project ‘Articulated truck seat’ and ‘Rail seat’. Gunston, TP.

ISVR, November 2003. Gunston, TP. Third series of suspension tests on the VIBSEAT project ‘Articulated truck seat’.

Workpackage 4:

FIOSH, 2005. Blüthner, R., Seidel, H., Gericke, L. and Keital, J. Laboratory Evaluation of the test method for driver seats with suspension in x- and/or y-direction. Federal Institute for Occupational Safety and Health, Berlin, Germany

FIOSH, April 2005. Blüthner, R. Seidel, H. Lutz Gericke, L. and Keitel, J. Laboratory Evaluation of the TEST method for driver seats with suspension in x- and/or y-direction.

INRS, November 2005, Fleury, G. Investigation of testing method conditions in laboratory for the case of a fore-and-aft suspended seat in a wheel loader.

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SNCF, November 2005. Clément, P. Laboratory test protocol for evaluating vehicle seat vibration. Draft Version No. 9.

SNCF, April 2005. Clément, P. Laboratory test protocol for evaluating vehicle seat vibration. Draft Version No. 8.

SNCF, January 2005. Clément, P. Laboratory test protocol for evaluating vehicle seat vibration. Draft Version No. 7.

SNCF, September 2004. Clément, P. Laboratory method for evaluating vehicle seat vibration - Draft No. 4.

ISVR, July 2004. Gunston, T. Vehicle floor motions for use in VIBSEAT laboratory seat tests – Draft #1.

Workpackage 5:

INRS, 2005. Fleury, G., Mistrot, P. and Schouller J.F. Mesures de vibrations avant-arrières sur chargeuse et analyse du rôle de la suspension, Document de Travail interne.

IMMM, November 2005. Stein, G.J., Múčka, P. and Zahoranský, R. Modelling of the horizontal vibration isolating system of the modified truck test seat. [VIBSEAT Project Internal Technical Report]. Code IMMM SAS 7.1-F, IMMM SAS, Bratislava.

IMMM, August 2005. Múčka, P. and Stein, G.J. Description of the rail test seat y-axis (transversal) suspension system MatLab® models. (Report Code IMMM SAS 13.1-F – full report for the respective industrial partner only).

IMMM, August 2005. Múčka, P. and Stein, G.J. Description of the test seat y-axis (transversal) suspension system MatLab® models. (Report Code IMMM SAS 13.2-A/R – abridged report for all partners).

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