

TITLE OF THE INVENTION

A CHAIR ASSEMBLY FOR A MOTION SIMULATOR

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BACKGROUND OF THE INVENTION

(a) Technical Field of The Invention

10 The present invention relates to a chair assembly for a motion simulator. The present invention also relates to a motion simulator which includes the chair assembly. Particularly, the present invention relates to chair assembly which can be applied to any vehicle simulation to achieve motion sensation.

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(b) Description of The Prior Art

Known motion simulators fall into three main categories, namely platform, mechanized seat, and harness system.

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Platform motion simulators include a platform which is supported for:

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(a) limited linear motion in forward/backward, upward/downward, and side-to-side directions; and

(b) limited rotational motion – pitch, roll, and yaw.

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A "payload", which typically includes the user and associated chair assembly and electronic equipment, is mounted on the platform and motion of the platform is transferred directly to the user.

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Platform motion simulators can achieve a maximum of 6 degrees of freedom ("DOF") – i.e. (i) horizontal – forward/backward directions (Nx), (ii) horizontal – side-to-side

directions (Ny), (iii) vertical – upward/downward directions (Nz), (iv) pitch (i.e. changes in the forward direction), (v) roll (i.e. sway to and fro about the forward direction), and (vi) yaw (i.e. turning from side to side).

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Mechanised seat motion simulators achieve motion sensation primarily by varying the “hardness” of the seat and backrest of simulator chairs to excite the haptic system of a user. The motion generators rely on inducing skin pressure variations in body areas in contact with the seat/backrest in order to simulate changes in cushion “hardness” as experienced under different G-loading conditions during vehicle motion. Asymmetric variations of left and right sides of the simulator chairs can also provide sideward motion effects similar to those experienced in turning or rolling motions. The motion simulators can create motion onset and sustained motion.

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The number of DOF that can be transferred to a user by mechanised seat motion simulators depends on the extent of mechanisation of the motion simulators.

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Harness system motion simulators directly induce pressure over the body of a user by applying loads to harnesses that extend over the shoulders of the user to simulate G forces as experienced during vehicle motion. Symmetric or asymmetric variations on the left and right shoulders produce symmetric G forces or asymmetric G forces (during turning and rolling motion), respectively. The motion generators can create motion onset and sustained motion.

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The number of degrees of freedom (“DOF”) that can be transferred to a user by harness system motion simulators depends on the mechanisation of the motion simulators.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an improved chair assembly for a motion simulator.

5 According to the present invention there is provided a chair assembly for a motion simulator, the chair assembly including:

- 10 (a) a chair for a user, the chair including a seat and a backrest; and
- (b) a pair of harnesses adapted to extend over each shoulder of the user when the user is seated on the chair, one harness of each pair being adapted to be connected at one end to a vertical motion actuator, the other harness of each pair
15 being adapted to be connected at one end to a horizontal motion actuator, and each harness being adapted to be connected at the other end directly or indirectly to the chair after the user is
20 positioned on the chair.

Preferably the chair includes a support member positioned rearwardly of the chair backrest which defines a contact surface for the harnesses for the horizontal motion
25 actuator.

Preferably the chair assembly includes a shoulder support pad for each shoulder which is formed from rigid material and is shaped to fit over each shoulder of the user to
30 uniformly transfer load applied by the harnesses to the shoulders of the user.

Preferably the seat of the chair includes a means for providing a restoring force in an opposite direction to a load
35 applied to the chair seat.

Preferably the backrest of the chair includes a means

for providing a restoring force in an opposite direction to a load applied to the chair backrest.

5 Preferably the restoring means is in the form of spring-loading of the seat and the backrest.

10 The above-described chair assembly can be applied to any vehicle simulation to achieve motion sensation for motion onset and sustained motion (both turning moment and linear forces) in the DOF of Nz, Nx, pitch, roll and yaw.

15 The loads that are generated by the vertical and horizontal motion actuators in order to create the sensation of motion are concentrated by the harnesses on the shoulders of the user. The harnesses produce direct loads on the shoulders in the vertical (upward/downward) directions and the horizontal (forward/backward) directions. The spring-loaded seat and backrest also cause limited movement of the shoulders and buttocks of the user thereby generating upper torso attitude
20 changes, thus simulating acceleration effects in the different directions. Loads applied in the vertical and horizontal directions via the harnesses cause depression of the spring-loading of the seat and the backrest which amplifies the resultant motion sensation. Upon release of the loads on the harnesses the
25 spring-loading provides restoring forces which return the user to an original chair position. The restoring forces provided by the spring-loading are important in terms of creating deceleration effects.

30 According to the present invention there is also provided a motion simulator including the above described chair assembly and vertical and horizontal motion actuators connected to the ends of the harnesses of the chair assembly.

35 The motion simulator also includes actuator software which provides software commands which selectively operate the vertical and horizontal motion actuators to provide the

required actuation forces for the harnesses which in turn transfer loads to the user on the chair so that the user experiences simulated G forces and body orientation changes.

5 Preferably the motion simulator includes two vertical actuators, one actuator per harness, and two horizontal actuators, one actuator per harness.

10 Preferably each vertical motion actuator is positioned rearwardly of the backrest.

 Preferably each horizontal motion actuator is positioned rearwardly of the backrest.

15 Preferably the vertical and horizontal motion actuators are positioned in relation to the chair so that the harnesses extend generally vertically upwardly from the actuators and forwardly over the shoulders of the user.

20 More preferably the horizontal motion harnesses extend generally vertically upwardly from the horizontal motion actuators and around the support member and forwardly over the shoulders of the user.

25 The primary source of motion generation for the chair assembly is by loading on the user's shoulders to excite the haptic system of the user into recognising vehicle-induced G forces and turning moments in various directions.

30 An object of the present invention is to provide a chair assembly for a motion simulator, wherein the integral body wrap mechanism attached to the seat improves force transmission to the body and this increased transmission provides more realistic motion sensation.

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 A further object of the present invention is to provide a chair assembly for a motion simulator, wherein the leg support

includes a bracket to rest the user's leg on and the bracket is attached rigidly to the seat and user's weight is fully supported by the seat back, seat pan and the leg support.

5 Yet another object of the present invention is to provide a chair assembly for a motion simulator, wherein by elevating the entire body, the body's entire body axis is fully translated to the seat, and the individual parts of the user are subjected to the motion of the seat, thus enhancing motion
10 sensation especially in the vertical "floating" sensation.

A further object of the present invention is to provide a chair assembly for a motion simulator, wherein the control system reduces in cost.

15 Various advantages and features of novelty which characterize the invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. However, for a better understanding of the invention, its advantages, and
20 objects attained by its use, reference should be made with reference to the accompanying drawings, of which:

BRIEF DESCRIPTION OF THE DRAWINGS

25 Figure 1.0 is a perspective view of the basic structure of the chair of a preferred embodiment of the chair assembly, which includes Part 1.1 Chair Cover, Part 1.2 Chair Frame, and Part 1.3 Support Member;

30 Figure 2.0 and 2A are diagrammatic views of the motion harness (for one shoulder) of the preferred embodiment of the chair assembly, which includes Part 2.1 Harness Connector, Part 2.2 Stationary Harness, Part 2.3 Stationary End Fixed to Chair Frame, Part 2.4 Motion Harness End Fixed to Horizontal Actuator,
35 Part 2.5 Motion Harness End Fixed to Vertical Actuator, Part 2.6 Vertical Directional Harness, Part 2.7 Support Member Positional Axis (Ref. To Part 1.3), Part 2.8 Shoulder Positional Axis, Part

2.9 Horizontal Directional Harness, and Part 2.10 Shoulder Harness Mount;

Figure 2B is a diagrammatic view of the motion harness (for one
 5 shoulder) of another preferred embodiment of the chair
 assembly, which further includes Part 2.11 Body Wrap in
 accordance with the present invention;

Figure 3.0 is a diagrammatic view of the spring loaded seat and
 10 backrest of the preferred embodiment of the chair assembly,
 which includes Part 3.1 Static Seat Support, Part 3.2 Dynamic
 Seat, Part 3.3 Dynamic Backrest, Part 3.4 Spring Mechanism,
 and Part 3.5 Leg Support; and

15 Figure 4.0 is a side view of the preferred embodiment of the
 chair assembly.

A summary of components with reference numerals is as
 follows:

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Part 1.1 Chair Cover
 Part 1.2 Chair Frame
 Part 1.3 Support Member

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Part 2.1 Harness Connector
 Part 2.2 Stationary Harness
 Part 2.3 Stationary End Fixed to Chair Frame
 Part 2.4 Motion Harness End Fixed to Horizontal
 30 Actuator

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Part 2.5 Motion Harness End Fixed to Vertical
 Actuator

Part 2.6 Vertical Directional Harness
 Part 2.7 Support Member Positional Axis (Ref. To

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Part 1.3)

Part 2.8 Shoulder Positional Axis
 Part 2.9 Horizontal Directional Harness

Part 2.10 Shoulder Harness Mount

Part 2.11 Body Wrap

Part 3.1 Static Seat Support

Part 3.2 Dynamic Seat

Part 3.3 Dynamic Backrest

Part 3.4 Spring Mechanism

Part 3.5 Leg Support

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The following is a brief description of the parts of the chair assembly, as illustrated in the drawings.

Chair

The chair includes: Part 1.1 Chair Cover; Part 1.2 Chair Frame, which defines a seat and an inclined backrest; and Part 1.3 Support Member, which is directly behind the user at approximately the shoulder level, as shown in Figure 4.0, and is "C" shaped, as shown in Figure 1.

Motion Harness

Part 2.1 Harness Connector secures both Part 2.6 Vertical Directional Harness (at the free end) and Part 2.9 Horizontal Directional Harness (at the free end) to Part 2.2 Stationary Harness (at the free end). The opposite end of Part 2.2 is secured via Part 2.3 Stationary End Fixed to Part 1.1 Chair Frame through a mechanical connection (not shown). The mechanical connection may be any suitable mechanical connection. The opposite end of Part 2.6 is looped over a shoulder of a user when seated on the chair (see Part 2.8 Shoulder Positional Axis - an imaginary horizontal axis of seated user's shoulder positioned in free space) and directly secured to Part 2.5 Motion End Fixed to Vertical Actuator through a

mechanical connection. The opposite end of Part 2.9 is looped over the seated user's shoulder (see Part 2.8 Shoulder Positional Axis - an imaginary horizontal axis of seated user's shoulder position in free space) and passed over Part 2.7 Support Member Axis (i.e. passed to the outside surface of Part 1.3) and secured to Part 2.4 Motion End Fixed to Horizontal Actuator through a mechanical connection. Prior to using Part 2.6 and Part 2.9, both harnesses are secured to Part 2.10 Shoulder Harness Mount (of rigid material conform to shoulder arch) and to Part 2.11 Body Wrap (as shown in Figure 2B) to distribute localized loads onto the shoulder and upper torso area. In accordance with the present invention, the Part 2.11 Body Wrap is used to wrap around the torso area and consists of one left and right piece, using VELCRO to fasten the two body wraps over the torso area of the user. Further Part 2.11 Body Wrap is adjustable with respect to the radius thereof to suit the torso width of the users. The integral wrap mechanism attached to the seat improves force transmission to the body. This distribution of localized loads is necessary to achieve higher realism of motion sensation to better simulate actual G loading conditions whereby preferably the entire shoulder and upper torso area experience applied loads. The distribution of loads also helps to increase the comfort level of a user as compared to localized loads on the specific shoulder area alone. The figure shown is for left shoulder of a user. The complete Motion Harness in the figure must be duplicated for the right shoulder of the user to create complete a harness configuration.

Spring Loaded Seat and Backrest

The chair is primarily made up of the various components as described in Figure 3 to provide spring-loading of the seat and the backrest.

Part 3.1 Static Seat Support is securely attached to the Part 1.2 Chair Frame in the seat and backrest regions. Both Part 3.2 Dynamic Seat Pan and Part 3.3 Dynamic Seat Backrest

are attached using Part 3.4 Spring Mechanism, which in turn is secured to Part 3.1 Static Seat Support. Part 3.2 Dynamic Seat Pan and Part 3.3 Dynamic Seat Backrest, when arranged in this configuration as shown in Figure 3.0, allow movement of the seat and the backrest upon compression or extension of the springs. This movement allows horizontal (forward/backward) motion of the torso and vertical (upward/downward) motion of the buttocks.

Part 3.2 Dynamic Seat Pan and Part 3.3 Dynamic Seat Backrest are allowed to move independently of each other, i.e. free of mechanical linkage. Part 3.2 Dynamic Seat Pan is mechanically linked to the associated Part 3.1 Static Seat Support with relative movement restricted by the vertically mounted spring mechanism. Likewise, Part 3.3 Dynamic Seat Backrest is mechanically linked to the associated Part 3.1 Static Seat Support with relative movement restricted by the vertically mounted spring mechanism.

Part 3.5 Leg Support is connected to Part 3.2 Dynamic Seat Pan and includes a bracket to rest the user's leg on. In the present preferred embodiment, the bracket is attached rigidly to the seat and the user's weight is fully supported by the Part 3.3 Seat Backrest, Part 3.2 Seat Pan and Part 3.5 Leg Support. By elevating the entire body of the user, the body's entire body axis is fully translated to the seat, and the individual parts of the user will be subjected to the motion of the seat, enhancing motion sensation, especially in the vertical "floating" sensation.

Side View of Chair Assembly

The side view of the completed chair assembly and the axes for Part 2.7 and Part 2.8 is shown in Figure 4. The exact positioning of the harnesses is also shown.

The following is a more detailed description of the

chair assembly , as shown in the drawings, and of a preferred embodiment of a motion simulator which includes the chair assembly.

5 **1.0 User Interface**

 The Spring Loaded Seat and Backrest, when mounted onto Part 1.1 of the Chair, allows limited degrees of freedom by horizontal (forward/backward) motion of the torso and heaving
10 (upward/downward) motion of the buttocks. With the user seated on the Spring Loaded Seat and Backrest, the motion harnesses of Part 2.6 and Part 2.9 for both shoulders can be strapped over the Part 2.10 Shoulder Harness and secured to
15 Part 2.2 via the Harness Connector. The harnesses should be as tightly secured over the shoulders as possible (just comfortable) and without any slack throughout the harnesses. This pre-load level on the shoulder serve will serve as "neutral condition".

20 **2.0 General Discussion of Motion Simulator Incorporating Chair Assembly**

 Part 2.6 Vertical Directional Harness. During actuation these harnesses compress the shoulders, torso area, neck muscles, and buttocks-to-seat, for Nz loading and pitch
25 moments.

 Part 2.9 Horizontal Directional Harness. During actuation these harnesses press the user's back against the backrest directly simulating Nx loading force.
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 The combination of Part 2.9 and Part 2.6 for left and right shoulders actuation (total of 4 harness) and, at the same time synchronizing the harnesses, enables motion sensation in all of the DOF except Ny to be experienced.
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 As described above, the Spring Loaded Seat and Backrest amplifies motion sensation, particularly for motion

onset.

The design of the chair assembly takes into account human physiology with respect to motion sensation. The following factors were identified by the applicant as relevant human motion "sensors":

(i) Skeleton structure and internal organs for compression and relaxation within the torso area; and

(ii) The ability of the auditory system within inner ear area to sense linear and rotational acceleration effects for various directions.

The Motion Harness and the Spring Loaded Seat and Backrest enable applied loads to be translated to the sensors to meaningfully detect motion. Providing compression and relaxation over the shoulders via the Motion Harness provides the perception of the body being loaded by gravity force. Positioning the Motion Harness as described above also ensures the direction of the pull/release is distinctive in terms of vertical and horizontal motion. This is achieved through the installation of the Support Member at the Back Arc Support Positional Axis location. In addition, allowing freedom of movement of the torso and buttocks through the Spring Loaded Seat and Backrest essentially displaces and tilts the head to cause the auditory system to interpret these as acceleration effects of motion onset.

3.0 Motion Actuators and Software

The motion actuators and software of the preferred embodiment of the motion simulator include the following parts:

Flight Algorithm
Control and Conversion Logic
Motion Actuator System
Flight Matrix

3.1 Flight Algorithm

A flight model provides relevant motion information to a Flight Algorithm logic. The Flight Algorithm Logic determines the amount of actuation required and selects the appropriate actuator(s) to activate as per the Flight Matrix below. The Flight Algorithm simultaneously provides actuation commands to relevant actuator channels VL, VR, HL, and HR, (where VL = Vertical Direction Left Shoulder, VR = Vertical Direction Right Shoulder, HL Horizontal Direction Left Shoulder and HR Horizontal Direction Right Shoulder) to be described hereinafter under the heading Motion Actuators. This process is a continuous loop within the Flight Algorithm. For each cycle of computer processing, the Flight Algorithm, based on inputs from the flight model, processes the entire matrix (right hand side of the equation) and produces outputs for each channel (left hand side of the equation) simultaneously.

3.2 Control and Conversion Logic

From the output of the Flight Algorithm, the Control and Conversion Logic processes the actual rate of signals to the Actuators. The processing performed by the Control and Conversion Logic includes noise filtering to usable levels and thereafter generates the rate of signals to achieve the required distance of pull/release of the harnesses and also the speed to do so. The distance of pull/release and speed of actuation is important so as to produce the types of motion for onset, slow/fast rate of increase, and sustained motion. The distance of pull/release also determines tightness of the harnesses on the body and thus the amount of load that is experienced by the user.

3.3 Motion Actuators

In the preferred embodiment of the motion simulator there are four motion actuators. Each of the motion actuators

includes motor control drivers, a motor, and an actuator arm of any suitable brand or type. Based on the output from the Control and Conversion Logic, the motor drivers generate required directional information and power to the motors so as to command the actuators to move to the required locations and at the required speeds. The actuator arms that are driven by the motors thus pull/release the harnesses as commanded.

3.4 Flight Matrix

4 Channels namely VL, VR, HL and HR:

Matrix for individual channel actuation:

$$\begin{array}{ccc}
 \begin{pmatrix} H_R \\ H_L \\ V_R \\ V_L \end{pmatrix} & \begin{pmatrix} 0 & 0.2 & 0.4 \\ 0 & 0.2 & - \\ 0.4 & -0.4 & \\ 0.7 & 0 & 0 \\ 0.7 & 0 & 0 \end{pmatrix} & \begin{pmatrix} N_z / 8^* \\ N_x / 2^* \\ \text{Yaw}_{\text{Rate}} / 90^* \\ \text{Roll}_{\text{Rate}} / 540^* \end{pmatrix} \\
 \text{Channel} & \text{Weighing Factors} & \text{Motion Parameter/ Normalizing Factor}
 \end{array}$$

Note:

* Denotes the Normalizing Factor for each associated Motion Parameter. This is to ensure maximum value of each Motion Parameter after division by the Normalizing Factor is to value of 1. This generic factor is based on the maximum perceivable value for each Motion Parameter.

4.0 Explanation of Actuation Process

Using loading in Nz direction as an example, the motion actuators command actuation to Vertical channel VL and VR symmetrically to generate synchronized load on the left and right shoulders. Based on the Nz output from the flight model, firstly the Flight Algorithm within Actuator System will determine and generate the individual actuator motion and speed requirements to channel VL and VR. Secondly the Control and

Conversion Logic will generate the required command to the motion actuators. The actuators VL and VR provide motion onset. After motion onset, if higher Nz is required, actuation force is increased until steady Nz is reached. At steady Nz, 5 actuation force is held at this position until the next change in direction of motion is detected. If the direction of required motion continues and Nz loading increases, the actuation force increases accordingly. If the direction of required motion changes, the actuation force decreases accordingly. Throughout 10 the loading change, the Part 3.4 Dynamic Seat will heave up or down accordingly.

Numerous characteristics and advantages of the invention have been set forth in the foregoing description, 15 together with details of the structure and function of the invention; the novel features thereof are pointed out in the appended claims. The disclosure, however, is illustrative only, and changes may be made in detail, especially in matters of shape, size, and arrangement of parts, within the principle of the 20 invention, to the full extent intended by the broad general meaning of the terms in which the appended claims are expressed.

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**CLAIMS:**

1. A chair assembly for a motion simulator, the chair assembly including:

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(a) a chair for a user, the chair including a seat and a backrest; and

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(b) a pair of harnesses adapted to extend over each shoulder of the user when the user is seated on the chair, one harness of each pair being adapted to be connected at one end to a vertical motion actuator, the other harness of each pair being adapted to be connected at one end to a horizontal motion actuator, and each harness being adapted to be connected at the other end directly or indirectly to the chair after the user is positioned on the chair.

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2. The chair assembly defined in claim 1 wherein the chair includes a support member positioned rearwardly of the chair backrest which defines a contact surface for the harnesses for the horizontal motion actuator.

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3. The chair assembly defined in claim 1 or claim 2 includes a shoulder support pad for each shoulder which is formed from rigid material and is shaped to fit over each shoulder of the user to uniformly transfer load applied by the harnesses to the shoulders of the user.

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4. The chair assembly defined in claim 1 or claim 2 includes a means for providing a restoring force in an opposite direction to a load applied to the chair seat.

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5. The chair assembly defined in any one of the preceding claims wherein the backrest of the chair includes a



means for providing a restoring force in an opposite direction to a load applied to the chair backrest.

6. The chair assembly defined in claim 4 or claim 5
5 wherein the restoring means is in the form of spring-loading of the seat and the backrest.

7. A motion simulator including;

10 (a) the chair assembly defined in any one of the preceding claims; and

(b) vertical and horizontal motion actuators
connected to the ends of the harnesses of
15 the chair assembly.

8. The motion simulator defined in claim 7 includes actuator software which provides software commands which selectively operate the vertical and horizontal motion actuators
20 to provide required actuation forces for the harnesses which in turn transfer loads to the user on the chair so that the user experiences simulated G forces and body orientation changes.

9. The motion simulator defined in claim 7 or claim 8
25 includes two vertical actuators, one actuator per harness.

10. The motion simulator defined in any one of claims 7 to 9 includes two horizontal actuators, one actuator per harness.

30 11. The motion simulator defined in claim 9 wherein each vertical motion actuator is positioned rearwardly of the backrest.

12. The motion simulator defined in claim 10 wherein each horizontal motion actuator is positioned rearwardly of the
35 backrest.

13. The motion simulator defined in any one of claims 8



to 12 wherein the vertical and horizontal motion actuators are positioned in relation to the chair so that the harnesses extend generally vertically upwardly from the actuators and forwardly over the shoulders of the user.

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14. The motion simulator defined in claims 2 and 13 wherein the horizontal motion harnesses extend generally vertically upwardly from the horizontal motion actuators and around the support member and forwardly over the shoulders of the user.

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15. The chair assembly defined in claims 1, 2 or claim 3 includes a body wrap positioning around the torso area of the user to improve force transmission to the body.

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16. The chair assembly defined in claim 1 or claim 2, includes a leg support connected to the seat to rest the user's leg such that the body's entire body axis is fully translated to the seat.

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