MOTION EFFECTS ON DRIVER TRAINING

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Summary.

Driver training in a non-motion simulator does not teach all the skills which are critical in the real world, because nobody drives in direct response to visual feedback information. The fast-response loop on which all trained reactions are based is a haptic one which includes tactile feedback from the controls and from the sensations of vehicle movement caused by control actions or by the irregularities of the environment. It follows that no driver training simulator is complete without well-designed motion and control-loading systems. Recent developments allow these to be provided at an acceptable cost.

The importance of motion

No one drives - or flies - in accordance with visual cues as the primary response. Careful studies show that a human being engaged in vehicle guidance control responds first to tactile disturbance and only later to visual field disturbance. This is thought to be due to the experiences of early life which teach balancing skills as fast reactions to external forces on the body. These reactions are entirely subconscious and they act to update the human model of its motion and to predict its future position - there is no delay in an interposed, consciously-accessible reasoning process. It appears that a similar subconscious and pre-programmed fast reaction is used to exert forces on the environment to cause movement; that is why we can play ball games which appear to require impossibly-fast calculation.

When we take control of a vehicle - surface, air or space - we bring with us our fast reactions to body forces and we use them to measure our mastery of the vehicle. We try to learn how to blend with the vehicle - to feel that it is a natural extension of our body - and to get an instinctive understanding of where the edges of the vehicle are and what is happening to them. By using the controls to move the vehicle we also gain an ability to predict the future position of the craft and when it is moving we learn how it interacts with the surrounding medium (land, sea, or air).

We say that a vehicle is under control when it “feels right” - when the driver is able to make the vehicle feel as he wishes, whether in response to his own input commands or against disturbances from the outside environment. The visual experience is not given the same level of importance in our assessment of our feelings of security in the vehicle. This is because what we feel is the complex of **accelerations**, which are integrated over time to produce velocities and further integrated to result in **displacements**. The displacements alter the visual field, but the changes are perceptible much later than the body sensations. I am sure that many of us have had the electrifying experience of losing control of a car on an icy surface, even for a second. Visually nothing happens - the event is felt - and control can often be regained before a passenger knows anything about it.

In this presentation I shall be mainly concerned with surface craft - with driver training simulators for road and cross-country vehicles - but I would like to spend a little more time on aircraft for the moment. There are many lessons we have learned from the use of aircraft simulators which we must remember to carry over to the business of driver training for surface craft.

In the U.K. some excellent work has been carried out at D.R.A. Bedford (or R.A.E. Bedford as it used to be) and I would like to remind you of some of it. In a paper entitled “The need for platform motion in modern piloted flight training simulators” published in 1989, John Hall refers to research since 1964 and sets out a convincing case that motion is essential for training of fast-response (high gain control loop) skills. He points out that there are two aspects to the control of a vehicle; making it go where you want it to go under the constraints of its own performance limits (which he calls “manoeuvre motion”) and sustaining your objectives in spite of external forces (which he calls “disturbance motion”)

John says that “....disturbance motion (simulation) allows a pilot to react correctly and far more quickly to a disturbance because it provides a more rapid and relevant alerting cue than can be obtained visually.” In relation to manoeuvre motion he refers to Caro and says “Learning to hover a VTOL aircraft simulator in the absence of motion cueing has been compared to riding a unicycle without being able to feel the onset of imbalance." Some of the conclusions of the paper are that motion cues are increasingly important as the task becomes more demanding, that they are necessary for high-gain tasks, even in the presence of strong visual cues and that they are essential where the pilot must react quickly and correctly in response to some unexpected external disturbance.

There is no doubt that driving or flying is a whole-body experience which cannot be learned thoroughly without the appropriate motion cues.

Unfortunately the simulation business has a history of attempts to produce motion systems which have not been thought through sufficiently. Stacked designs have had axes which do not intersect; synergistic designs have had restraint mechanisms which enforce coupled motions; response times have not been matched for all axes; inertias have been high and bandwidths far too low; there have been strong resonances, excited by non-linearities. Most mechanisms have been heavy, bolted to expensive foundations, hungry for power and needing frequent maintenance. As a result the real benefits of motion-related training have not been appreciated and there has been no enthusiasm to invest in the development of better mechanisms. Simulation system designers and their client users have assumed that they have tried the best that is available - and the best has not been worth its cost. The motion system part of a simulator has gained the reputation of an unnecessary and troublesome luxury.

To quote John Hall - "The evidence to date for using platform motion cueing in training simulators has been obtained largely using low performance motion platforms and it is strongly suspected that past experiments which have failed to demonstrate the benefits of motion, or motion systems which have been found to be unacceptable and have been turned off, have either provided false cues or suffered from excessive lags."

Nevertheless, it is clear that driver training without motion is not training at all but merely academic knowledge. Thoughtful clients ask that we do better - that we provide good motion systems and that we do it for an acceptable price. We can now do so.

The nature of vehicle motion

For most surface vehicles operating within their normal limits the vertical accelerations experienced by the driver do not exceed ±0.5g. More extreme fore and aft (surge) forces can be experienced under violent braking, but more than 1g is only possible in a high-performance road car on a good surface. (The U.K. "Highway code" assumes a best condition of 0.3g in calculating minimum stopping distances) Centrifugal (sway) forces can exceed 1g in a modern road vehicle - and 4.5g on the race track. The pitch and roll actions of normal use are therefore subsumed by the lateral accelerations to which they are coupled in a simulation. Disturbance motion in a road vehicle trainer must include road camber, kerbs, surface irregularities (up to 20Hz) and potholes.

A battle tank suspension system, because it is associated with a massive vehicle, is remarkably efficient and, unless the suspension system is "bottomed", the ride is not harshly violent. The strong "lurching" movements, either in pitch or in roll, associated with the movement of a tank across irregular terrain are also damped by the suspension system and the large inertia of the body mass. The most violent forces of motion are caused by the brakes, the gear changes and the recoil of the gun. It is also necessary to simulate an environment of pseudo-random motions or "terrain noise" at frequencies up to about 5 Hz which result from the pounding of the individual sections of tank track over different types of terrain. This motion has a bandwidth which is capable of stimulating strong resonances in parts of the tank and even in parts of the crew at certain critical speeds!

Steering control feedback

An important element of the "feel" of a road vehicle comes from the sensation of the steering control. It is not only that the force applied to turn the wheel quickly becomes associated with the centrifugal force on the body which results: it is possible to tell a lot about the surface friction from the force needed to turn the steering wheel and it is possible to perceive the softness and irregularity of the surface from the forces exerted by the wheel on the driver. (There is no equivalent feedback from a tank steering mechanism.)

Driver training simulators need to have a sensitive and fast-acting torque device fitted to the steering column which is capable of representing the correct tactile feedback from interaction with the road surface.

Simulator motion synchronisation

Because the motion cues are used in a predictive way, it is obviously important for them to be generated with an

accurate time relationship to the action of the controls and to the change in the visual scene. Motion cues which are late, or which result from spurious couplings in the mechanism, are worse than useless because they cause nausea. If a trainee actually persists in such circumstances and learns to accept the late cues as "normal" the training is negative: reality will feel wrong.

High-performance motion bases.

Clearly, the market for driver training simulators will not accommodate the size, weight, cost and complexity of a full 6-axis motion base. It is necessary to design one which is optimised for the application.

A 6-axis motion system can be represented very adequately by a 3-axis motion mechanism, using gravitational coupling to a pitch movement for pseudo-surge and gravitational coupling to a roll motion for pseudo-sway. Yaw-rate (centrifugal force) can be simulated by adjusting the instantaneous pitch and roll vector to match the outward acceleration of the body undergoing yaw. These approximations are of course achieved at the expense of losing the edges of the motion, since it takes a finite time to re-orientate the capsule in pitch or roll. Nevertheless, the simulation is quite acceptable: a 3-axis, heave, pitch and roll mechanism is the most cost-effective option for driver training purposes.

The use of hydraulic power to position a simulator capsule is extremely wasteful of power; about 98% wasteful in fact. Hydraulic and pneumatic rams generate a substantial thrust all the time they are acting, whereas an inertial object like a simulator capsule only requires a series of impulsive thrusts of highly-variable intensity to change its position and to apply the perceptible accelerations which are the essence of the simulation. Hydraulic actuators have been used for simulation only because it has been possible to buy control valves with a response delay which is small enough to be acceptable. No equivalent pneumatic valves exist; and if they did the system response would still be limited by the speed with which pressure can be changed in a volume of gas. Until recently there was no practical alternative to a hydraulic simulator mechanism.

Thomson CSF has recently produced an advanced electrical system using a torque-motor, gearbox and crank arrangement for the Leclerc tank motion simulator, but even this suffers from the inevitable bandwidth limitations of a rotary electrical actuator.

A real breakthrough has now been achieved with the pneumatic suspension and electromagnetic ram ("PemRam") technology. This patented arrangement supports the capsule deadload on long stroke air springs whilst the pneumatic piston also forms part of a powerful DC linear electromagnetic actuator; the motion base itself is designed to move easily at a touch and to be stable in any position. Thus the electromagnetic forces are only applied to accelerate or decelerate the capsule; very little power is consumed, the bandwidth is very high (there are no moving parts between the computer and the rams), the parts count is low, the reliability is good and the cost is well below that of an equivalent hydraulic system. 3-axis PemRam machines are already in high demand for leisure industry applications.

Compactness

It is important that the simulator motion base should not add greatly to the height of the simulation capsule. There are a number of designs of three-axis motion system in which the actuator rams are folded beneath the simulator in the form of a tetrahedron or of an inverted rectangular pyramid. These provide plus or minus 25 degrees of pitch or roll and 0.5 m heave from a folded or "loading" height of about 0.7 m.

Seat-only motion systems

Clearly, a simulator must have the lowest possible size and weight in order to reduce the power, cost and complexity of the motion system. With this in mind it has been proposed that the main body of a simulator might be fixed whilst the seat alone is moved; the idea being that only the driver feels the motion, so only the driver needs to be moved. But the idea of moving a seat separately to its visible, fixed, near environment breaks the most fundamental rule of motion simulation; that the real instantaneous position and orientation of the human being in a simulator shall not be perceptible to him. In any case it would be necessary to allow a manoeuvring space in all directions around the seat - which would make the simulated surroundings unreal.

There is, however, the possibility that vehicle motion cues could be provided for a driver training simulator by an adaptation of the "g seat" technology used in high-performance aircraft simulators. The "g seat" convinces the human occupant that motion is taking place by modulating the pressures exerted on the skin of the occupant by various parts of a seat, which is fitted with seat belts whose tensions are also modulated. If the seat appears to be moving there is a direct and irresistible impression that the simulated vehicle itself is moving. In fact the real motion is negligible - only the local skin pressures change. This solution seems at first to be ideal, since the "g seat" mechanism can even be fitted to existing stationary simulators. However, it should be pointed out that the motion cueing produced by a “g seat” does not correspond with actuality because there is always a change in the area of the pressure pad which balances the change in pressure (otherwise the net force is modified and real movement must occur). The pad area variations are a noticeably strange artefact and the trainee has to get used to them.

Previous designs of “g seat” have used an expensive pneumatic pressure control valve to modulate the volume of air in each pad in response to computed algorithms. It is easy to show that the bandwidth of such a system is restricted and the cost and power consumption is high; this was acceptable for the specialised military market for which they were intended. Some bandwidth improvement was achieved by using hydraulic rams to move pressurising diaphragms in research simulators - but the cost and the power consumption were even greater than before.

Where it is impractical to apply motion to the simulator as a whole, a “g seat” system can be used, but the new markets we now have to address demand high-bandwidth performance, at a much lower cost. Work on low cost “g seats” has proceeded for several years and patent applications have been lodged on a technology which uses electromagnetic rams to construct high bandwidth, quiet “g seats” at an acceptable price and with a very low power consumption.

Conclusions

- It is essential that driver training simulators incorporate body motion cueing mechanisms and that they provide the correct tactile feedback to the steering control.
- Cues for both manoeuvre motion and disturbance motion of surface craft must have a high bandwidth - which pushes the limits of conventional hydraulic motion simulator technology.
- Driving simulators have to be made for a low price and they must simulate the danger limits of driving control if they are to be justified.
- The new airspring electromagnetic ram technology allows a range of driving simulators to be designed which use no hydraulics but have an even faster response, are lightweight, silent, reliable and inexpensive.
- When it is quite impossible to use a conventional motion mechanism, an adaptation of the electromagnetic ram technology to “g seat” control can provide motion cues.

Biography

Eur. Ing. Phillip Denne is a Physicist and Engineer who has been responsible for new product design throughout a career in many different industries. After building the Electronic Warfare Simulator facility for Marconi at Stanmore he took an interest in motion-related simulation and founded Super X.

1994