STUDIES ABOUT MOTION SICKNESS
Effect of combined lateral and roll oscillations

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Summary
Very few passengers suffer from motion sickness on conventional trains and high-speed trains. Nevertheless, field tests carried out between Paris and Toulouse on a tilting train showed some sickness among passengers.

Up to now, the standardised motion sickness index has been mainly developed for shipping and only takes into account the vertical motion experienced by passengers. This index did not correlate with motion sickness incidence during two field tests realised in tilting trains conducted during 1998 and 2000. Therefore, a railway motion sickness index is required to predict the lack of comfort likely to be experienced by passengers in tilting trains. In the future, this motion sickness index could be used to specify and to optimise the settings of tilting systems.

This paper presents the latest laboratory tests realised in collaboration between SNCF and the University of Southampton (Institute of Sound and Vibration Research). The goal of these tests is to characterise on human subjects the influence of combined lateral and roll motions. A new simulator has been created to conduct the studies.

Keywords
Motion sickness, motion sickness index, tilting train comfort, motion sickness questionnaires, laboratory study.
1. BACKGROUND AND OBJECTIVES

In the context of commercial speed improvements on railway lines, field tests carried out in France on the line Paris-Orléans-Toulouse on a tilting train showed some sickness among passengers. Although only a few passengers may experience motion sickness symptoms, it is important to check that speed growth will be realised without reducing passenger comfort.

The current standard motion sickness index, as published in the ISO2631 [1], was mainly developed for shipping and only takes into account vertical oscillation. This index did not yield useful predictions of motion sickness incidence on the railway field tests conducted at various speeds in 1998 and 2000.

Since 1997, laboratory studies have been performed as a result of collaboration between SNCF and the University of Southampton (ISVR – Institute of Sound and Vibration Research). The goal of these studies is to adapt the present MSDV index by taking into account lateral and roll oscillations, as well as vertical oscillations. This adaptation would yield an extended MSDV index for the case of combined vertical-lateral-roll motions, as on tilting trains. The new index will then be used to propose specifications for railway vehicles, and to optimise the settings of the tilting system of the coaches.

This approach, which is still in progress today, has to consider very low frequency motions (below 0.2Hz), caused by the riding on railway lines with frequent curves. Three different steps are envisaged:

- step 1: realise tests on laboratory simulators to quantify the incidence of motion sickness among groups of subjects exposed separately to vertical, lateral and roll oscillations and to combinations of lateral and roll oscillations.
- step 2: from these results, propose a new motion sickness index (taking into account the frequency, magnitude and time dependent characteristic of motion sickness)
- step 3: check the accuracy of this index for the field tests realised in 1998 and 2000, with different settings of tilting systems and a wide range of riding conditions; to do so we will compare:
  - the results of questionnaires used with different groups of subjects (10,000 questionnaires used)
  - the values of the proposed index, when applied to motion measurements.

This paper briefly presents previous results from this study and emphasises recent results with combined lateral and roll motion considering the effects of frequency of oscillation (after step 1).

2. MOTION SICKNESS INDEX

2.1 Previous studies

International Standard 2631 [1] defines the Motion Sickness Dose Value (MSDV\(^1\)) in the vertical axis to estimate the percentage of passengers who may vomit. This index uses measurements of

\[ ISO2631-1: MSDV = \int_0^T a(t)^2 dt \]  

with \(a(t): \text{weighted vertical acceleration (filter Wf)} \) (in ms\(^{-1.5}\)).
the vertical acceleration, weighted with a frequency filter \((W_f)\). This standard successfully predicts the incidence of motion sickness in the case of marine vessels, where vertical oscillation is the main cause of motion sickness. In the case of trains, field tests carried out in France showed that this index was not appropriate to predict motion sickness arising from railway coach motions, for which it appeared necessary to consider low frequency lateral oscillation and roll motion.

Numerous publications summarise previous motion sickness studies (see [5] to [8]). Most studies have not considered lateral and roll motion.

2.2 Previous laboratory experiments

The results obtained by ISVR prior to 1997 are listed below:

**Influence of seating conditions and visual effects**

Several different conditions were investigated: lateral and fore-and-aft motions, with subjects seated with a low or a high backrest, eyes closed or open [9]. With these configurations, fore-and-aft oscillation with a low backrest provided the greatest motion sickness incidence. The influence of postural conditions seemed greater than the influence of the two visual conditions within a closed cabin.

**Effects of frequency and direction of horizontal oscillation**

Between 0.2 and 0.8 Hz, for motions having the same peak velocity \((0.5 \text{ ms}^{-1})\), the frequency and the direction of motion (fore-and-aft and lateral) had similar effects on motion sickness emergence.

**Influence of magnitude and direction of horizontal oscillation**

For oscillation at 0.315 Hz, motion sickness increased with the magnitude of motion and the duration of exposure.

The results obtained since 1997, presented in [3] and [4], are listed below:

**Influence of TGV seating conditions**

For lateral oscillation at 0.25 and 0.5 Hz, the type of seat (hard seat or TGV first class seat) had less influence than the postural condition (i.e. with or without backrest) previously investigated.

**Influence of oscillation magnitude at 0.25Hz**

At 0.25Hz, the incidence of motion sickness tended to increase with increasing magnitude of lateral oscillation.

**Influence of lateral oscillation versus vertical oscillation at 0.25 Hz**

A comparative study of the influence of lateral oscillation and vertical oscillation at 0.25 Hz indicated that at this frequency, vertical motion was more nauseogenic than lateral motion.

**Influence of roll oscillations**

With a roll magnitude of ±8 degrees, there was little motion sickness and no clear difference in sickness at eight frequencies between 0.025Hz and 0.4Hz. Roll motion alone does not seem to lead to much motion sickness. However, roll motion may contribute to sickness when combined with motions in other directions.

**Influence of waveform of lateral oscillation around 0.2Hz**

For lateral oscillation alone, there was no significant difference in motion sickness between pure sinusoidal motion and a band of random motion around 0.2Hz.
2.3 Recent laboratory tests

Methodology used for the tests
Groups of 20 male subjects (aged 18 to 26 years) were exposed to oscillations for up to 30 minutes. Prior to exposure, subjects completed a motion history questionnaire providing information on travel and motion sickness experience. The subject responses were used to match the subject groups used in the experiments. Subjects employed a 7-point scale to provide ratings of their motion sickness symptoms at one-minute intervals during the experiment (see Table 1).

<table>
<thead>
<tr>
<th>Rating number</th>
<th>Corresponding feelings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No symptoms</td>
</tr>
<tr>
<td>1</td>
<td>Any symptoms, however slight</td>
</tr>
<tr>
<td>2</td>
<td>Mild symptoms, e.g. stomach awareness but not nausea</td>
</tr>
<tr>
<td>3</td>
<td>Mild nausea</td>
</tr>
<tr>
<td>4</td>
<td>Mild to moderate nausea</td>
</tr>
<tr>
<td>5</td>
<td>Moderate nausea but can continue</td>
</tr>
<tr>
<td>6</td>
<td>Moderate nausea and want to stop</td>
</tr>
</tbody>
</table>

Table 1. Illness rating scale (adapted from [2])

Figure: 1
Title: Lateral-roll simulator used at ISVR (University of Southampton)
**Test conditions**

There have been three recent studies of the effects of roll compensated lateral oscillation on motion sickness:

1) Effect of frequency of pure lateral oscillation (0.0315, 0.05, 0.08, 0.125, 0.16, 0.125, 0.315 Hz) on motion sickness. In these studies, the 0.0315 to 0.2 Hz oscillations had equal peak velocity of 1.0 ms\(^{-1}\), whereas the 0.315 Hz oscillations had a peak velocity of 0.5 ms\(^{-1}\).

2) Determination of the motion sickness caused by six different frequencies of lateral oscillation (0.05, 0.08, 0.125, 0.16, 0.2 and 0.315 Hz) with 100% roll compensation (no lateral acceleration felt by subjects). The lateral oscillations had the same peak velocity as the first experiment. Roll displacement, roll velocity and roll acceleration increased with increasing frequency.

3) Effect of varying degrees of roll compensation with 0.2 Hz 0.89 ms\(^{-2}\) r.m.s. lateral oscillation: 0% compensated lateral motion (i.e. pure lateral motion), 50% compensated lateral motion (50% of the lateral acceleration felt by the subject at the seat surface) and 100% lateral motion (0% of the lateral acceleration felt by the subject at the seat surface). The 0.89 ms\(^{-2}\) r.m.s. lateral oscillation had a displacement of 0.80 metres. The roll oscillation corresponding to 100% compensation was 7.36 degrees.

**Results**

**Effect of oscillation frequency with 0% roll compensation**

Figure 3 shows the mean accumulated illness ratings for each frequency of lateral oscillation (mean of the total illness ratings for all the 20 subjects). Illness appears to increase with increasing frequency.

The relative effects of acceleration magnitude and the frequency of oscillation can be obtained by assuming that the effect of magnitude is linear over the range tested. By normalising the percentage of subjects in each condition to reach the illness rating of “3 – mild nausea” with respect to acceleration magnitude, an acceleration frequency weighting can be formed [10]. This tentative frequency weighting is compared with the \(W_f\) weighting for vertical oscillation from ISO 2631 in Figure 4 (note that the \(W_f\) filter was derived from the percentage of subjects who vomited: a more severe effect than investigated in the current studies.
Figure 3

Title: Mean accumulated illness ratings in each condition with 0% compensation
(0.315Hz motion had half the peak velocity of the other frequencies; 0Hz is a static control condition)
**Effect of oscillation frequency with 100% roll compensation**

With full roll compensation for the lateral oscillation, illness increased significantly with increasing frequency of oscillation (Figure 5) and was generally greater with 100% roll compensation than found previously with the same lateral motions without roll compensation. The greatest increase in sickness due to roll compensation appeared to occur at the higher frequencies of oscillation.
Comparison of 0%, 50% and 100% compensation with 0.2 Hz oscillation

It was found that 100% roll compensation produced greater accumulated illness ratings than obtained with 0% and 50% roll compensation (Figure 6). With 0% compensation, the accumulated illness ratings were greater than with 50% roll compensation.

The effect of compensation is therefore non-linear and there appears a minimum in the motion sickness response, possibly in the region of 50% compensation.

Also, roll compensation of 50% decreased motion sickness to the level of a non-compensated motion with half the lateral acceleration magnitude.

These results confirm some trends pointed out during the field tests.
3. CONCLUSION
The paper gives a preliminary presentation of results from studies of sickness arising from motions existing in trains (tilting or not). The main goal of the research is to understand the mechanisms leading to motion sickness and develop an index for the specification of future railway systems, particularly tilting trains.

Over the frequency range 0.05 to 0.315 Hz, the addition of roll oscillation so as to fully compensate for the acceleration caused by lateral oscillation appears to increase motion sickness.

The effect of roll compensation on motion sickness was found to be non-linear: there was less motion sickness with 50% roll compensation than with either 0% or 100% roll compensation. It is not known whether 50% compensation results in the condition for minimum sickness. It is not known whether the same phenomenon occurs at other frequencies of oscillation.

4. PROSPECTIVE
The next phase of this study will include different combinations of lateral and roll motion to determine more precisely the optimal characteristics of the tilt angle.

It is proposed that the increased understanding of the causes of sickness associated with combined lateral acceleration and tilt will be used to identify a new index that can be tested by reanalysing results of studies conducted on an experimental tilting TGV in 1998 and 2000.

BIBLIOGRAPHY


