The ‘SUSTRAIL’ high speed freight vehicle: 
Simulation of novel running gear design

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ABSTRACT
As part of the European Commission project ‘SUSTRAIL’ the authors together with other industry and academic partners are designing a freight vehicle optimised for the carriage of high value, low density, time sensitive products. A review of potential engineering innovations has been carried out and a vehicle is being designed based on optimised parameters for this combination of innovative technologies including radial steering, disk braking and optimised bogie frame structure. The results of the selection and optimisation of the running gear are presented here together with an assessment of the potential improvement in running behaviour and its impact on the railway system.

1. INTRODUCTION
The aim of the SUSTRAIL project is to promote modal shift of freight in Europe from road to rail [1]. A key objective of the policy is the shift of 30% of road freight over 300km to other modes such as rail or waterborne transport by 2030 (and 50% by 2050) as targeted by the European Commission. The SUSTRAIL project intends to provide the approach, structure, and technical content to support this modal shift through improvements in the railway freight system including innovations in rolling stock in track components. The project includes workpackages focused on market research, vehicles, infrastructure and assessment of cost benefits. The work described here is part of workpackage 3: ‘The freight vehicle of the future’.

2. THE SUSTRAIL FREIGHT VEHICLE
The main scientific and technological innovations being considered for the SUSTRAIL freight vehicle are:
- The development of advanced vehicle dynamics concepts based on new wheel profiles and improvements in suspension design responding to the needs of a mixed traffic railway;
- Developments in the traction and braking systems for high speed low impact freight operation;
- Novel designs and materials for lightweight high performance freight wagon body vehicles and bogie structures;
- Advanced condition based predictive maintenance tools for critical components of both railway vehicles and the track;
- Identification of performance based design principles to move towards the zero maintenance ideal for the vehicle/track system.

Partners in the project have carried out a technology review to identify the potential innovative technologies to meet the above requirements and the results have been ranked and two concept vehicles are being designed. The ‘Conventional’ vehicle will use optimised existing technology and a demonstrator for this is being built as part of the project. The ‘Futuristic’ vehicle will utilise technology which has not yet been proven in the railway field but has potential to make greater improvements. An extract from the innovations matrix used in the assessment is shown in Figure 1. The results of the concept design will be assessed within the project using LCC and RAMS analysis and benefits compared with a benchmark vehicle with Y25 bogies will be presented.
3. **RUNNING GEAR SIMULATIONS**

The authors are working together to carry out simulations of the dynamic behaviour of the concept design vehicles running on typical track in tare, part laden and fully laden cases. In line with the target of a 50% reduction in lateral forces on the track and stable running at 140km/h a suspension using double Lenoir linkages, longitudinal linkages between axle boxes and centre pivot suspension has been selected. Computer simulation has been used to optimise the suspension and to select suitable parameters for the various components. Assessment of the results is based on:

- Stability: stable running on typical European track at the design speed of 140km/h must be ensured and ride quality (vertical lateral and longitudinal accelerations experienced by the goods transported) will be assessed.
- Reduced track forces: track geometrical deterioration (ballast settlement and horizontal level, alignment and buckling), rail surface damage (wear, rolling contact fatigue – RCF) and track components damage (sleeper cracking, rail pad deterioration, rail fatigue, fastening deterioration) will all be assessed.

A benchmark vehicle has been selected based on a Y25 bogie and flat bed wagon and will be used to allow quantification of the benefits of the new design. Figure 2 shows the simulation and assessment methodology and figure 3 shows a sample output of the ride force coefficient for the benchmark vehicle.
Figure 3 predicted ride force coefficient for the SUSTRAIL benchmark vehicle running at 120kph and 140 kph on two different tracksections compared with a passenger vehicle.

**4. DOUBLE LENOIR LINK**

In order to achieve the critical target for the SUSTRAIL vehicle of reducing the lateral forces by 50% it has been decided that the conventional Y25 type suspension is not appropriate. The Y25 suspension is very common in European railway operations and this brings advantages for operation and maintenance however it does have a high level of longitudinal stiffness after the small amount of longitudinal clearance has been exceeded and this can result in relatively poor curving and high lateral wheel-rail forces [2]. A number of radical innovations were considered during the technology review stage of the project but it was decided that the use of double Lenoir link primary suspension, shown in Figure 4, would be investigated. The double Lenoir link suspension provides much lower longitudinal primary stiffness while still utilising standard components and methods which are well established within the railway industry.

![Figure 4 Bogie with double Lenoir links](image)

As part of the optimisation of the primary suspension the following parameters were varied:

- The vertical coil spring stiffness
- The angle of the Lenoir link
- The length of the Lenoir link
- The friction coefficient at the sliding surfaces (through changing material)
- The vertical clearance to the bump stop.

These parameters are illustrated in Figure 5.
A model of the SUSTRAIL vehicle was set up with double Lenoir links using the computer simulation tool GENSYS[3] and the influence of variations in the suspension parameters on the critical speed of the wagon was simulated. Straight track was used for this simulation and an initial lateral disturbance was introduced followed by ideal track with no irregularities. Axle load is 22.5T, wheel profile is S1002 and rail profile UIC60 inclined at 1:40. The wheel rail coefficient of friction is set at 0.35.

The wagon speed was reduced from an initial 170km/h and critical speed assumed to have been reached when $\Sigma Y$ drops below 2.5kN. An example is shown in Figure 6.

![Figure 6](image1.png)

**Figure 6.** A sample simulation results showing the establishment of the critical speed for the SUSTRAIL vehicle with double Lenoir links

The effects of the various suspension parameters on the critical speed are summarised in Figure 7.

![Figure 7](image2.png)

**Figure 7.** The effect of Lenoir link angle, length and friction coefficient on the critical speed of the SUSTRAIL vehicle
The simulations were repeated with a speed of 120km/h on straight track with measured irregularities and the maximum vertical track force was established for each track section as shown in Figure 8.

![Figure 8. Maximum vertical force on the rail for the SUSTRAIL vehicle running at 120km/h](image)

Further variations were carried out and the effect of the friction coefficient and stiffness within the suspension on the maximum contact force is shown in Figure 9.

![Figure 9. The effect of friction coefficient and spring stiffness on the contact force](image)

It can be seen that the maximum vertical contact forces tend to increase with the coefficient of friction and with the spring stiffness.

5. **LONGITUDINAL LINKAGES**

In order to improve the running behavior of the SUSTRAIL vehicle it was decided to assess the benefit of linkages providing longitudinal stiffness between the axleboxes using a radial arm. The radial arm was designed by Dr. Scheffel and is shown in Figure 10. This has been studied previously in the Infra-Radial project [4] which aimed to develop a bogie for heavy haul vehicles (axle loads over 25T) with reduced life cycle costs.
Tests using the radial arm with four different primary suspension types showed good results with stable running and radially aligned wheelsets in curves. Wear of the wheels was seen to reduce significantly [5].

In the work reported here simulation was carried out using MEDYNA [6] for the SUSTRAIL vehicle with double Lenoir links and radial arms. Four cases were compared:

- original Y25 bogie with one Lenoir link on axle box and without radial arms;
- bogie with two Lenoir links without radial arms;
- bogie with one Lenoir link with radial arms between wheelsets;
- bogie with two Lenoir links with radial arms between wheelsets.

Wagon movement was simulated on a straight track with irregularities positioned at the distance of 40 m from the start with velocity reducing from 160 km/h to 40 km/h and the results are shown in Figure 11. The results show that the critical velocity for laden wagon:

- for the original Y25 bogie is near 100 km/h;
- for the Y25 bogie with 2 Lenoir links is less than 40 km/h;
- for the Y25 bogie with radial arms is a little less than for the first case - 99 km/h;
- for the Y25 bogie with 2 Lenoir links and radial arms is 66 km/h.

Further optimisation of the suspension properties is required to increase the critical speed for the bogie with 2 Lenoir links and radial arms.
Figure 11 – Simulation results of the lateral displacement of the first wheelset in the bogie of the SUSTRAIL vehicle:

a) Y-25; b) Y-25 with 2 Lenoir dampers; c) Y-25 with radial arms; d) Y-25 with 2 Lenoir dampers and radial arms.
6. SECONDARY SUSPENSION

The UIC-interface between the car body and the bogie frame for freight wagons with Y25 bogies consists of a centre pivot bearing and two side bearers as shown in Figure 12. [7]. The pivot bearing has three rotational and no translational degrees of freedom. A composite-material intermediate layer provides load dependent frictional damping. The spring side bearer is mounted atop the ends of each bogie and consists of a composite-material friction pad supported by springs. Overall the connection between car body and bogie frame is almost rigid.

![Figure 12. The UIC centre pivot for freight wagons [7]](image)

In the development of the LeiLa bogie by the Technical University of Berlin [8] the secondary suspension was extended by a circular rubber spring mounted between the bogie frame and the lower part of the centre pivot bearing as shown in Figure 13. In this work the use of a similar arrangement for the SUSTRAIL vehicle has been investigated with the aim of improving the dynamic behaviour of the vehicle.

![Figure 13. The LeiLa secondary suspension ring [8]](image)

A model of the SUSTRAIL vehicle with Y25- bogies was built using the simulation tool Simpack [9] and after an initial benchmark test against the other models described here simulations were carried out to investigate the following points.

- Influence on the eigenmodes
- Vehicle stability
- Radial steering
- Vehicle dynamics on realistic track (virtual test track)

The suspension ring is made of rubber and provides stiffness in all three translational and rotational directions. A standard Y25-bogie will be compared to a bogie extended with the secondary suspension ring. Overall, four different configurations have been investigated:

- Standard Y25-bogie approved within the SustRail benchmark test
- Adjusted Y25-bogie with a secondary suspension ring and the similar stiffness properties as used for the LeiLa-bogie [4] called "Sustrail"
- Adjusted Y25-bogie with a secondary suspension ring and half the stiffness called "Sustrail low"
- Adjusted Y25 bogie with a secondary suspension ring and one and a half the stiffness called "Sustrail high"
Initial tests have focused on the modal behaviour of the vehicle with simple excitation to establish the potential benefits or problems with the suspension ring.

6.1 Bouncing mode

A sinusoidal irregularity with a vertical amplitude of 1 mm and a wave length of 7.1 m (half of the distance between bogie pivots) is used to excite the bouncing mode of the vehicle. The maximum of the amplitude ratio occurs at 3.38 Hz (laden), 3.53 Hz (partly) and 4.31 Hz (tare). The first two are weak with an amplitude ratio below 1.0. Normally the highest amplitudes occur at resonance, when the excitation frequency and the eigenfrequency are equal. Therefore, the bouncing eigenmode of the vehicle should be at the same frequency.

The secondary suspension ring has just a small impact. The amplitude ratio does not change significantly and the bouncing eigenfrequency is shifted to a slightly higher value.

6.2 Pitching mode

A sinusoidal irregularity with a wavelength of 9.47 m (three-quarters the distance between bogie pivots) and a vertical amplitude of 1 mm is used to excite the pitching mode of the vehicle. Due to the chosen wavelength the up and down movement of the bogies will be exactly opposing. The results for the standard bogie are shown in the figure below. The amplitude ratio is nearly constant and no resonance can be observed in the considered frequency range. Therefore the pitching mode is not investigated any further.
6.3 Hunting mode

In order to excite the hunting mode a sinusoidal irregularity with a wavelength of 7.1 m and a lateral amplitude of 5 mm is applied to the bogies laterally with no phase difference. The results for each load condition are shown in the figures below. The peak response for the standard Y25 bogie is at 2.2 (partly), 2.5 (laden) and 2.9 Hz (tare) and should be equal to the eigenfrequency of the associated eigenmode. The maximum amplitude ratio is 1.96 (laden), 2.63 (partly) and 2.52 (tare). If a secondary suspension ring is introduced, the maximum of the amplitude ratio increases in combination with a decreasing frequency.

![Figure 16. The hunting mode](image)

6.4 Yawing mode

To excite the yaw mode a sinusoidal excitation with a wavelength of 9.467 m and a lateral amplitude of 5 mm is applied. The vehicle response is shown in the figure below. There is no clear maximum for the vehicle with standard Y25-bogies. It is more a widespread maximum around 2.5 Hz (laden, partly) or 3 Hz (tare). This changes, if a secondary suspension is added. The maximum becomes clearer and the resonance frequency decreases. The amplitude maximum for Sustrail low is at 2.02 Hz (laden), 2.23 Hz (partly) and 2.70 Hz (tare). The amplitude ratio also increases significantly.

![Figure 17. The yawing mode](image)
7. CONCLUSIONS AND NEXT STEPS

A novel high speed low impact freight vehicle has been proposed based on existing innovations which have the potential to improve the dynamic behaviour and reduce track forces even at relatively high speeds. This vehicle has been modelled and the results of the simulations compared against an existing freight vehicle. Double Lenoir links and longitudinal arms linking the axle boxes are included in the primary suspension and a resilient secondary suspension added below the standard centre bowl at the secondary suspension. These innovations have been modelled and conclusions drawn regarding the stability and modal behaviour of the vehicle on straight track.

The next steps are to model the vehicle on curved track and to carry out an overall optimisation considering the effects of the double Lenoir link and the longitudinal linkages and the secondary suspension ring acting together.

References