Rail Technology Unit

Manchester
Metropolitan
University

# Wheel – Rail Contact Benchmark

**Version 3.0**

**Revised on 10/11/06**

**Contact Details:**

Phil Shackleton p.shackleton@mmu.ac.uk
Simon Iwnicki s.d.iwnicki@mmu.ac.uk

Rail Technology Unit
Manchester Metropolitan University
Department of Engineering and Technology
Chester Street
Manchester M1 5GD
UK

Telephone +44 (0) 161 247 6247

## 1. Introduction

The Rail Technology Unit at Manchester Metropolitan University (MMU) is coordinating a benchmark of the wheel-rail contact models currently used in railway vehicle simulations. The benchmark aims to allow an informed choice when selecting a contact model for a particular modelling situation.

## 2. Background

Computer models are used to predict the behaviour of railway vehicles in an ever widening variety of applications. A key aspect of railway vehicle modelling is the interaction between the wheels and rails. A wide range of contact models exist to define the wheel-rail interaction, and to achieve acceptable computational times all of these models make simplifying assumptions. As a result each model has a limit to its validity and restrictions to its application.

The effects of these simplifications are not always apparent to the end user, and due to the widening scope of railway simulations the possibility arises that contact models are used beyond the extent of their initial validation.

## 3. Aim

To allow an informed choice of wheel-rail contact model for railway simulations.

## 4. Objectives

### 4.1. To investigate the difference between predicted

- Contact size, shape and position
- Normal stress distribution
- Tangential stress distribution
- Creep forces

by different contact models

### 4.2. To investigate the effects of different wheel-rail contact models on dynamic vehicle simulation

The effects of the contact models on the dynamic behaviour of a vehicle simulation will be evaluated and their capabilities in handling straight, transitional, curve and switch track sections assessed.

## 5. Simulation Cases

To satisfy the objectives above, two distinct simulation cases are proposed:

A) Prescribed single wheel or wheelset contact study
B) Dynamic vehicle simulation

# 6. Simulation Case A

This case aims to compare data from different contact models for clearly defined contact conditions. Real wheel and rail profiles will be used, with prescribed lateral displacement, yaw angle, wheel load, velocity, and friction coefficient. The simulated contact size, shape and position, stress distribution, creep forces generated and computational time will be compared. Combinations of wheel attitude and position have been selected to represent typical modelling cases that challenge the contact models.

To include all aspects of interest Case A is split into two sub-cases:

Case A-1 – Normal contact

Case A-2 – Tangential contact

## 6.1. CASE A-1

This simulation case is concerned only with normal contact and uses a static wheelset. The wheel-rail contact should be evaluated for the given lateral displacements and yaw angles, in turn, for each of the three wheel/rail combinations. Throughout Case A the following should be assumed; wheel tape-circle radius of 460mm taken 70mm in from the flange back (see fig 6.1); track gauge of 1435mm measured 14mm below a plane that rests across the two rails (see fig 6.2); flange back separation of 1360mm; axle vertical load of 20 kN applied at the centre of the axle, any weight of axle and wheels should form part of this load. The wheelset and track should be considered rigid bodies, any contact stiffness should be included. The two wheel and rail profile combinations are shown in the table below.

| Combination No | Wheel profile | Rail profile |
|---|---|---|
| 1 – New | S1002 (file: S1002.whe) | UIC60 (file: UIC60.rai) |
| 2 – Worn | Worn S1002<br>(file: S1002_worn.whe) | Worn UIC60<br>(file: UIC60_worn.rai) |

Table 6.1. Showing the combinations of wheel and rail profiles to be used in Simulation Case A

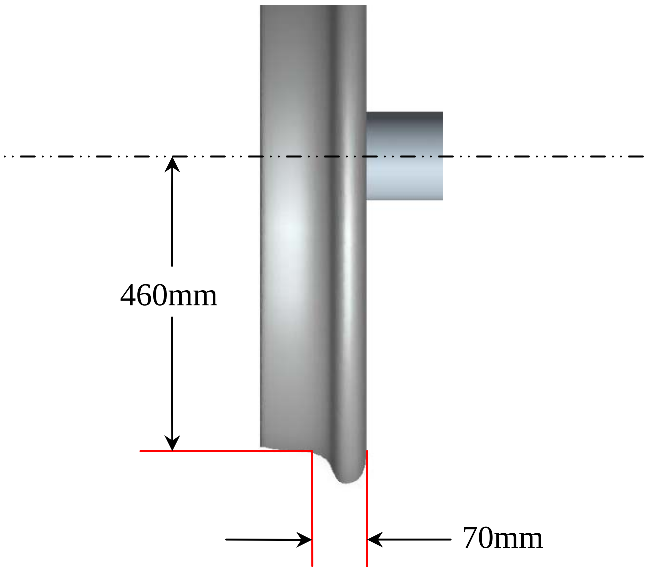

Fig 6.1 Showing the position of the tape-circle radius on the left wheel

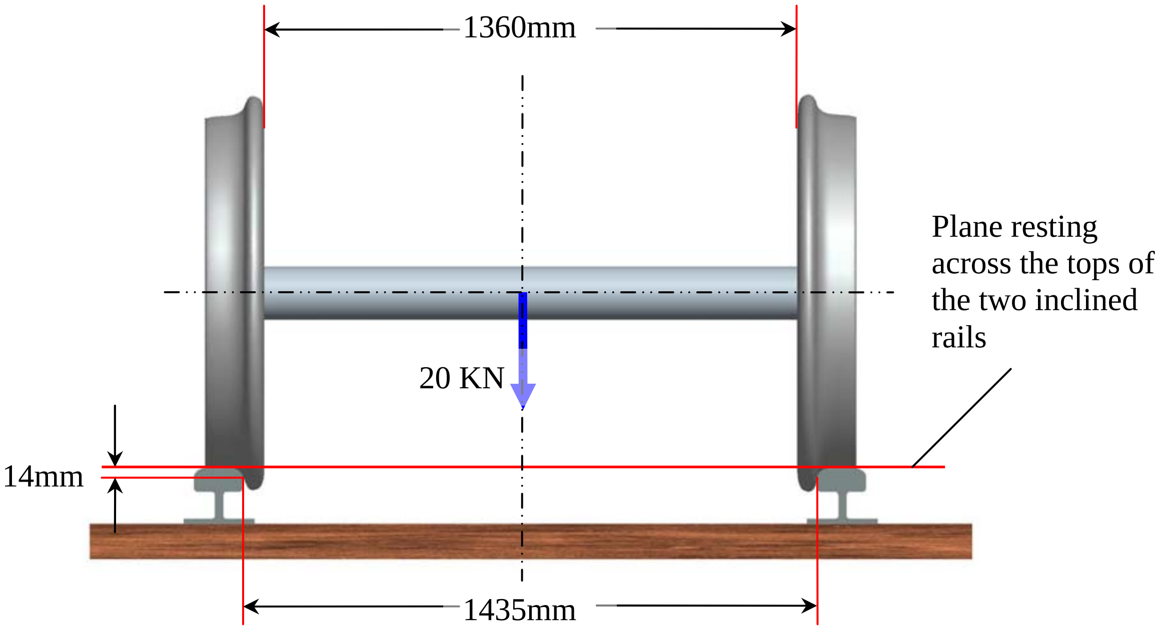

Fig 6.2 Showing the gauge and flange-back dimensions and the positioning of the vertical load

### 6.1.1. Case A1.1 – Lateral displacement

The wheelset should be located at the lateral displacements from 0mm to +10mm at 0.5mm increments, and at each point the normal contact should be evaluated for each wheel and the outputs detailed in table 6.3 should be returned.

### 6.1.2. Case A1.2 – Lateral displacement and Yaw

The wheelset should be located with the combinations of yaw angle and lateral displacement stated in table 6.2, and at each point the normal contact should be evaluated and the outputs detailed in table 6.3 should be returned. If track geometry requires inclusion (perhaps in the case of a 3D contact model) then the simulation should be performed on straight track.

| Lateral displacement of wheelset centre (mm) | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yaw angle (mrad) **All values are Negative** | 0 | 1.2 | 2.4 | 3.6 | 4.8 | 6 | 7.2 | 8.4 | 9.6 | 10.8 | 12 | 13.2 | 14.4 | 15.6 | 16.8 | 18 | 19.2 | 20.4 | 21.6 | 22.8 | 24 |

Table 6.2 Showing the lateral displacements and yaw angles simulation Case – A1.2

| Outputs | Dimensions | Notes |
|---|---|---|
| Contact position | mm | Initial contact point for each lateral displacement and yaw combination. Stated for each wheel and rail in their respective coordinate system. |
| Other contact positions | mm | The points of any secondary contact positions which occur stated in their respective coordinate system. |
| Contact angle | mrad | At each point of contact for each wheel. |
| Rolling radius difference | mm | Defined as Left rolling radius minus Right rolling radius |
| Contact area | $mm^2$ | |
| Contact patch shape | n/a | If elliptical provide ratio of semi-axes ‘a/b’, if non-elliptical provide a plot if possible. |
| Normal pressure distribution | Pa | If deemed elliptical or quadratic state which, else provide a plot if possible. |
| Computational time for 1000 runs | s | Time taken to return the contact data for each Sub-case for each W/R combination, 1000 times. |
| Computer specifications | | Brief description of computer set-up. E.g. CPU type, RAM, Executable program / Matlab routine etc. |

Table 6.3 detailing the outputs for simulation Case A-1.

## 6.2. CASE A-2

The aim of this study is to asses the solution of the tangential contact problem quasi-statically, using the simulation cases described in section 6.1. A forward wheelset speed of 2m/s should be used throughout and lateral and yaw velocities should be considered zero. Output should be returned for one time step, at a point where the simulation has reached a steady-state solution. Outputs required are detailed in Table 6.4.

The wheelset should be run on straight track and the wheelset and track should be considered rigid bodies. Any contact stiffness should be included.

| Output | Dimension | Notes |
|---|---|---|
| Creepages | | |
| Creep forces | N | Acting on the wheel, in the Contact Patch coordinate system. |
| Resolved creep forces | N | The creep forces as above, resolved into the Track coordinate system. |
| Resultant tangential stress distribution | Pa | If elliptical state so, else provide a plot if possible. |
| Computational time for 1000 runs | s | Time taken to return the contact data for each Sub-case, 1000 times |
| Computer specification | | Brief description of computer set-up. E.g. CPU type, RAM, Executable program/Matlab routine etc. |

Table 6.4 detailing the outputs for simulation Case A-2

## 6.3. Coordinate Systems

### 6.3.1. Track Coordinate System

The track coordinate system is right handed Cartesian, with 'x' parallel to the tracks, in the direction of rolling, 'y' horizontally to the right and 'z' vertically down. With y = 0 on the track centre line, x = 0 at the centre of the axle and z = 0 in the plane resting on top of both rails, vertically below the wheelset centre. A clockwise rotation is assumed positive when looking along the axis, away from the origin.

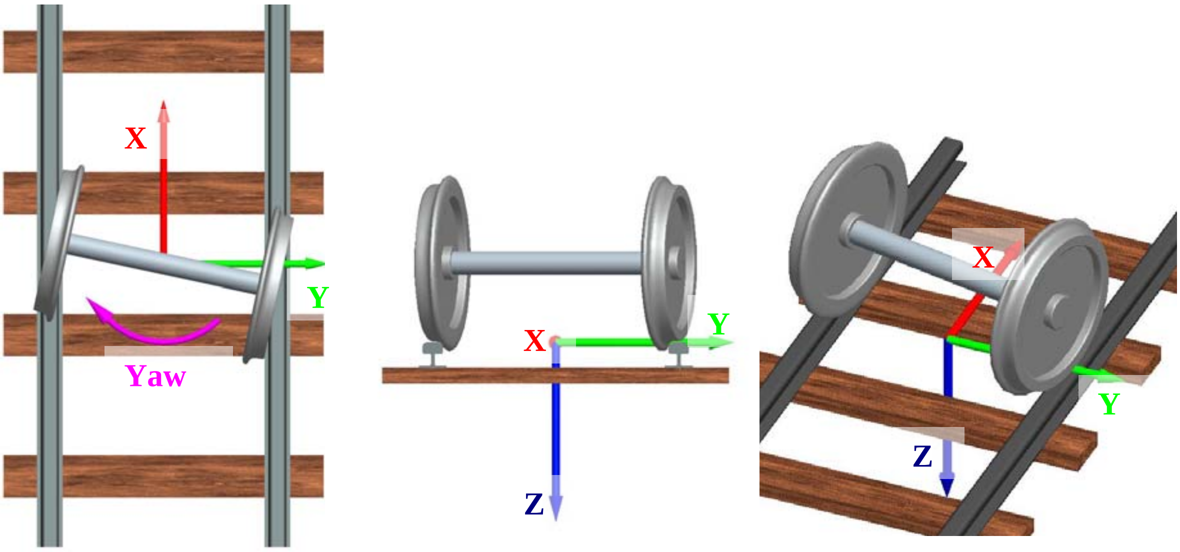

Fig 6.3 showing the orientation of the track coordinate system, with X in the direction of rolling.

### 6.3.2. Wheel & Rail Local Coordinate Systems

The right hand wheel and rail local coordinate systems are right handed Cartesian systems, while the left hand wheel and rail local coordinate systems are left handed, with 'y' to the left of the direction of rolling. The wheel coordinate system is positioned with y=0 on the circumference relating to the tape-circle radius, x=0 vertically below the wheel centre and z=0 on the wheel surface.

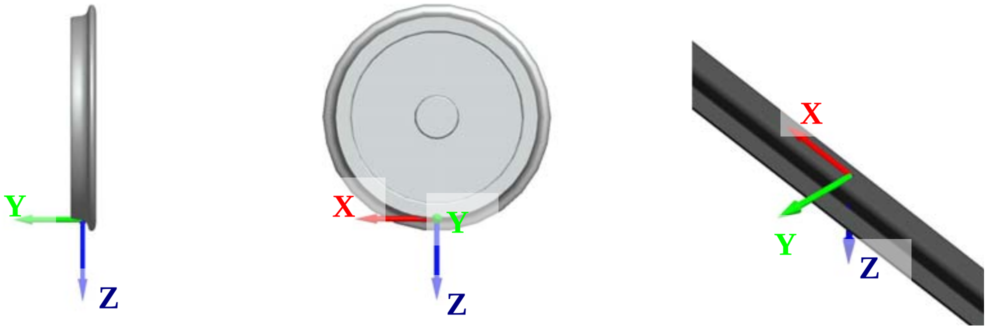

Fig 6.4 showing the local coordinate systems for the left hand wheel and rail.

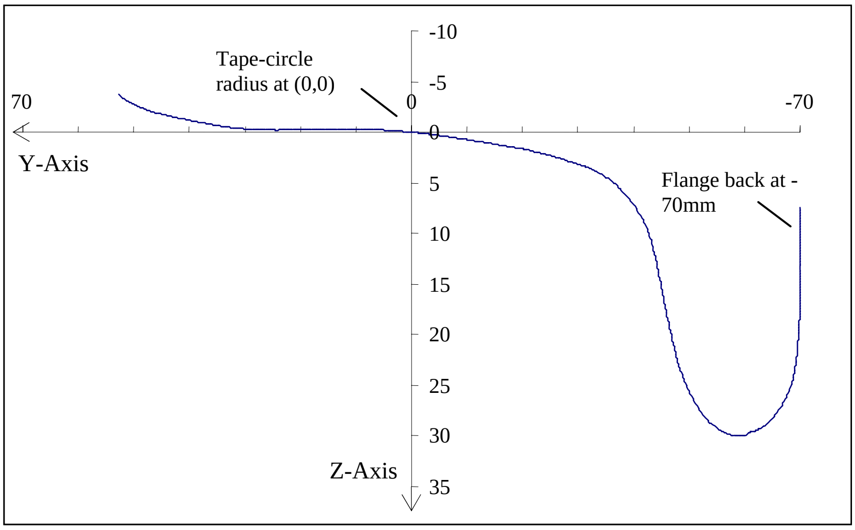

Fig 6.5 showing the position of the left-hand wheel local coordinate system. Note that this system is left handed Cartesian.

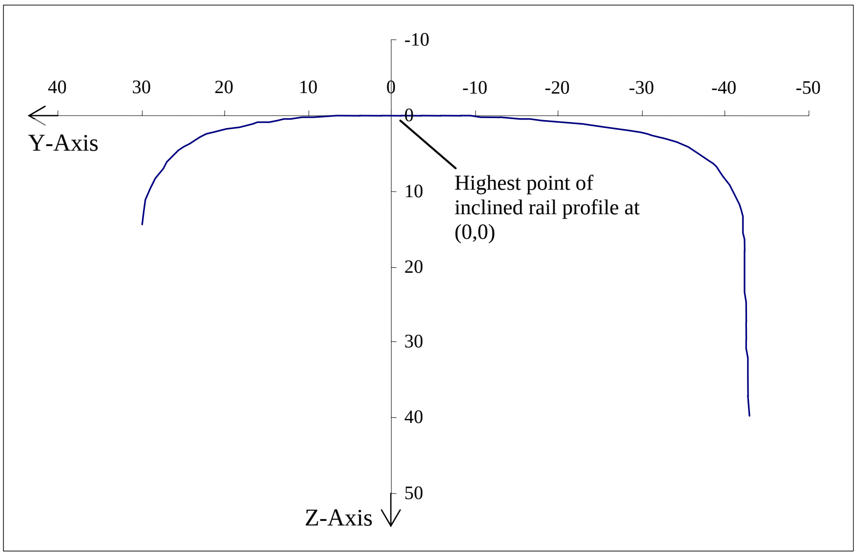

Fig 6.6 showing the position of the left-hand rail local coordinate system. Note that this system is left handed Cartesian.

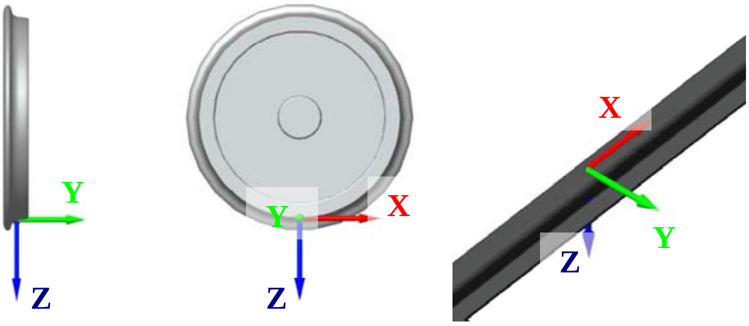

Fig 6.7 showing the local coordinate systems for the right hand wheel and rail.

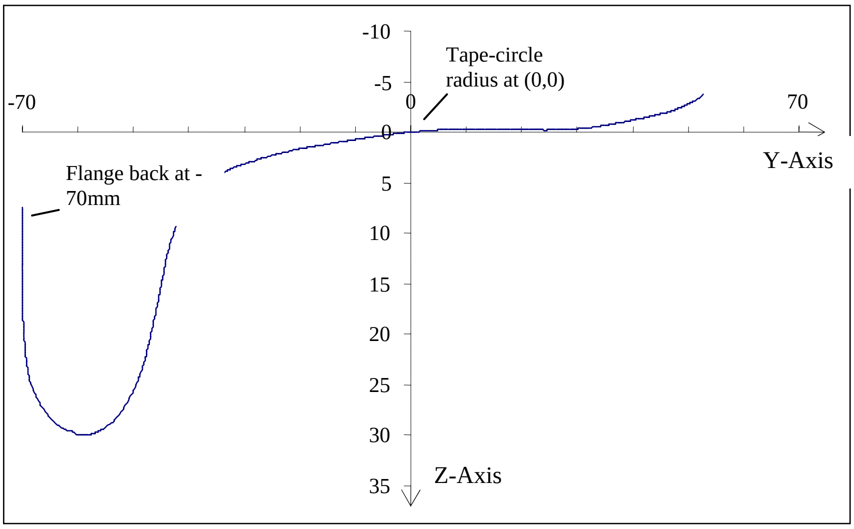

Fig 6.8 showing the position of the right-hand wheel local coordinate system. Note that this system is right handed Cartesian.

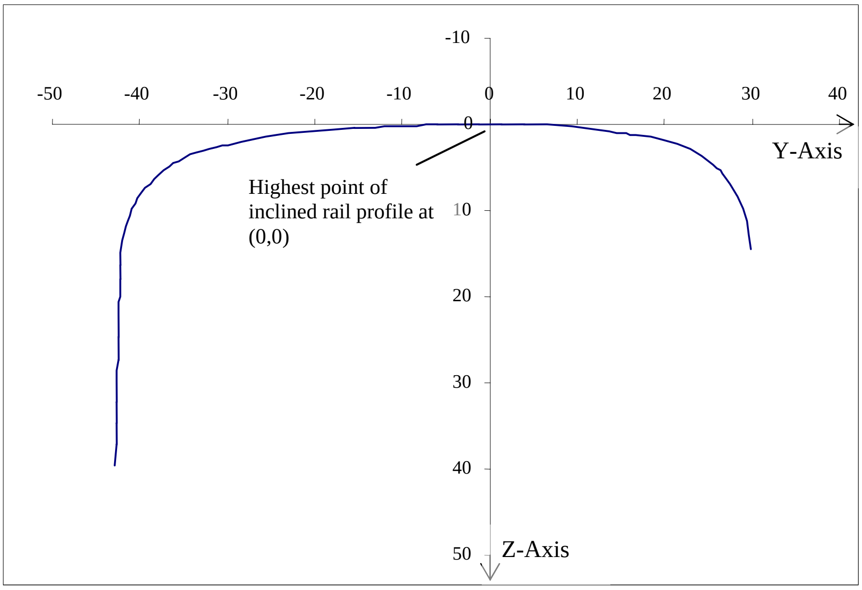

Fig 6.9 showing the position of the right-hand rail local coordinate system. Note that this system is right handed Cartesian.

The rail coordinate system is positioned with y=0 and z=0 at the highest point of the inclined rail profile and x = 0 in line with the centre of the axle. For clarity the wheel and rail profile files are provided in their local coordinate systems.

The contact patch coordinate system is orientated similarly to that of the corresponding rail, with (0,0,0) at the initial point of contact / highest normal pressure and rotated about the x-axis so that the x-y plane is tangential to the initial point of contact as shown below in figure 6.10 (for the Left wheel / rail).

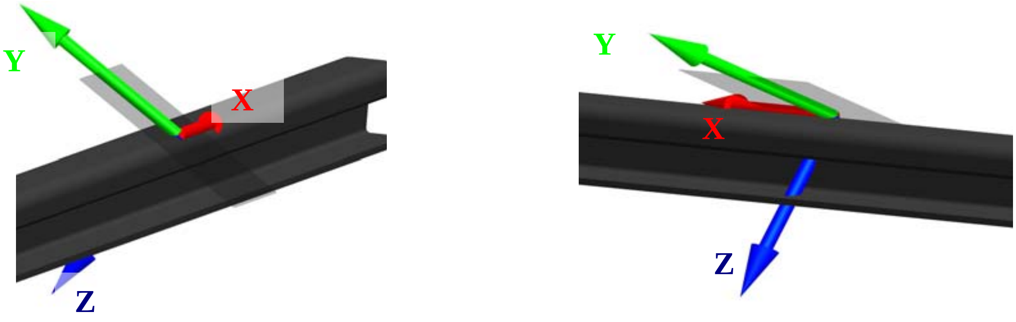

Fig 6.10 Showing the orientation of the contact patch coordinate system for the Left wheel / rail. Note that this system is Left handed Cartesian while that for the Right wheel / rail is Right handed Cartesian.

### 6.4. Material properties

| | |
|---|---|
| Young’s modulus for wheel and rail | 2.1e11 N/$m^2$ |
| Poisson’s ratio for wheel and rail | 0.28 |
| Coefficient of friction | 0.3 |

## 7. Simulation Case B –Dynamic vehicle simulation

This case aims to evaluate the effects of the individual contact models on the dynamic behaviour of a vehicle simulation. A simple vehicle with two axle bogies will be simulated along various, realistic lengths of track. The resulting wheelset path, normal forces, creep forces and contact size/shape/position will be compared. The sections of track used could include straights, transitions, curves and switches. Evaluation of derailment, curving and stability could also be carried out.

The precise criteria for this simulation case will be proposed shortly.

## 8. Validation

It is thought that validation of the benchmark tests would be beneficial, and allow the results to be put into some sort of context, however the difficulties in comparing computer models to field measurements are recognised.

It is hoped that solutions to the normal contact problem (Case A1) may be compared with ultrasound tests for the new wheel and rail profiles, and that field data may form a basis for validation of Simulation Case B.

## 9. Summary

| Input | Case A | Case B | Twin Disc Rig | Ultrasound |
|---|---|---|---|---|
| Wheel/Rail Profiles | ✓ | ✓ | ✓ | ✓ |
| Wheel Load | ✓ |  | ✓ |  |
| Lateral displacement | ✓ |  | ✓ | ✓ |
| Attitude/Yaw | ✓ |  | ✓ | ✓ |
| Velocity | ✓ | ✓ | ✓ |  |
| Friction Coefficient | ✓ | ✓ |  |  |
| Track Geometry |  | ✓ |  |  |

| Output |  |  |  |  |
|---|---|---|---|---|
| Contact size/shape/position | ✓ | ✓ |  | ✓ |
| Normal Stress Distribution | ✓ |  |  |  |
| Tangential Stress Distribution | ✓ |  |  |  |
| Creep Forces | ✓ | ✓ | ✓ |  |
| Wheelset Path |  | ✓ |  |  |
| Normal Forces | ✓ | ✓ | ✓ |  |
| Derailment Quotient |  | ✓ |  |  |
| Stability |  | ✓ |  |  |
| Computational Time | ✓ | ✓ |  |  |

Table 9.1 above summarises the inputs and outputs from the two simulation cases and the validation tests.