The UKAxle Project
RSSB T356: Optimising Wheelset Design and Maintenance

Presentation to ESIS
Milan, 13 – 14 October 2008
Project Partners

- **RSSB**
  - Management and funding of overall T356 programme
  - Link to stakeholders
  - Liaison with wider research programme (WIDEM, Deufrako)

- **DeltaRail**
  - Manage and carry out T356 work packages WP1 and WP3
  - Apply technical expertise and railway experience
Why do we need new Axle Design Standards?

- **Existing standards only address fatigue crack initiation**
  - Only valid for axles fully protected against corrosion and impact damage
  - Other axles will need regular NDT throughout their service lives
  - Existing standards do not provide a methodology to set the NDT periodicity

- **Existing standards do not take account of actual stress spectrum applied to axle**
  - Do not account for route geometry – likely to be non-conservative for LRT (Metro) type axles
  - Do not account for actual passenger load spectrum

- **Existing standards are not consistent for different axle layouts**
  - Tend to be over-conservative for outboard-journal powered axles
  - Can be non-conservative for inboard-journal powered axles

- **Has led to unexpectedly short NDT intervals for axles that actually comply with design standards**
Possible New Basis for Axle Design Standard

- Use fracture mechanics to calculate probability of failure during service life, with or without NDT
  - “Allowable” failure probability based on currently acceptable axle design?
  - Relative approach of this type has considerable operational advantages

- Principal inputs to fracture mechanics based methodology
  - Fracture mechanics model – to be considered in detail in RSSB Project T728 (currently underway) and recent WIDEM work
  - Axle material crack growth behaviour – RSSB Project T728 and WIDEM
  - Flaw size distribution – RSSB Project T728
  - Effectiveness of NDT procedures – considered in recent WIDEM work
  - Axle stress spectrum – considered in RSSB Project T356. First stages of this work now complete.
Background to RSSB Project T356

Aims

- Optimise the design and maintenance of wheelsets
- Provide input to new European axle design standards
- Reduce whole life costs

Work Package 1 (complete)

- Data acquisition for one UK vehicle type (Class 319 EMU)
- Data validation and processing

Work Package 3 (complete)

- Use of WP1 data to develop predictive model
- Validation for Class 319 EMU
- Limited validation for a few other vehicle types (high speed locomotive and passenger coach)

Work needs to be extended to other vehicle types
T356 Work Package 1 – Data Acquisition

- **Trial Vehicle:** Southern Class 319 EMU

- **Route:** Bedford to Brighton & Sutton Loop

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<th>Linespeed (mph)</th>
<th>% running</th>
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<td>45 - 60</td>
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<td>&gt; 5000</td>
<td>46.4</td>
<td>&gt; 100</td>
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T356 WP1 - Data acquisition process

- Parameters measured:
  - Bending strains at both ends and centre of axle: 2000 samples/sec
  - Torsional axle strains: 2000 samples/sec
  - Vertical axlebox accelerations: 2000 samples/sec
  - Lateral axlebox accelerations, and body accelerations in three directions: 500 samples/sec
  - Yaw damper displacement (curve radius): 500 samples/sec
  - Brake pressure and AWS detector (location on route): 500 samples/sec
  - Airspring pressure (passenger loading) and digital line: 1 sample/sec
  - GPS recorded to establish geographic location.

- Test started March 2006 and finished January 2008
  - Data downloaded approximately monthly
  - About 3 Terabytes of time history data recorded, covering 160,000 miles

- Also strain histograms from data loggers, covering 240,000 miles
Use data measured in Work Package 1 to understand the influence of a range of inputs, for example:

- Route geometry and overall track quality
- Effect of discrete irregularities such as S&C
- Wheelset and suspension characteristics
- Effect of braking and position of axle within train

Develop methodology to predict axle stress spectrum

Validate for Class 319 EMU over test route

Limited validation for other UK vehicles and routes

Define directions for any further work

Output intended to form a key input to new European standards
Axle stress prediction methodology - overview

- Firstly calculate quasi-static stresses based on:
  - Axle load
  - Curvature of route

- Then correct for influence of additional relevant parameters:
  - High frequency dynamic forces
  - Discrete irregularities (e.g. S&C or wheelflats)
  - Braking loads
  - Changes in wheel profile

- But which effects are important?
  - Class 319 measurements used to find out

- Leads into proposed methodology
Axle stress prediction methodology - stage 1

- Service route expressed as a matrix (“Service Matrix”) of geometry and track quality
  - Geometry expressed by curve radius and cant deficiency
  - Track quality best expressed by line speed. Currently no routinely measured track quality parameter that can be directly related to axle stress

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Axle stress prediction methodology – stage 2

- A railway vehicle track interaction package, such as VAMPIRE®, is used to predict wheel/rail forces generated in quasi-static curving
  - Calculate for the same combination of curvature and cant deficiency as in the Service Matrix
  - Derive the increment in axle stress for these geometry cases (“Stress Increment Matrix”)
Axle stress prediction methodology – stage 3

- Corrections are applied to the quasi-static Stress Increment Matrix to allow for the effects of high frequency behaviour and track roughness as a function of line speed.
  - Both these corrections are currently derived from Class 319 measurements, but in principle they should apply to the particular vehicle and perhaps route under consideration.
Axle stress prediction methodology – stage 4

- The Service Matrix and corrected Stress Increment Matrix are combined to derive a “Quasi-static histogram” of stress increment against percentage of cycles.
Axle stress prediction methodology – stage 5

- The final dynamic axle stress histogram is derived by combining:
  - static stress
  - quasi-static histogram
  - dynamic scatter histogram, which characterises the effect of track roughness,
  - passenger load spectrum (if appropriate)
Sensitivity analysis methodology

- List input parameters that might influence axle strain
- Define reasonable range of inputs that might occur on UK railways
- Determine effect on axle stress
  - use measured Class 319 data and/or VAMPIRE® simulations
- Determine effect on failure probability using a probabilistic fracture mechanics model developed by DeltaRail
  - standard axle NDT assessment methodology
  - assume far end scan at periodicities between 125,000 and 1 million miles
- Parameters divided into three final categories
  - must be included in model to predict stress histograms
  - should be included as correction factors on failure probability
  - not significant and can be discounted
Results of sensitivity analysis (1 of 7)

- **Route**, covering track curvature, cant deficiency, and track quality (expressed in terms of linespeed)
  - Increase in failure probability between least severe (Kings Cross – Peterborough) and most severe (North London Line) UK routes: **11.7**
  - Increase in failure probability from including track roughness: **2.3**
  - Reduction in failure probability from using an approximation of Class 319 service network: **1.3**
  - Conclusion: track geometry and quality must be included in predictive model
  - 1.3 factor taken as threshold of sensitivity. Any change that gives a larger factor should be included in predictive model
Results of sensitivity analysis (2 of 7)

- Discrete track irregularities, such as dipped joints, lateral misalignment, and S&C
  - Cannot easily be included in model (track data not available)
  - Effect investigated by removing small groups of large cycles from measured strain data – reduced calculated failure probability by a factor of 1.2
  - Discrete irregularities not regarded as significant for axles according to proposed criterion
  - Included implicitly anyway in proposed model as part of track roughness
Results of sensitivity analysis (3 of 7)

- **Vehicle type, covering wheelset and suspension parameters**
  - Class 319, Mk4 coach and Class 91 locomotive compared over a range of routes
  - Maximum difference in failure probability between vehicles: **2.4**. This is significant and means that vehicle type must be included in predictive model.

- **Static Axle Load**
  - Increase in calculated failure probability from 5% overestimate in calculation of tare static stress: **1.75**
  - Increase in failure probability if Class 319 axle load was increased to maximum allowable according to BASS design standards (currently 80% of allowable): **14**

  Conclusion: static stress must be calculated accurately
Results of sensitivity analysis (4 of 7)

- **Passenger Load Spectrum**
  - Measured for Class 319 from airspring pressure. Shows that previous estimates for multiple unit trains and current standards requirements are grossly conservative.

![Graph showing passenger load spectrum comparison](image)

- Increase in calculated failure probability if estimated spectrum used instead of measured: **3.3**
- Conclusion: Passenger load spectrum must be included.
Results of sensitivity analysis (5 of 7)

- **Weather, influencing wheel/rail friction**
  - No observable effect from considering similar runs under different weather conditions
  - Does not need to be considered in model.

- **Braking**
  - Effect depends on brake configuration. Including realistic Class 319 braking conditions could increase failure probability by up to $1.3$
  - Conclusion: as braking is relatively easy to incorporate into predictive model, it should be included
Results of sensitivity analysis (6 of 7)

- **High Frequency Behaviour**
  - defined as any cycles of a frequency greater than that corresponding to maximum wheel rotation frequency (~20 Hz). More marked on tight curves - stick-slip behaviour?
  - Included by an empirical correction in predictive model. Resulting increase in calculated failure probability: 2.4
  - Conclusion: Should be included in predictive model

- **Position of Axle in Train**
  - Proposed European axle design standards assume a more severe environment for leading axle of train
  - Confirmed by Class 319 test. Failure probability 1.3 times higher for leading axle compared to centre of train
  - Conclusion: may be appropriate to apply correction to calculated failure probabilities
Results of sensitivity analysis (7 of 7)

- **Long term changes, including wheel wear and suspension degradation**
  - Axle stress environment became less damaging as test progressed
  - Reason not clear, but could be linked with changes in wheel profiles – more work needed
  - If such changes are to be included, best as correction to calculated failure probabilities

- **Wheel Defects, covering wheelflats and out-of-round wheels**
  - can have significant effect on axle stress, but severe cases will not remain in service for long, particularly if WHEELCHEX on route
  - Probable maximum increase on failure probability: **1.2**
  - Conclusion: can be ignored for purposes of model
Summary of sensitivity analysis

- **Parameters that need to be included in synthesising axle stress histograms:**
  - Route geometry and quality, vehicle type, static axle load, passenger load spectrum, braking (for some brake configurations), high frequency behaviour

- **Parameters that may need to be included by applying corrections to calculated axle failure probabilities.**
  - Leading axle in train effects, long term changes in wheelset

- **Parameters that do not need to be included because their effect is not significant:**
  - Discrete track irregularities, weather, wheelflats and out-of-round-wheels (for routes fitted with WHEELCHEX)
Validation

- **Stage 1** – Replicate Class 319 measured strain data over extended period of running (2 months)
- **Stage 2** – Extend to further vehicles and routes, by replicating readily available measured axle stress histograms
  - Mk4 coach measured from Kings Cross to Glasgow
  - Mk4 coach measured from Kings Cross to Peterborough (particularly straight route)
  - Class 91 locomotive measured over 105 miles covering various portions of the ECML
  - Some approximation necessary (track roughness and high frequency behaviour assumed identical to Class 319 as measured)
Validation: Class 319 histogram

Calculated Failure Probabilities at 125,000 mile UAT interval:

- Based on measured histogram: 0.000451%
- Based on predicted histogram: 0.000415%
- Measured / Predicted: 1.09 (within 1.3 threshold)
Validation: Mk4 coach, Kings Cross - Glasgow

Calculated Failure Probabilities at 125,000 mile UAT interval:

- Based on measured histogram: 0.000223%
- Based on predicted histogram: 0.000328%
- Predicted / Measured: 1.47
Validation: Mk4, Kings Cross - Peterborough

Calculated Failure Probabilities at 125,000 mile UAT interval:

- Based on measured histogram: 0.000071%
- Based on predicted histogram: 0.000107%
- Predicted / Measured: 1.51
Validation: Class 91, 105 miles of ECML

Calculated Failure Probabilities at 125,000 mile UAT interval:

- Based on measured histogram: 0.0153%
- Based on predicted histogram: 0.0125%
- Measured / predicted: 1.22
Additional Findings from T356 WP3

- Class 319 unpowered axle is significantly overdesigned
  - However very little opportunity to reduce the diameter whilst maintaining safety levels
  - NDT periodicity could be safely extended
- Class 319 unpowered axle subject to static torsion and torsional oscillation, but the stress amplitudes are not large enough to affect the structural integrity of the axle.
- Running within depots and sidings can be very damaging per mile run (tight curves), but the actual mileages involved are not large enough to be significant
- For relatively long service routes, axle tests should cover at least 500 miles of representative track
Future work for RSSB T356

- For use in a European design standard, the proposed methodology would need to cover all UK and European vehicles and routes
  - Needs to include vehicles with inboard journals
  - Needs to include LRT routes with tighter curves than mainline routes
- Measured axle strain histograms are needed to determine the effect of track roughness and high frequency for other vehicles
  - Some suitable data already available from previous tests
  - Little or no axle strain data for freight wagons
- Possible work programme
  - Review existing axle data in UK and Europe
  - Additional testing if necessary
  - Further development and validation of proposed predictive model to include all required vehicles and routes
Questions and discussion...