CBA Issues
Update to the Transit Commission

May 31, 2024

RIDEAU TRANSIT GROUP
GROUPE de TRANSPORT RIDEAU

CONFEDERATION LINE PROJECT:

TUNNEY'S PASTURE TO BLAIR STATION

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Introductory Remarks

- The issue has been summarized by Alstom as the Vehicle being subjected to lateral loads in excess of the level estimated at the design phase

- In May 2023, Alstom formulated a number of recommendations impacting the track infrastructure to address this issue:
  - Friction coefficient management
  - Restraining Rail contact
  - Track stability in high temperature
  - Reducing rail wear and corrugation
  - Improve the wheel to rail interface

- In February 2024, Alstom released a root cause analysis report which identified a number of contributing factors and concluding that:
  - The current vehicle design was fit for purpose
  - The Root Cause of the high loads is the Wheel/Rail Interface which includes the integrated combination of the wheel profile, rail profile, track and rail geometry, and coefficient(s) of friction at the interface.

Introductory Remarks

- RTG has dedicated the past 12 months to analyze the various reports issued by Alstom with a view to better understand the issue and more importantly to assess how the issue can be satisfactorily resolved.

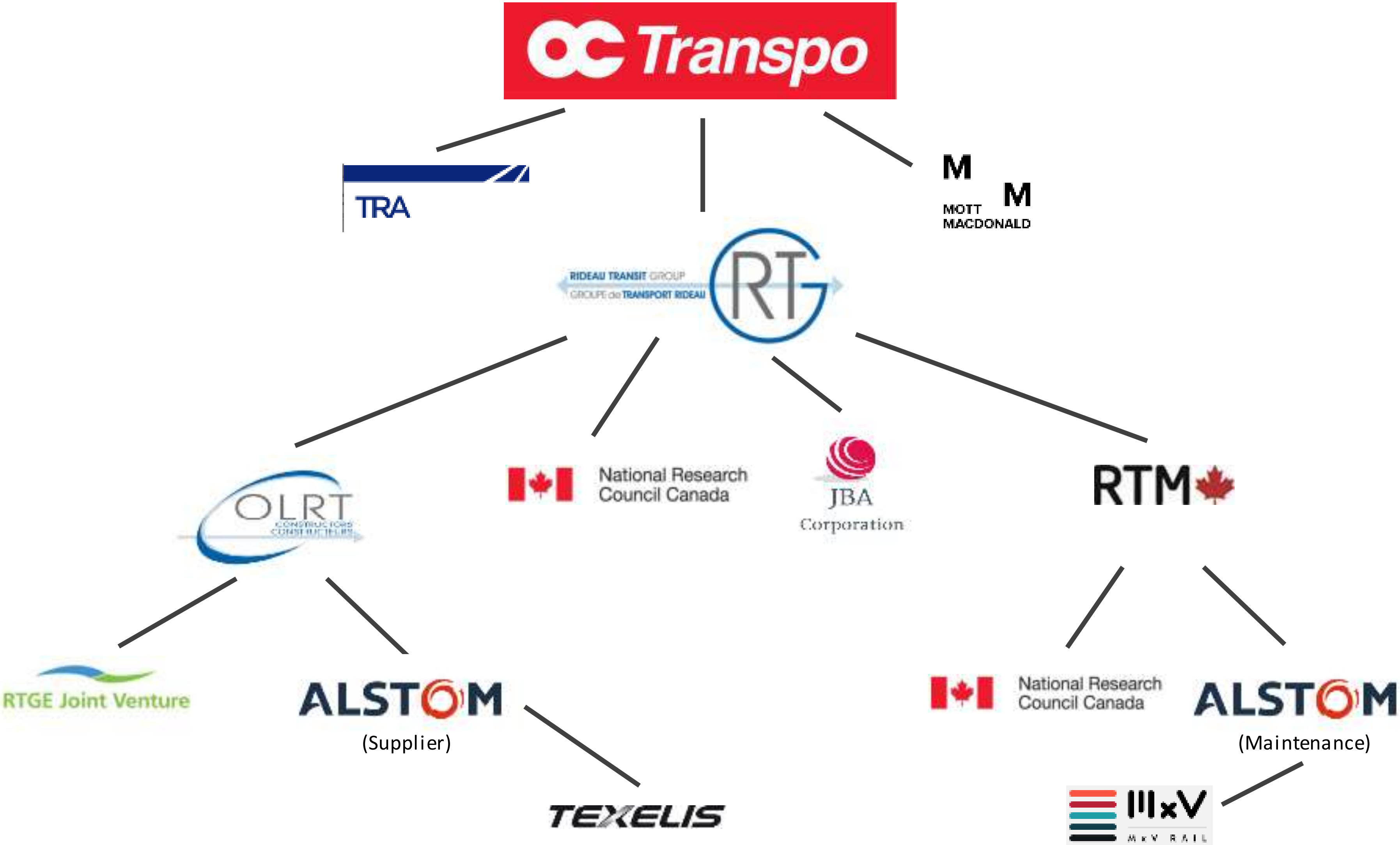
- To do so, RTG has benefitted from the technical support of two independent consultants:
  - National Research Council Canada (NRC)
  - James Boyle and Associates (JBA)

- Where required, RTG carried out independent testing and analyses to further its understanding of the issue

Introductory Remarks

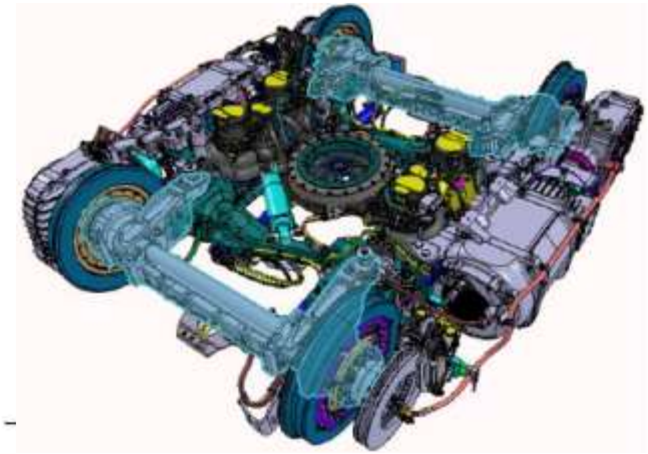
- In May 2024, JBA issued its report identifying a number of discrepancies within the Alstom root cause analysis which must be reconciled
- In the meantime, RTG continues to implement improvements to the infrastructure to assist with the mitigation of the issue
- The objective for today's presentation is to update Transit Commission and the LRT Sub-Committee on the mitigation measures currently deployed in addition to measures that will be actioned in the coming months

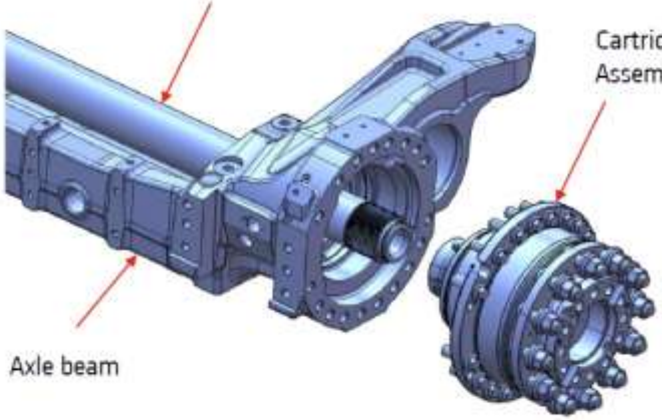
Introductory Remarks



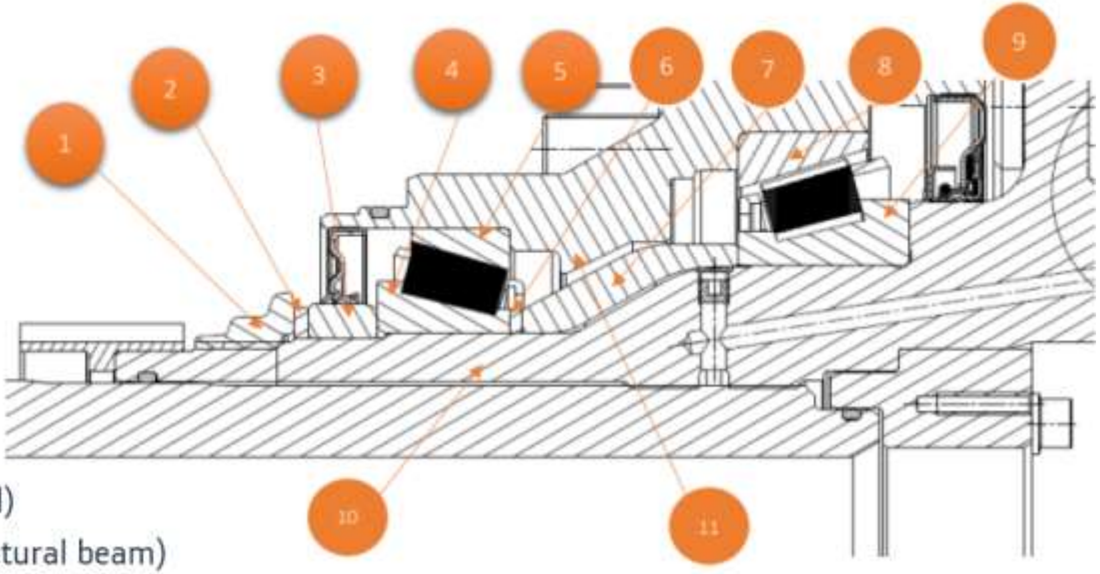
Introductory Remarks

Sections of the Cartridge Bearing Assembly





1. Nut (crimped on hub)
2. Tab washer (tabs located in hub slots)
3. Seal seat ring
4. Inner ring of small bearing
5. Outer ring of small bearing
6. Bearing preload set washer
7. Spacer
8. Outer ring of large bearing
9. Inner ring of large bearing
10. Rotating hub (centered and bolted to the wheel)
11. Fixed housing (centered and bolted to the structural beam)



1.0 RCA for the Issue

Evolution of Alstom's understanding of the Issue

May 2022 — Excessive lateral loads generated by the <u>design of the track</u>

↓

May 2023 — Inducement of excessive lateral loads from the <u>System</u>

↓

February 2024 — The root cause of the high loads is the **<u>Wheel/Rail Interface</u>**, which includes the integrated combination of the wheel profile, rail profile, track and rail geometry and coefficient(s) of friction at the interface (TOR and rail gauge face)

1.0 RCA for the Issue

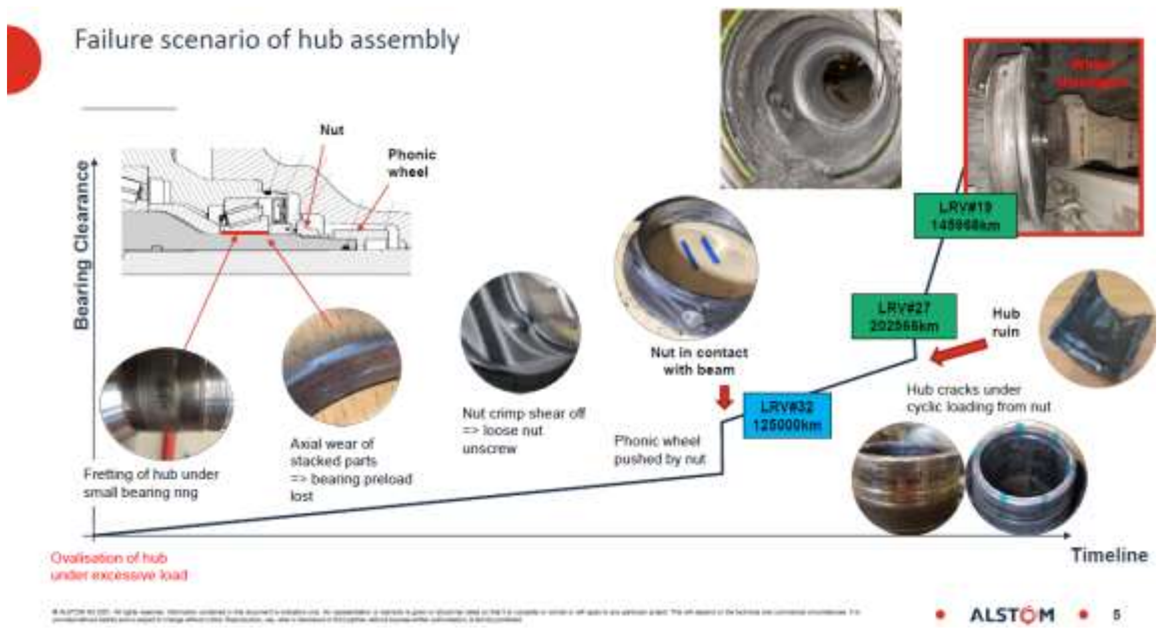
Alstom analysis of the Failure sequence

Table 4. CBA Failure Sequence

Stage	Description	Reference CBAs or Events
1	Fretting under the small bearing	-
2	Wear of parts in the assembly leading to axial play	Pry Bar Checks >100 CBAs have failed to date
3	Loss of preload on the assembly/nut	LRV 18 Investigation
4	Micro-rotation of the nut	-
5	Damage to nut crimps	-
6	Loss of nut crimps (nut unlocks)	-
7	Nut begins to unscrew	LRV 02 Investigation
8	Completely loose CBA	LRV 32 Incident
9	Hub fractures	LRV 26 Investigation LRV 27 Incident
10	Dislocation of wheel	LRV 19 Incident

There are a number of questions still outstanding:

- Why some CBA generate Axle play at 70,000 km while others can easily reach 400,000 km
- How can two CBAs on both ends of a same axle not exhibit the same wear patterns



1.0 RCA for the Issue

JBA approach to the commencement of the failure sequence and forces on the hub

About the unscrewing of the nut

- The axial force on the small bearing inner race seat will promote microscopic fretting movements (‘Partial slip’) on the seat/bearing interface.
- The small bearing can rotate on the spindle after losing the fit on the spindle, but without any measurable radial play.
- Once this rotation is happening, the nut can unscrew because the rotation has not yet worn the bearing abutments enough to relax the preload in the spindle and eliminate the necessary pressure required to unscrew the nut.

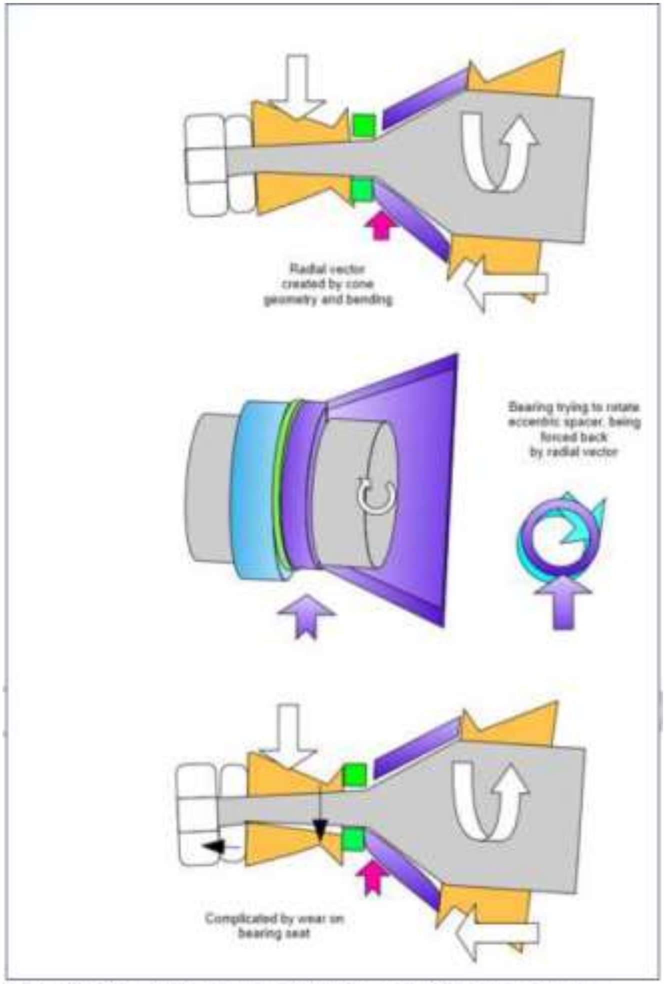


Figure 88 - Mechanism for rotational force and fretting on spacer.

1.0 RCA for the Issue

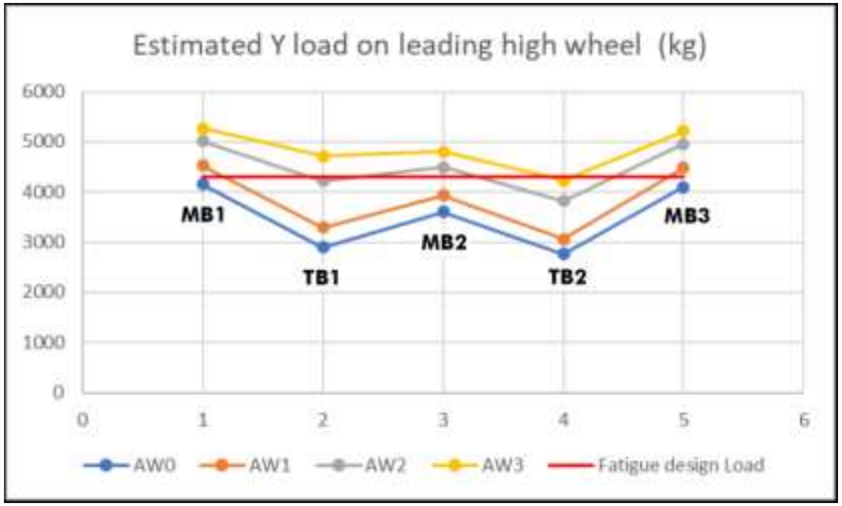
JBA comments about the Infrastructure

- In summary, the Ottawa Confederation Line has no unique features and is currently maintained within the applicable standards. These standards are consistent with standards for similar railroads, and nothing peculiar or unique could cause damage to trains using the line.

1.0 RCA for the Issue

Measurement of lateral loads

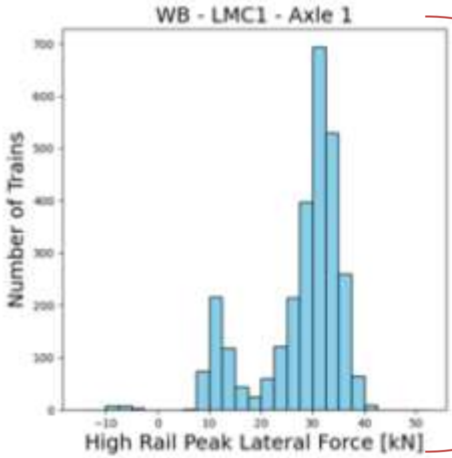
The following graph summarizes the current situation:



- Lateral Loads increase with passenger loading.
- Forces are higher on leading and trailing motor bogies (MB1 & MB3).
- Lateral Loads on trailing bogies (TB1 & TB2), which are not motorized, are below the ‘Fatigue design Load’ in AW2 condition.
- Axial play has occurred on all axles.

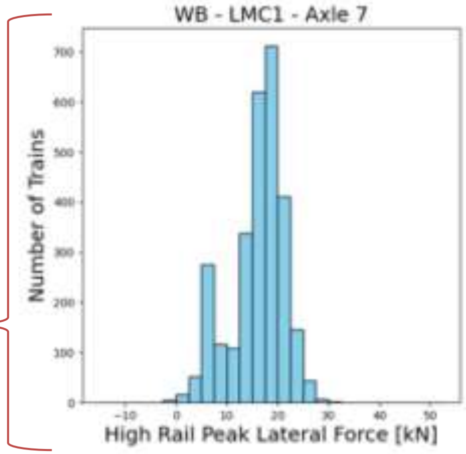
1.0 RCA for the Issue

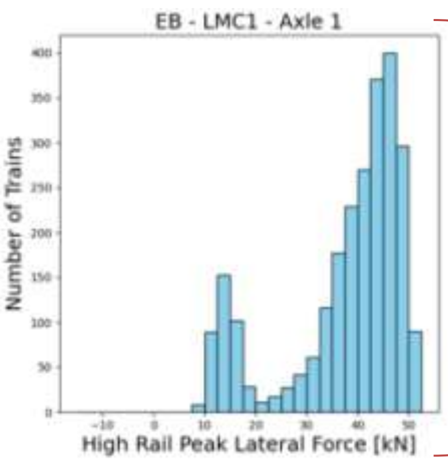
Measurement of lateral loads (NRC track instrumentation project C-280):



WB-280 peak high rail lateral force when LMC1 is the leading unit

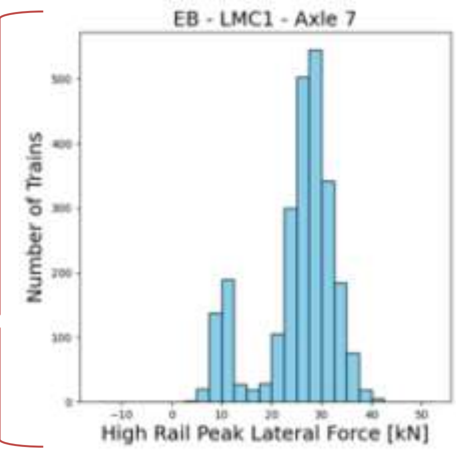
Axle	95th percentile [kN]	Median [kN]	Mean [kN]
1	36.56	30.54	27.69
2	2.33	-4.51	-3.55
3	26.51	20.51	19.26
4	4.39	-1.44	-0.67
5	28.11	22.45	20.7
6	3.04	-2.83	-2.25
7	23.17	17.13	16.06
8	6.35	1.97	2.01
9	32.77	25.97	23.51
10	4.22	-3.28	-2.4





EB-280 peak high rail lateral force when LMC1 is the leading unit

Axle	95th percentile [kN]	Median [kN]	Mean [kN]
1	49.71	41.67	37.83
2	6.22	-5.53	-4.13
3	37.72	30.93	28.57
4	4.88	-1.38	-0.46
5	44.25	35.25	33.1
6	5.73	-3.21	-2.34
7	34.38	27.09	25.35
8	5.54	1.27	0.61
9	47.99	39.27	36.16
10	7.73	-4.24	-2.59



2.0 Approach to solving the Issue

Excessive lateral loads

Safety mitigations

- Temporary Speed Restrictions – Under evaluation
- Nut pinning
- Inspection frequency
- CBA replacement based on mileage

Short Term Initiatives

- TOR friction modifier
- RR adjustment
- Ballast retention

Long Term Initiatives

- Vehicle modification
- Wheel-rail Interface optimization to reduce lateral load
- Onboard Monitoring

Alstom – RTG/JBA/NRC technical evaluation

Agreement on failure mode and failure sequence is required to identify the permanent solution

Unrelated improvements recommended by Alstom

- Harder rail
- RR extension

2.0 Approach to solve the Issue

Alstom Investigation

Evaluate the 'gaps' & reach technical agreement on failure modes/sequence

Independent Validation

Mitigation actions.

Alstom preliminary analysis on:

- ❑ CBA reinforcement
- ❑ Axle redesign

Other initiatives to be considered:

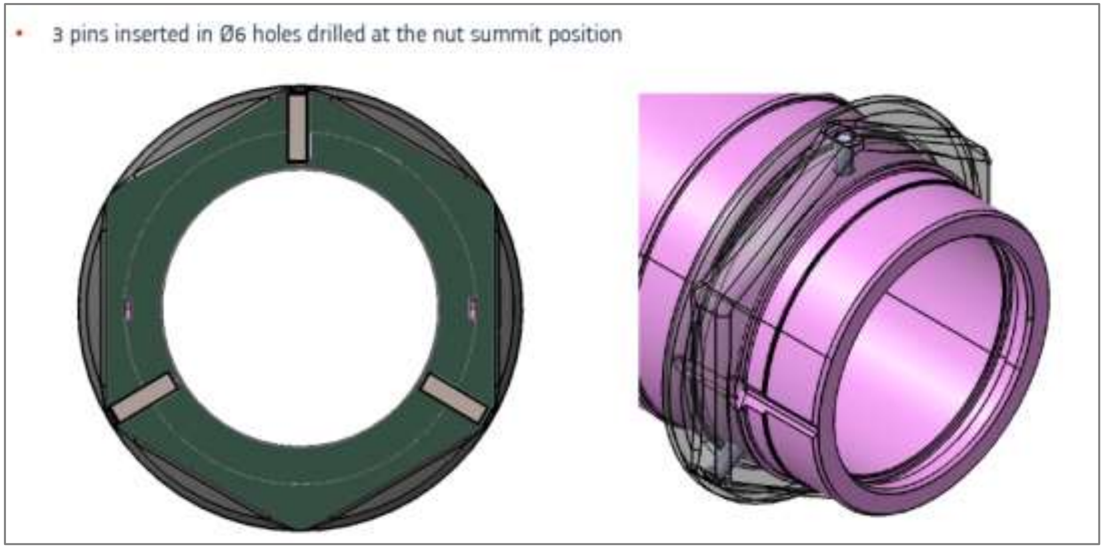
- ❑ Bogie Yaw damper
- ❑ Track gauge - angle of attack
- ❑ Wheel profile / wheel hardness
- ❑ Bogie dynamic

Two complementary paths:

1) Reduction of lateral loads
2) Improve of Vehicle resiliency to lateral loads

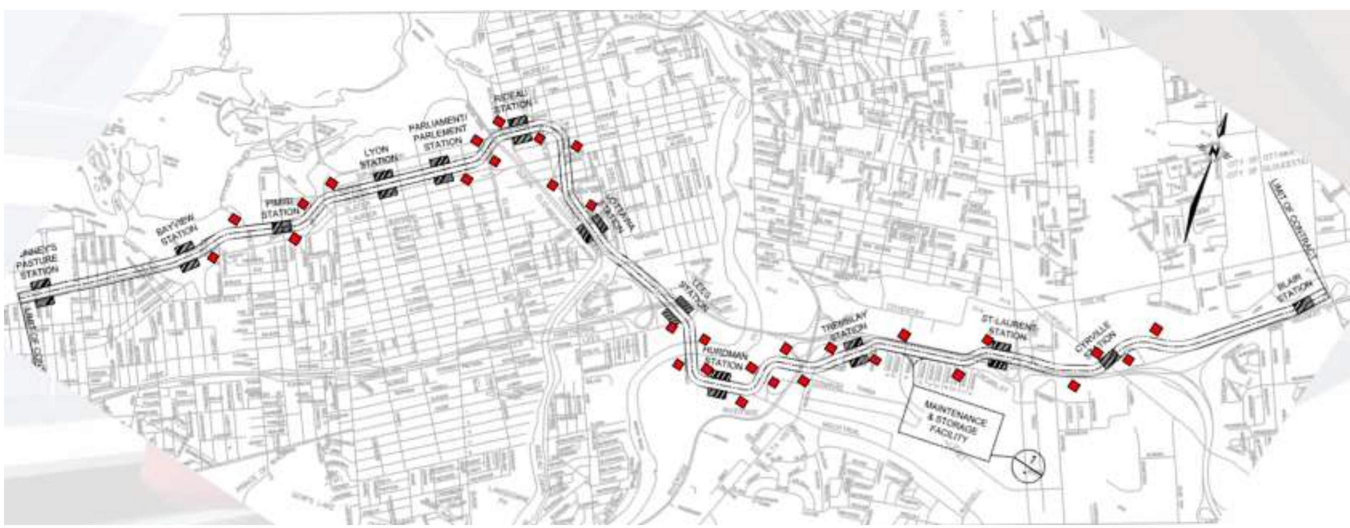
3.1 Containment by nut pinning

- The Nut unscrewing is the failure mode that can have a catastrophic impact
- In August 2023, the Nut pinning was proposed as an additional containment measure
- After analysis and testing, the modification was approved for deployment in the fleet in January 2024
- Full fleet deployment will allow changes to the containment plan detailed in the Alstom Safety Note



3.2 Friction Coefficient Management

- RTM is currently implementing a TOR friction modifier System (wayside)
    - 21 units installed above ground and operational
    - 10 units to be installed in the tunnel in the fall of 2024
- Test in progress to validate effectiveness
- In addition to reducing lateral loads, Top-of-Rail lubrication is also expected to reduce:
    - Corrugation growth rate
    - Noise



3.3 Restraining Rail contact

- Adjustment of the Restraining Rail (adjacent to the low rail of tight curves) to avoid contact was identified as a priority last summer
- All curves have been inspected and have had their Restraining Rail adjusted
- RTM is transitioning from a visual to a parametric inspection to ensure compliance with the no contact criteria
  - Monitor the track parameters and confirm stability of the Restraining Rail in high temperature conditions.

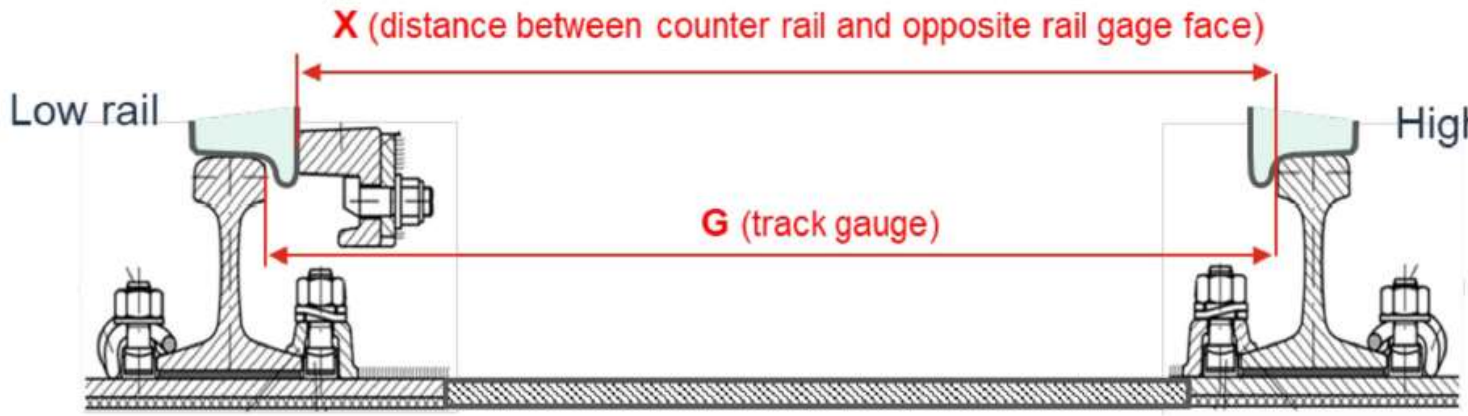


Figure 11 Restraining rail position and X dimension (Alstom)

3.4 Track stability at high temperatures

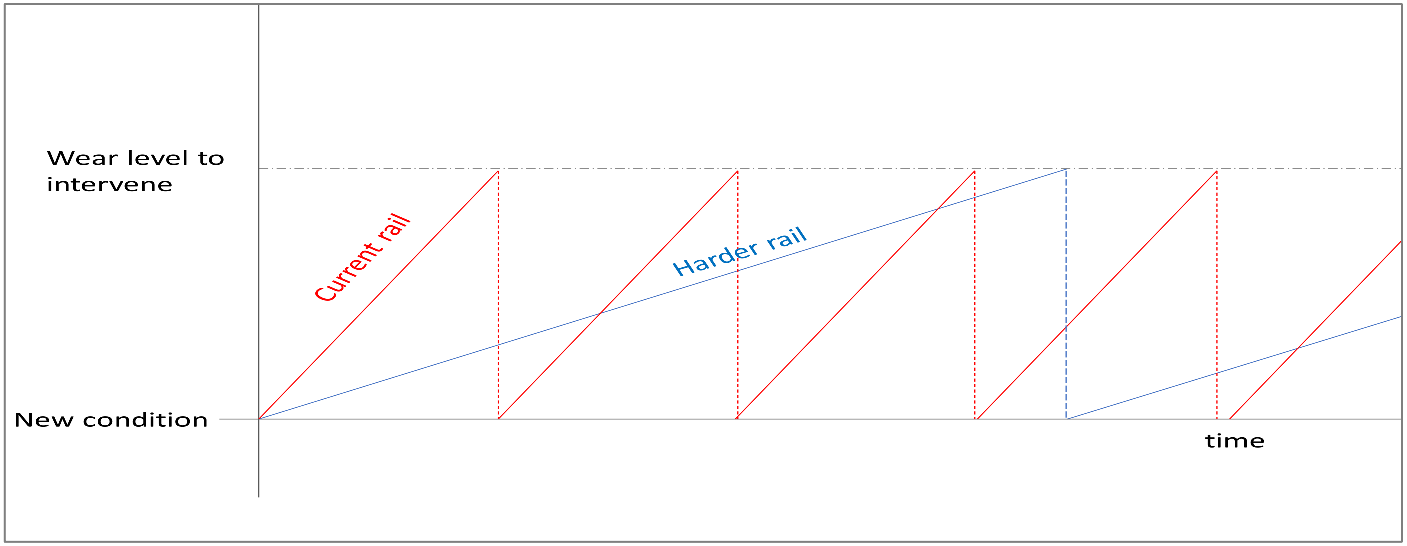
- The Confederation Line infrastructure in at grade areas is mainly ballasted track
- Ballast maintenance is one of the key components to restrain lateral track movement to avoid buckles and kinks.
    - Last campaign in Summer 2021
    - Next campaign is scheduled for Fall 2024
- RTG/RTM have also been analyzing areas where a retention system can help to maintain the stability of the ballast

3.5 Reduction of rail wear and corrugation

Rail wear and corrugation are two concerns raised by Alstom with their recommendation to replace the rail in tight curves with harder rails.

The following considerations apply:

- A harder rail does not avoid corrugation or gauge wear, it only impacts the wear rate
- Flange lubrication is the most effective method to reduce gauge wear in curves
- Top-of-Rail Lubrication will reduce corrugation and rail head wear



3.5 Reduction of rail wear and corrugation

- There is a difference between the wheel and the rail hardness specified in the design of the Confederation Line.
- Harder rail is a legitimate initiative to reduce wear that will be considered when current rail is ready for replacement
  - There is no justification to accelerate the replacement of the existing rail
  - Harder rails come with their own set of challenges such as rolling contact fatigue (RCF), increase of wheel wear, etc.
- There are other avenues to reach a similar outcome
  - A review of the wheel hardness would achieve a similar objective

3.6 Improvements in the Wheel-Rail Interface

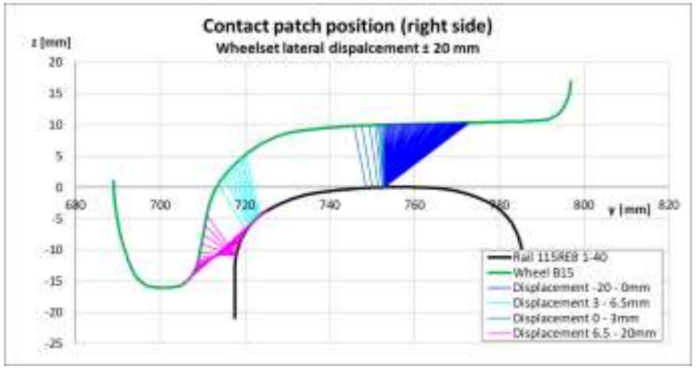
W-R Interface

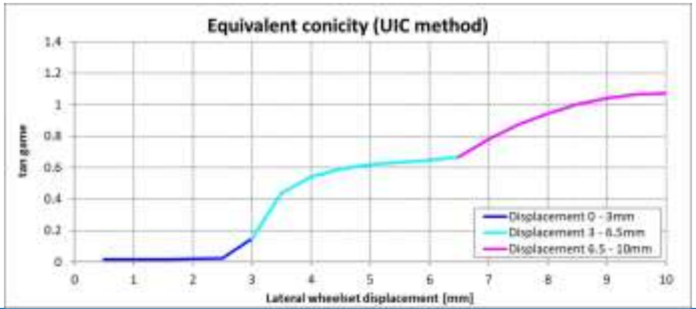
theory → Design

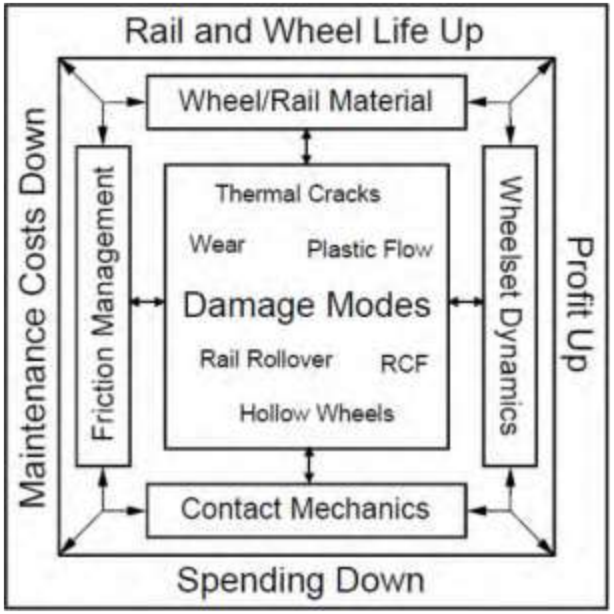
reality → Operations

Simulated profiles

Actual profiles







3.6 Improvements in the Wheel-Rail Interface

Several inputs to consider:

- Rail profiles
- Wheel profile / conicity
- Wheel / Rail hardness
- Track geometry parameters (gauge, cant)
- Track alignment
- Friction management (TOR, flange)
- Rail damage modes (corrugation, RCF, wear patterns, etc)
- Bogie dynamic (stiffness in curve, angle of attack, resilient wheel, etc)
- Weather conditions

Desired outcomes:

- Maintainability improvements (reduction on wear rates, improvements on reliability)
- Maintenance thresholds (grinding and wheel reprofiling criteria, wear limits)
- Cost savings (reduction of interventions)
- Impact on lateral loads

The more parameters to calibrate, the more complex the analysis

4.0 Real time monitoring initiatives

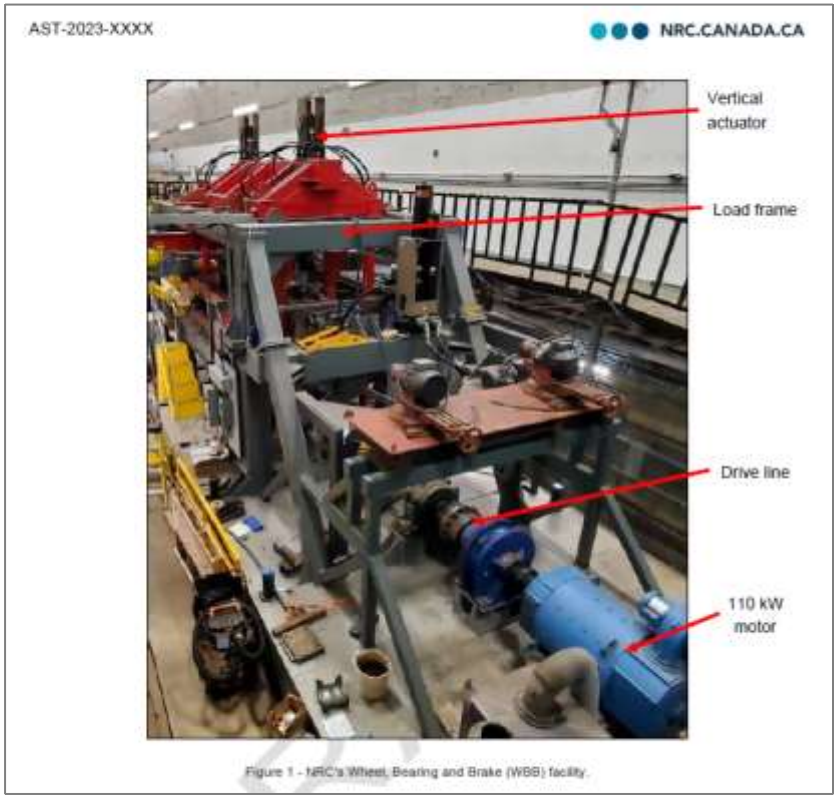
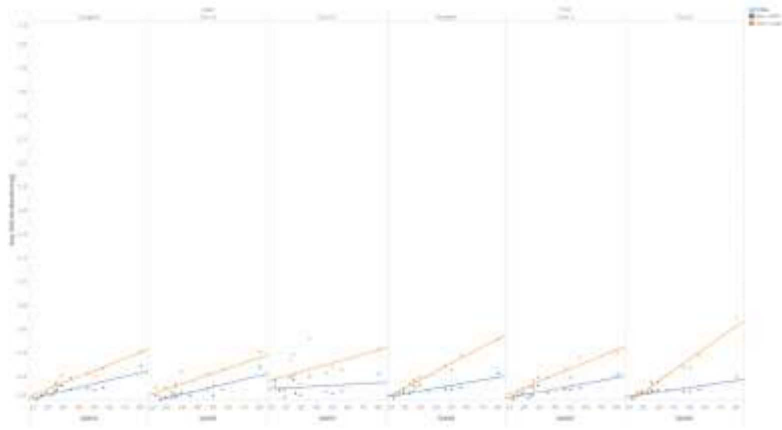


Figure 1 - NRC's Wheel, Bearing and Brake (WBB) facility.

- The configuration of the Ottawa Citadis creates a number of challenges in deploying existing monitoring technologies
- In 2023, we experimented with onboard, battery powered, vibration detection for a 9-month pilot program
  - Test results were inconclusive
- Tests have moved to the NRC facility in Ottawa to create an environment where defective cartridges can be safely tested
- Testing is currently underway

4.0 Real time monitoring initiatives

0.045 in axle play with 0.002in axle play



Lateral, 7,500-10,000Hz

We have been testing axles with different levels of axle play

Preliminary results suggest:

- Vibration patterns, at high frequency, could provide some kind of failure identification.

These results are all preliminary and will require further testing to confirm.

5.0 Next steps

Timeline	Action
May 2024	TOR friction modifier (at grade)
May 2024	Restraining Rail Contact Management Plan
Jun 2024	Workshop on Vehicle modifications
Jun-Jul 2024	Instrumented axle test for TOR evaluation
Oct 2024	Grinding Campaign
Oct 2024	Ballast restoration
Oct-Nov 2024	TOR friction modifier (tunnel)
T.B.D.	Early detection – vibration pattern
T.B.D.	Removal of Temporary Speed Restrictions

Questions?

Thank you for your attention