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February 3, 2023

Wendy Stephanson
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Dear Wendy Stephanson:

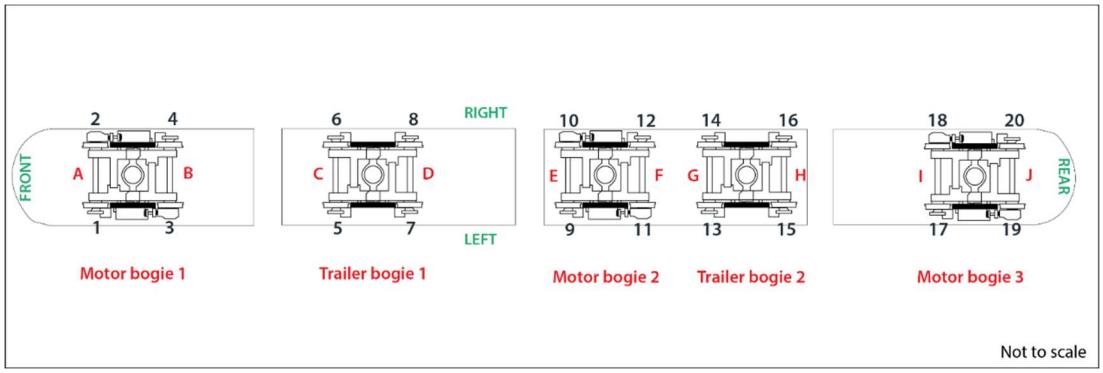
Subject: Rail Transportation Safety Advisory Letter 01/23 (occurrence R22H0037) Ongoing failures of cartridge roller bearing assemblies on Ottawa Light Rail Transit vehicles

On 14 September 2019, Ottawa Light Rail Transit (OLRT) stage 1 commenced operation of its 13-station, 12.5 km-long Confederation Line in Ottawa, Ontario, operating at speeds of up to 90 km/h. The vehicle selected for OLRT operations was the Citadis Spirit light rail vehicle (LRV),[1] mounted on Iponam bogies[2] (Figure 1). The LRV and bogies were newly designed and manufactured by Alstom specifically for the OLRT project. OLRT purchased 34 such LRVs (numbered 1101 to 1134) for stage 1 and usually operates 2 LRVs together as 1 commuter train set.

1 LRV is a North American term for a tram. LRVs are usually operated for systems that transport between 3000 and 10 000 passengers per hour per direction (PPHPD). For comparison, a metro or subway system is a heavier rail system that transports between 10 000 and 50 000+ PPHPD.

2 Bogie is a term commonly used in the industry to describe a commuter passenger LRV truck assembly. The Citadis Spirit bogie named Iponam (Ixège POur North AMerica) is an evolution of the Alstom Ixège classic bogie used for Paris, France, and Istanbul, Turkey, LRV systems.

Figure 1. Light rail vehicle schematic showing bogies, axle locations A–J and wheel positions 1–20 (Source: TSB)

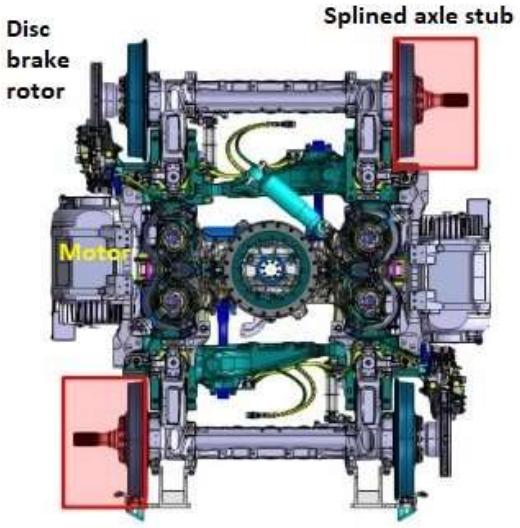


Each bogie is equipped with 4 resilient wheel assemblies and 2 axle assemblies, among other components. Each axle assembly includes 2 wheel hubs and 2 cartridge roller bearing sub-assemblies (cartridge assemblies) connected by a splined axle.

The cartridge assemblies are located inboard of the wheels, and the wheels are secured to the exterior of each wheel hub by bolts to complete the bogie assembly. Each cartridge assembly integrates the splined axle with the wheel assembly, which allows the wheels to turn. The cartridge assembly was designed and manufactured by Texelis in Limoges, France, based on the Alstom specification for the whole axle assembly. It was then shipped to Canada for installation. The components of the cartridge assembly are stacked together and held tightly by a large locking nut (thrust nut). A cartridge assembly is installed on each end of a splined axle stub, secured with bolts. Each cartridge assembly includes 2 tapered roller bearing assemblies, a spacer and an axle hub, among other components. A cartridge assembly has an expected life cycle of 1.2 million km.

Motor bogies have 1 traction motor mounted on each truck side (2 motors in total per bogie). Each traction motor is connected to a drivetrain gearbox that fits onto the splined axle stub to complete the drivetrain. Each wheel set contains a splined axle/gearbox drivetrain on one side and a disc brake on the other side (Figure 2).

Figure 2. Bogie schematic (Source: Alstom, with TSB annotations)



08 August 2021 Ottawa Light Rail Transit light rail vehicle 1119 main-track train derailment

On 08 August 2021, an eastbound OLRT commuter train derailed about 90 m east of Tunney's Pasture Station in Ottawa. It was determined that the No. 3 wheel on LRV 1119 severed from the axle due to an

undetected catastrophic roller bearing failure and subsequent axle journal burn-off. There were no passengers on board at the time of the occurrence (TSB occurrence No. R21H0099).

Following the derailment, the OLRT LRV fleet was removed from service while cartridge assembly axial end play clearance (free play) measurements were completed on the entire fleet (20 per LRV). Measured clearances in excess of 0.1 mm required the cartridge assembly to be replaced with a new assembly, and a new periodic inspection was implemented to measure cartridge assembly free play on all LRVs every 7500 km, on an ongoing basis.

This initial fleet inspection identified 1 destroyed cartridge assembly on LRV 1119 and 17 additional loose cartridge assemblies on 9 other LRVs with measured free play that ranged from 0.12 mm to 0.89 mm.

During the fleet inspection, 3 loose cartridge assemblies were identified on LRV 1121 in the motor bogie 2 (BM2) No. 11 wheel position and in the motor bogie 3 (BM3) No. 17 and No. 19 wheel positions. LRV 1121 was held at the OLRT Belfast Yard Maintenance and Storage Facility (MSF) for repairs where the 3 loose cartridge assemblies were replaced between 08 and 11 September 2021. LRV 1121 was released from the MSF on 13 September 2021 and resumed passenger service on 14 September 2021.

On 27 September 2021, the TSB issued Rail Safety Advisory (RSA) letter 617-02/21[3] related to the cartridge bearing assembly failure that caused the derailment. The RSA suggested that OLRT may wish to ensure that it has heat detection systems in place to monitor temperatures of LRV cartridge roller bearing assemblies in order to detect overheated roller bearings in a timely manner and intervene before an in-service catastrophic failure occurs.

To date, other than ongoing cartridge assembly free play monitoring, no concrete steps have been taken to resolve the safety deficiency identified in the RSA.

19 September 2021 Ottawa Light Rail Transit light rail vehicle 1121 main-track train derailment

On 19 September 2021, westbound OLRT commuter train 1121-1138 was proceeding on track 1 when the BM2 on the trailing LRV 1121 derailed near the mid-point of the north platform of Tremblay Station as it departed the station. The train continued in the derailed condition for about 1400 feet, over the rail bridge that traverses Riverside Drive, then went into emergency and came to a stop just west of the rail bridge. The 12 passengers and 1 operator on board at the time were evacuated once it was safe to do so. There were no injuries (TSB occurrence No. R21H0121).

[3] TSB Rail Safety Advisory 617-02/21, “Roller bearing failure resulting in derailment of Ottawa Light Rail Transit vehicle” (issued 27 September 2021).

On 02 November 2021, the TSB issued RSA letter 617-03/21,[4] which identified that the bolts securing the splined axle stub to the BM2 No. 11 wheel hub of LRV 1121 were not adequately torqued during refurbishment. LRV 1121 was then allowed to enter service without a complete set of torque data or any verification that all work was complete. The lack of applied torque led to the failure of all 12 retaining bolts after only about 800 km of service. Once the bolts failed, the drivetrain gearbox disconnected from wheel position No. 11. The disconnected gearbox dropped from the LRV and contacted the track infrastructure, causing the derailment.

In this case, LRV 1121 was repaired and released from a shop only to have a safety-critical component fail and cause a serious accident within 5 days of its release. The accident demonstrated that there can be serious consequences resulting from the inconsistent and incomplete maintenance of safety-critical components on an LRV. The RSA suggested that OLRT may wish to conduct an in-depth review of all work performed on safety-critical components to confirm that procedures are followed and that there is sufficient oversight in place to prevent a similar occurrence from happening again. Since the RSA was issued, steps have been taken to improve maintenance procedures and oversight for work performed at the MSF on OLRT LRVs.

21 July 2022 Ottawa Light Rail Transit light rail vehicle 1127 axle hub failure

On 21 July 2022, an OLRT driver reported that LRV 1127 experienced an unusual vibration while in operation. LRV 1127 was subsequently removed from service and taken to the MSF for inspection (TSB occurrence No. R22H0037).

On 23 July 2022, while inspecting all 20 of the LRV cartridge assemblies for free play, the assembly on the disc brake of axle 1 on BM1 (wheel position 1) displayed 10 times the maximum limit of free play. The assembly was removed, and further examination identified that the axle hub was damaged so severely that catastrophic failure was likely to occur had it remained in service (Figure 3).

Subsequently, 3 cartridge assemblies were sent to the TSB Engineering Laboratory for detailed examination (Table 1).

Figure 3. Light rail vehicle 1127 failed axle hub (Source: TSB)

[4] TSB Rail Safety Advisory 617-03/21, "Work procedures for Ottawa Light Rail Transit vehicle maintenance" (issued 02 November 2021).

Table 1. List of 3 cartridge assemblies subjected to TSB examination

LRV	Axle	Wheel position	Side	Cumulative mileage (km)	Date of previous inspection	Mileage since last inspection (km)
1127	A	1	Disc brake (failed)	197 967	08 July 2022	4493
1127	A	2	Motor	197 967	08 July 2022	4493
1131	B	3	Motor	240 597	03 August 2022	3201

TSB examination of 3 cartridge assemblies

The failed axle hub from LRV 1127 was examined at the TSB laboratory under both optical and scanning electron (SEM) microscopes. Under SEM examination, the fracture surfaces exhibited indications of beach marks, which are synonymous with classic fatigue failures. The fracture initiation point was identified at the chamfered end of the axle hub.

The inner roller bearing cone raceway of the large cone assembly was fractured. The fracture was an instantaneous overstress fracture and was not caused by fatigue. The raceway fracture surfaces displayed the presence of oxidation, which suggests that the raceway fracture was present for some time prior to the axle hub failure. The cone raceway exhibited some spalling, which most likely occurred as a result of the fracture.

During the cartridge assembly examinations, areas of heat discolouration were observed on several components, and the condition of some grease samples suggested that the assemblies had been subjected to a higher-than-average heat event, likely related to a deteriorating cartridge assembly condition.

In summary, the 3 cartridge assemblies examined by the TSB exhibited numerous failure modes. The modes included fatigue fractures, rolling contact fatigue, surface wear, impact wear, environmental erosion, and frictional wear. The observed damage was widely spread throughout the cartridge assemblies and was not limited to any one particular component. Consequently, it was not possible to determine which of the observed failure mechanisms occurred first. However, based on the observations made, the following can be stated:

1. The materials used in the manufacture of the components conformed with the manufacturer’s engineering drawings and/or specifications.
2. There was clear evidence of fatigue failure in the hub, brittle overstress failure in the large bearing inner raceway and spacer, and spalling on the bearing raceway of the LRV 1127 axle A wheel position 1 failed cartridge assembly.
3. When free play develops in Texelis cartridge assemblies, significant damage to the internal parts can result in roller bearing burn-off and derailment.
4. Cartridge assembly failures are more prominent in motor bogie assemblies.
5. Accumulated mileages at the time of removal from service are well below industry standards for cartridge assemblies.

Since the LRV 1127 axle A disc brake side cartridge assembly axle hub failed within an interval shorter than 7500 km (4393 km) from the previous inspection, on 29 July 2022, Alstom revised the cartridge assembly free play inspection intervals for OLRT LRVs as follows:

- The 7500 km inspection interval to be maintained on all axles with cumulative mileage below 175 000 km.
- Axles for the 3 middle LRV bogies to be inspected every 3750 km when mileage exceeds 175 000 km.
- Axles for motor bogie at each end of the LRV are to be replaced when cumulative mileage exceeds 175 000 km.

Since OLRT LRVs have no on-board automated cartridge assembly heat detection system, the free play inspections continue to be necessary. However, this additional maintenance task is labour intensive and time consuming for a component that should last over 1.2 million km.

Analysis of cartridge assembly periodic inspection results

Following the LRV 1119 derailment on 08 August 2021, Alstom implemented a new periodic inspection to measure and record cartridge assembly free play on all LRVs every 7500 km, on an ongoing basis. The TSB examined the data recorded for these inspections for the period of 08 August 2021 to 11 August 2022. A total of over 11 000 individual free play measurements were completed and the following observations were made:

- A total of 68 cartridge assemblies had free play in excess of the 0.004-inch (0.1 mm) condemning limit with measurements ranging from 0.005 inches (0.12 mm) to 0.035 inches (0.89 mm). This resulted in the replacement of 68 axles and 136 cartridge assemblies.
- Of the 68 failed cartridge assemblies, 63 were observed to have come from motor bogies, while only 5 were from trailer bogies.
    - Of the 63 motor bogie cartridge assembly failures, 57% (36/63) occurred on the drivetrain motor side and 43% (27/63) occurred on the disc brake side.
- At the time of replacement, the cartridge assemblies had accumulated between 64 140 km and 233 042 km in service, with the average mileage at replacement equal to 140 219 km.

Development of the Alstom Citadis Spirit light rail vehicle for Ottawa Light Rail Transit

Alstom is a leading manufacturer of commuter LRVs and has successfully rolled out designs for other light rail transit (LRT) commuter rail projects throughout the world such as Istanbul, Turkey (Citadis X01), and Paris, France (Citadis Dualis), to name a few. These are both established LRV platforms that have had few reported reliability issues.

In contrast, the Alstom Citadis Spirit LRV built for OLRT has had numerous reliability issues and experienced 2 serious main-track derailments since it commenced operation. All 3 of the Alstom LRV designs are equipped with the same cartridge assembly. Table 2 provides a brief comparison of some of the differences between the 3 Alstom LRV designs.

Table 2. Differences between 3 Alstom light rail vehicle designs

Item	Istanbul (Citadis X01)	Paris (Citadis Dualis)	Ottawa (Citadis Spirit)
No. of axles	6	10	10
No. of motor bogies	2	3	3
No. of trailer bogies	1	2	2
LRV length	28 m	42 m	48 m
LRV empty weight	42 tons	77 tons	81 tons
LRV loaded weight	57 tons	99 tons	113 tons
Bogie type	Ixège	Ixège	Iponam
Bogie frame	Rigid	Rigid	Articulated
Suspension	Rubber	Rubber	Steel spring and air cushion
Motor	Permanent magnet motor (PMM)*	PMM	Induction**

* A permanent magnet motor (PMM) is a synchronous speed electric motor that rotates at constant speed (rpm) and has a uniform torque.

** An induction motor is an asynchronous speed electric motor that can produce more power and has higher torque at lower rpms than a PMM. Multiple stop-starts using induction motors can introduce higher stress and torque fluctuations on the drivetrain elements.

In January 2012, Alstom presented a proposal for the OLRT project that corresponded to the City of Ottawa's original technical specification at the time. The proposed concept was a 29 m-long LRV that was closely derived from the Paris Citadis Dualis. Alstom's initial bid did not meet the City of Ottawa's requirements, and Alstom was disqualified from the process.

Shortly thereafter, the City of Ottawa changed the requirements and now required LRVs that could transport up to 24 000 PPHPD at speeds of up to 100 km/h, a service that was more typical of a higher-capacity subway system. Subsequently, the Rideau Transit Group (RTG) approached Alstom to provide LRVs for the project. Alstom indicated to RTG that the trains they wanted did not yet exist but could be developed. This led to the development of the longer, heavier, and faster Citadis Spirit LRV platform in conjunction with the new Iponam motor bogies equipped with induction motors, which were similar to those used for the New York subway system.

The induction motor used for the Citadis Spirit produces more torque and accelerates quicker than the PMMs used for the Istanbul and Paris LRVs. With an original operating speed of 90 km/h and 13 stations over the 12.5 km-long OLRT Confederation Line,

frequent starts and stops could potentially introduce accelerated wear to motor bogie drive and brake components. This observation is consistent with the TSB analysis of cartridge assembly inspections, which identified that most of the 68 cartridge assembly failures occurred in motor bogies (63); 57% (36/63) on the drivetrain motor side and 43% (27/63) on the disc brake side.

To date, there have been 2 serious main-track derailments and a near catastrophic component failure that all involve OLRT LRV cartridge assemblies. While the materials used to manufacture the cartridge assemblies conformed to the manufacturer's specifications, the 3 cartridge assemblies examined by the TSB exhibited numerous failure modes. The observed damage was widely spread throughout the assemblies and was not limited to any one particular component. Furthermore, areas of heat discolouration observed on several components and the condition of some grease samples suggested that the assemblies had been subjected to a higher-than-average heat event that was likely related to a deteriorating cartridge assembly condition that went undetected.

In the cases cited, the root cause of the cartridge assembly failures cannot be attributed to a single component. It is likely that the combination of the newly designed LRV, new Iponam bogies, and a more powerful drivetrain may play a role in the failure of cartridge assemblies.

These cartridge assembly failures continue to pose a risk to safety until the issues are resolved. Therefore, the City of Ottawa may wish to ensure that all parties involved in the OLRT undertaking work together to resolve design, operational, and maintenance risks to safety, as they emerge. Furthermore, the parties involved should ensure that effective on-board monitoring systems for safety-critical LRV components, such as cartridge roller bearing assemblies, are put in place to protect the travelling public.

The TSB would appreciate being informed of what action, if any, will be taken in this regard.

Yours sincerely,

Vincenzo De Angelis

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