# Main Features of Cleveland's LRV

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When the Greater Cleveland Regional Transit Authority (GCRTA) issued its invitation to bid on light rail vehicles (LRVs), Breda Costruzioni Ferroviarie (BCF) submitted a bid. The LRV technical specifications were flexible in that they did not impose any specific type of car nor did they impose a precise number of vehicles; instead the specifications called for 4,000 passenger seats to be supplied within certain weight and dimensional limits. Breda offered 48 vehicles with 84 seats each for a total of 4,032 seats and won the contract.

## TECHNICAL DESCRIPTION

The cars consist of two half bodies joined by an articulation section with three trucks. The two end trucks are powered, and the central truck under the articulation section is trailed.

The dimensional, functional, and structural requirements guided the designers in producing a car with simple lines and an almost total lack of curved surfaces.

The car is slightly more than 24 m (79 ft 10 in.) long, is rated AW2 (84 seated passengers and 40 standees), and can travel at a maximum speed of 90 km/hr (55 mph). This speed can be reached in less than 35 sec from a standing start.

The main technical features of the vehicle are summarized in the following table:

| Feature | Measurement |
|---|---|
| Overall length | 79 ft 10 13/16 in. |
| Gauge | 4 ft 8 1/2 in. |
| Width | 9 ft 2 15/16 in. |
| Car body length | 77 ft 1 11/32 in. |
| Tare weight | 84,000 lb |
| Seats | 84 |
| Seats and standees | 270 |
| Line voltage | 600 V |
| Maximum speed | 55 mph |
| Hourly rating | 2 x 245 kw |
| Acceleration | 3 mph per second |
| Service braking | 4 mph per second |
| Emergency braking | 6 mph per second |

The LRV is bidirectional with an operator's cab at either end and three doors per side. The passenger door near the operator's cab is arranged to allow the operator to control fare collection. The 84 seats are arranged in compliance with the specification requirements. Half the seats face one direction and half the other. Each end of the car is equipped with an anticlimber device and an automatic coupler with mechanical, electrical, and pneumatic functions so that the cars can operate in trains of up to four vehicles. The couplers were built by the Ohio Brass Company.

The car frame, sides, and external sheathing are made of stainless and semistainless steel. The sides, floors, and steps are made of stainless steel, and the rest of the car is made of Corten-semistainless.

The underframe has two central members that can transfer car loads to the truck support and distribute longitudinal loads to the surrounding parts of the structure. The two side sills made of bent sheeting and a series of extruded beams and two end structures provide support for the coupler and anticlimber on one end and for the articulation section on the other. The underframe can be considered "classic" except that its height is limited to allow space for underfloor equipment.

A reticular frame made it possible to arrange the sturdy sections of the structure so as to obtain the most uniform distribution of stresses possible and thus, at a parity of strength, an optimal use of the properties of the materials and a considerable weight savings.

The roof is made of a series of carlines and covered with longitudinally corrugated sheeting.

The entire structure is welded. Critical portions of the car body were built and subjected to strenuous fatigue tests before assembly of the vehicles. The end of the car body is a structure with differential strength that makes it possible for it to absorb the kinetic energy caused by impact against fixed obstacles at speeds of up to 15 km/hr with controlled deformation of the car body up to a depth of 600 mm.

The trucks were designed to guarantee a functionally valid product and to ensure reliable stress resistance. Finite element calculations were used for the study of stresses, and the results of the calculations were verified by fatigue tests on the completed truck frame (at the University of Pisa) and on the bolster beam (at the University of Milan).

The motor and trailer trucks are practically identical: they have an H-frame and two levels of vertical suspension and one level of transverse suspension. The primary suspension consists of helical springs and is controlled by four hydraulic shock absorbers. The transverse and longitudinal loads are transmitted to the journal bearings by an articulated connecting arm on a silent block.

The secondary suspension consists of air springs that also assure the transverse suspension of the car.

The car is attached to the truck by a swing bolster beam, a ball bearing center plate, and two longitudinal connecting rods.

The suspension system and construction techniques along with the resilient wheels by SAB guarantee ride comfort and low noise levels both inside and outside the car. This was confirmed by the ride quality test performed with the cooperation of specialists from the Italian State Railways. The average vertical and transverse accelerations measured during maximum speed operation on a straight track and on 100-m-radius curves were lower than 0.4 m per second.

The monomotor trucks on either end have Hurth-type hollow shaft transmission bridges built by SPAR of Canada. Motion is transmitted to the axles by a BBC elastic joint. Thus the motor is completely suspended. The trucks are equipped with disc brakes on each axle and with track brakes.

The interior lining and finish of the cars were the subject of special attention because they must satisfy the riding public. A full-scale mock-up, which also included the operator's cab, was built so that many solutions could be tried before final decisions were made. The interior linings were designed and manufactured with materials and methods that, in addition to comfort, provide passengers with a high level of safety. The shock-resistant seats are comfortably padded. The wall panels are made of plastic laminate with low flame propagation characteristics. Plymetal (plywood sandwiched between two layers of stainless steel) floors are covered with self-extinguishing neoprene rubber. The fixed, athermic windows are made of self-extinguishing polycarbonate.

Wide doors, ample aisles, and the configuration of the central articulation section guarantee safe and easy passenger movement. The doors are equipped with sensitized edges and are controlled by an electronic device completely designed and built by BCF.

Comfort for passengers and operators is further guaranteed by an air comfort system that provides cooling and heating to maintain comfortable ambient temperatures under the rigorous outdoor climate of Cleveland that reaches the extremes of a summertime temperature of 111°F and a winter temperature of -20°F. The air comfort system, built by the Stone Safety Corporation of Connecticut, can supply 3,620 $ft^3$ per minute during the summer and 95,000 Btu per hour in the winter with the aid of floor heaters.

Both propulsion equipment and low voltage circuits, supplied by BBC, are fed by DC-DC static converters. The full chopper traction equipment provides two choppers for each motor, each of which works at a constant frequency of 440 Hz.

The traction circuit has the capacity of automatically weakening the field without the intervention of electromechanical components. The full chopper also makes it possible to achieve regenerative braking simply and efficiently without any need for special auxiliary equipment. Continuous line voltage information fed into the system makes it possible to switch to resistive braking when the line is partially or totally nonreceptive, thus guaranteeing continuity of electric braking with maximum energy recovery.

The electrical equipment is located in a single housing that facilitates ventilation of the static components, reduces wiring, facilitates maintenance, and practically eliminates electromagnetic interference to and from the chopper.

The two traction motors are of the series type without compensating windings. They are completely laminated and cooled with forced air.

The auxiliary systems power supply is provided by a static converter that is able to supply 37.5 V DC with maximum current of 200 A at input voltages that vary from 450 to 750 V. Both the traction circuits and the auxiliary circuits are protected by a main line circuit breaker manufactured by BBC.

The pneumatic brakes and compressed air systems are produced by Westinghouse Air Brake Division, who worked with WABCO, Italy, in the design and construction of the pneumatic actuators that command the brake discs on the trucks. The pneumatic braking system is capable of completely replacing the electric brakes in case of failure and can guarantee the same braking rates.

The pneumatic brake controls are electrically activated. The operator can release a braking command for a given entity. This signal is modulated by other signals in proportion to the weight of the car and in relation to the presence or absence of electric braking and of slip-slide so that the signal reaches the pneumatic brake control and is transformed into the appropriate braking force. Under normal conditions and at speeds exceeding 3 km/hr, the pneumatic brake does not go into action because the electric brakes are sufficient. The two braking systems can be continuously and fully blended.

WABCO supplies the track brakes for both the motor and the trailer trucks. Safety is enhanced by a dead-man device and the on-board cab signaling system that is capable of providing automatic overspeed protection on the basis of the different top speeds allowed by track conditions. The device is completely static with the exception of the vital relay interface components and is designed to be fail safe. The cab signal system was supplied by WABCO Union Switch & Signal with the cooperation of Westinghouse, Italy.

The layout of the underfloor and in-car equipment was prepared on a full-scale mock-up that provided complete and detailed answers to the difficult problems posed by this type of car and equipment.

High and low voltage wiring is enclosed in steel sheaths. The ground return circuit does not provide for any on-car ground points. All of this was developed to avoid electromagnetic interference, which is extremely important because the wayside signaling system works at a frequency of 4500 Hz.

The commands and controls on the car are simply designed and almost completely automatic so that the motormen can operate the cars with ease.

The operator's cab, completely separated from the passenger section, is particularly comfortable and is equipped with all the instruments needed for total command of the car. The air comfort system inside the cab is independently controlled. High visibility makes the operator's job easier and increases car safety.

A communication system allows the operator to make announcements to the passengers, and a two-way train-to-wayside system permits the operator to communicate with the control centers and allows passengers to hear announcements directly from the control center.

The following table gives car performance levels:

| Parameter | Performance Level |
|---|---|
| Starting acceleration with normal load (103,000 lb) and line voltage ranging from 475 to 750 V | 3.13 mph per second |
| Time required to cover 600 ft under normal load conditions | 19.8 sec |
| Time required to reach speed of 50 mph under normal conditions | 26 sec |
| Maximum service braking at 55 mph with normal load and electric and pneumatic braking | 3.51 mph per second |

| Parameter | Performance Level |
|---|---|
| Emergency pneumatic braking at 55 mph at maximum load | 3.83 mph per second |
| Emergency braking at 55 mph with pneumatic and track brakes | 6.34 mph per second |

All of these performance levels were obtained using new wheels, although they had been conceived for wheels subject to average wear; this gives even further validity to the performance levels.

The quality of the truck has been confirmed by the ride quality tests. The following values were recorded at maximum speed on a straight line and on curves of 1000 m (in mph per second):

| | |
|---|---|
| Vertical acceleration | 0.9 |
| Latitudinal acceleration | 0.78 |
| Longitudinal acceleration | 0.34 |

Measured at slightly more than 49 ft from the vehicle running at a speed of 40 mph, the noise level was less than 78 dB(A).

Table 1 gives a comparison of the Breda LRVs used in Cleveland and five other vehicles.

## WORKING RELATIONSHIP

From the preceding technical description of the Cleveland light rail vehicle a number of useful conclusions can be drawn about how to design and build a modern LRV.

First, a good working relationship between the authority and the car builder is important. This relationship is necessary in order to precisely define the true needs of the authority and its riding public, keeping in mind project feasibility and costs.

The approach Breda and GCRTA took during the design phase of the project centered on this relationship and produced a vehicle that completely satisfied the car builder and, given the high level of ridership, continues to satisfy the authority.

On the part of GCRTA there was a constant effort to monitor the needs of its riders and to project future ridership estimates in order to be able to provide effective service in the years to come and consequently to reduce the life-cycle costs of the vehicles.

Breda provided full engineering and design support by constantly offering alternative solutions that took both engineering and cost control considerations into account. Car reliability and passenger safety were always of paramount importance.

It was within this type of working arrangement that the general vehicle dimensions were established; that mock-ups were built of the car interior, exterior, underframe, and articulation section; and that an entire series of preliminary tests was conducted to identify components.

During the preliminary study a vehicle was designed that, because of its spacious interior, number of doors per side, acceleration, high speed performance, and level of passenger comfort, has permitted the authority to reduce the number of cars in its fleet (with resulting reduced capital expenditures) and to provide the greater Cleveland area with both urban and commuter-like service.

The immediate result of procuring such a versatile vehicle is a reduction not only of capital expenditures but of operating costs as well.

It should be noted that the very size of the vehicle, which has proven so beneficial in Cleveland, has penalized the design in other procurements and excluded it from prequalification. In those instances, one of the advantages of the Cleveland LRV, its high passenger capacity, became a disadvantage.

The only other problem with the vehicle became evident when it started service in October 1981. The air filter of the chopper ventilation system was vulnerable to powdery snow. The problem, however, was resolved thanks to the working relationship between Breda's and GCRTA's engineering and operating staff. This provides yet another example of how important it is to establish such a relationship between the authority and the car builder.

Utmost attention was given to containing costs during the entire design phase of the project. Attention was given not only to versatility of design

**TABLE 1 Technical Comparison of the Breda and Other Vehicles**

| | PCC | GCRTA Breda | San Diego Duewag | Portland Bombardier | WMATA Breda | Naples Circumvesuviana |
|---|---|---|---|---|---|---|
| Body length (ft) | 47 | 77 | 75.62 | 86.9 | 74 | 129.7 |
| Width (ft) | 8.33 | 9.25 | 8.75 | 8.75 | 10.1 | 8.85 |
| Weight (lb) | 39,360 | 84,000 | 72,000 | 92,000 | 80,000 | 123,500 |
| Cars in consist (minimum) | Not applicable | [1] ÷ 4 | | | [2] ÷ 8 | [1] ÷ 3 |
| Car body type | Nonarticulated | Articulated | Articulated | Articulated | Nonarticulated | Double articulated |
| Car body material | Steel | SST/Corten | Steel | Steel | Aluminum | Steel/aluminum[a] |
| HVAC | No | Yes | Yes (no heating) | Heating only | Yes | Ventilation only |
| Doors and sides | 2 | 3 | 4 | 4 | 3 | 4 |
| Driver's cab | 2 | 2 | 2 | 2 | 1 | 2 |
| Seats | 49 | 84 | 64 | 76 | 68 | 124 |
| Total capacity | 118 | 218[b] | 188 | 211 | 250[b] | 334[b] |
| Propulsion | | | | | | |
| Line voltage (V DC) | 600 | 600 | 600 | 750 | 700 | 1500 |
| Power (kw) | 164 | 490[c] | 300[c] | 420[c] | 635[c] | 700 |
| Motors/truck | 2 | 1[d] | 1[d] | 1[d] | 2 | 1[d] |
| Regenerative braking | No | Yes | | No | Yes | No |
| Maximum speed (mph) | 40 | 55 | 50 | 55 | 75 | 55 |
| Acceleration (mph per sec) | 3 | 3 | 3 | 3 | 3 | 2.25 |
| Indices | | | | | | |
| kw/passenger | 1.39 | 2.25 | 1.60 | 2 | 2.54 | 2.1 |
| Weight/passenger (lb/passenger) | 334 | 385 | 383 | 436 | 320 | 370 |
| Power/weight (w/lb) | 4 | 5.8 | 4.2 | 4.56 | 7.9 | 5.7 |

[a] Sheeting and roof.
[b] Five standees per square meter.
[c] Hourly rating.
[d] Two out of three are truck powered.

but to reliability of parts and materials as well. Furthermore, care was taken in selecting modular components to ensure interchangeability. Preference was always given to those solutions that allowed maintenance to be the least complicated and the least expensive possible.

## CONCLUSIONS

Passengers appreciate the Cleveland LRV for its high level of comfort (low noise level, efficient lighting, effective public address system, wide cushioned seats, ample center aisle, wide passenger doors, and efficient air conditioning system).

The public also appreciates the LRV's modern exterior design, for the balance of colors, for the image of efficiency that it projects, and for the status it gives to the area it serves.

The transit authority is satisfied with the LRV because of its reliability, its ease of maintainability and operation, and the sense of safety it offers operators.

Elected officials can be proud of the LRV's versatility, its provisions for passenger and traffic safety, its excellent performance, and the measures taken to reduce energy consumption and to recuperate lost energy through regenerative braking.

As a result it can be concluded that the basic objectives were fully reached and that the vehicle as built can be considered one of the most modern and efficient means of mass transit in service today.