Effects of experimental bogie fairings on the aerodynamic drag of the ETR 500 high speed train

*Giampaolo Mancini, Antonio Malfatti, Angelo G. Violi, +Gerd Matschke

*FS – Trenitalia – Unità Tecnologie Materiale Rotabile
Sperimentazione – Viale S. Lavagnini 58 – 50129 Firenze – Italy
E-mail: mancini@asamrt.interbusiness.it

+DB AG – Forschungs- und Technologiezentrum
Völcherstr. 5 – D-80939 – München – Germany

Summary
A research project is presented in which the effects of bogie fairings on the aerodynamic drag have been investigated with reduced and full-scale tests carried out on the new ETR 500 high speed train at speeds up to 300 km/h.

Abstract
The well streamlined design of the last generation European high speed trains has already taken in account the necessity to minimise drag. A further development to reduce drag for such trains is to cover the bogie areas with smooth and streamlined surfaces. To quantify the aerodynamic effects of bogie fairings on drag a research project joining DB, SNCF and FS, with the co-operation of the train manufacturer Ansaldobreda, has been undertaken on the new multi-voltage ETR 500 high speed train.

The research programme has included both wind tunnel tests and full-scale tests. Reduced scale tests were performed by a 1:7.5 model of ETR 500 with a locomotive and two trailers. Measurements carried out on the first trailer without fairing and with different fairing geometries have shown that optimised fairings can decrease drag of about 20% while retrofittable fairings allow a reduction higher than 10%.

After this results FS ordered to Ansaldobreda the design and the construction of a complete set of bogie fairings to be assembled on all the bogies of the ETR 500. The effects of the bogie fairings were tested in 95 test runs undertaken by FS and DB in October 2000 on the high speed line linking Roma to Firenze. Full-scale tests were carried out on an ETR 500 normally used in operations, made of 2 locomotives and 8 trailer cars, both with and without bogie fairings. A reduced configuration with only 3 cars was also tested in order to investigate the effects of train length on drag. Drag measurements, undertaken by the coasting method, were carried out within a test section of straight track with small slope, where speed up to 300 km/h can be reached under test conditions. The tests covered a speed range about from 100 km/h to 300 km/h.

The full scale tests of the ETR 500 have shown a strong effect of the bogie fairings on the aerodynamic drag. The measured drag of the ETR 500 with fairings is approximately 10% lower than the drag of standard configuration without fairings. This drag reduction could be further increased if the fairing design was aimed for the aerodynamic optimisation and not only for the retrofitting on the existing bogies. The success of this research project proved that the optimisation of the train surface in the bogie area can strongly affect the aerodynamic drag of the high speed trains.

Keywords
Running resistance, high speed trains, bogie fairings, full-scale tests, coasting method
1 Introduction

A large European high speed network already today allows commercial speeds of 300 km/h. In few years the new high speed lines in all the European countries will extend the operations of TGV, ICE and ETR 500 at 300 km/h to a large number of routes. Future high speed trains will lead to further increase in speed. Such increase generates a strong rise in the energy costs of operations, so research efforts have to be made on the reduction of the running resistance.

In the past years the aerodynamic research on the shape of the nose and the tail of high speed trains took into account the necessity to minimise drag and led to the design and the manufacturing of well-streamlined configurations of TGV, ICE and ETR 500. As the bogie area was dominated by the maintenance needs requiring ease of access, in the actual European high speed fleets this area is not confined by streamlined surface. Finally, the trend to the increase of speed has provided the support to study the covering the bogie area with fairings which have to be cost-effective both for maintenance and for the aerodynamic drag.

The study of the impact of bogie fairings on the aerodynamic drag has been put as the objective of the aerodynamic work programme within a co-operation project among the railway companies DB, SNCF and FS in the field of research.

The project was divided in two phases. In the first one the goal was to assess by means of reduced scale tests the effects of bogie fairings on the aerodynamic drag of an high speed train ant to quantify the amount of drag reduction. The tests were carried out on the Pininfarina wind tunnel in Turin in 1998 on four different bogie configurations. An 1:7.5 scale model of the ETR 500 high speed train was tested in a configuration composed of a locomotive and two trailer cars.

The positive results of the wind tunnel tests, showing a significant reduction in drag, legitimated the prosecution to the full scale tests, the second phase of the research project. The tests were performed on the new multi-voltage ETR 500, the Italian high speed train designed for a maximum speed of 300 km/h, in operations on the Italian network since May 2000. In January 2000 the design and the manufacturing of the bogie fairings was ordered by FS to AnsaldoBreda, one of the main partners of the ETR 500 manufacturer consortium. After about 6 months 40 bogie fairings were available to be mounted on the ETR 500.

In summer 2000 a big effort was made by FS to organize a large test campaign on the Italian high speed line linking Rome to Florence, the Direttissima line, where speed up to 300 km/h can be achieved under test conditions. To give an idea of the complexity of the test campaign it is sufficient to say that it covered a time period of 4 weeks and included 90 testruns carried out both by night, in an interval of about 4 hours free from commercial trains, and by day, running between the trains in operations. Full-scale tests were undertaken on October 2000 on an ETR 500 normally used in operations, made of 2 locomotives and 8 trailer cars, both with and without bogie fairings. A reduced configuration with only 3 cars was also tested in order to investigate the effects of the train length on drag.

Drag measurements on the ETR 500 were undertaken by the FS; measurements on the wind conditions were carried out by the DB at two locations along the test line.

The paper gives an overview on the research project and presents the main results achieved in wind tunnel and full scale measurements.
The multi-voltage ETR 500 high speed train

Both reduced and full scale tests were carried out on the new multi-voltage ETR 500, the second generation of the high speed train operating in Italy. The fleet of the new ETR 500 started the operations on May 2000 at a maximum speed of 250 km/h.

The main difference with the first series is the possibility to feed energy at three different voltages: 3 kV dc, as the first series, 25 kV ac and 1.5 kV dc. The main features of the multi-voltage ETR 500 are listed in Table 1.

Table 1  Main features of ETR 500 Politensione series

<table>
<thead>
<tr>
<th>ETR 500 Politensione features</th>
<th>Locomotive</th>
<th>Trailer car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration for Italian routes</td>
<td>2 locomotives and 11 trailer cars - Length 328.0 m</td>
<td></td>
</tr>
<tr>
<td>Configuration for Italy – France routes</td>
<td>2 locomotives and 8 trailer cars – Length 249.7 m</td>
<td></td>
</tr>
<tr>
<td>Supply voltage</td>
<td>3 kV dc</td>
<td>25 kV ac</td>
</tr>
<tr>
<td>Working voltage:</td>
<td>2 – 4</td>
<td>19 – 27.5</td>
</tr>
<tr>
<td>Continuous power at rim [kW]</td>
<td>4400 x 2</td>
<td>3300 x 2</td>
</tr>
<tr>
<td>Traction force at leaving [kN]</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td>Maximum speed [km/h]</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Lowest speed at constant power [km/h]</td>
<td>164</td>
<td>125</td>
</tr>
<tr>
<td>Vehicle feature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motors</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Bogie type</td>
<td>2 motors</td>
<td>2 level vertical suspens.</td>
</tr>
<tr>
<td></td>
<td>2 level vertical suspens.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Omokynetic with double quill fully suspended</td>
<td></td>
</tr>
<tr>
<td>Gear type</td>
<td>Central pivot</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Traction and braking force transmission type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seats</td>
<td>-</td>
<td>first class cars: 52 second class cars: 68</td>
</tr>
<tr>
<td>Dimensions</td>
<td>4000 x 3020 x 20460 mm</td>
<td>3800 x 2860 x 26100 mm</td>
</tr>
<tr>
<td>Distance between pivots</td>
<td>11450 mm</td>
<td>19000 mm</td>
</tr>
<tr>
<td>Wheel-base</td>
<td>3000 mm</td>
<td>3000 mm</td>
</tr>
<tr>
<td>Wheel diameter</td>
<td>1040 mm</td>
<td>890 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>67200 kg</td>
<td>44500 kg</td>
</tr>
<tr>
<td>Bogie mass</td>
<td>8900 kg</td>
<td>6380 kg</td>
</tr>
<tr>
<td>Translating mass equivalent to rotating masses</td>
<td>3900 kg</td>
<td>1320 kg</td>
</tr>
</tbody>
</table>

The figure 1 shows a picture of the ETR 500 locomotive with the bogie fairings.
As far as the aerodynamic features are concerned, the nose of the locomotive is a well-streamlined aerodynamic shape with a length of about 4.5 m. The cross section of the vehicles is quite large, reaching 10.94 m² for the locomotives and 9.79 m² for the trailer cars. The wet surface of the vehicles is very smooth, both on the lateral walls and on the roof, with small inter-car gaps and a reduced number of appendixes.

The standard composition operating in Italy measures 328 m and consists of 2 locomotives and 11 trailer cars. Full-scale tests were carried out on the configuration that will operate the service on the Italy – France routes, consisting of 2 locomotives and 8 trailer cars and which has a total length of 249.7 m.

3 The wind tunnel tests

The objective of the first phase of the project was to quantify the impact of the bogie fairings on drag by means of reduced scale tests. The tests were carried out on December 1998 on the Pininfarina wind tunnel in Turin.

An accurate model of the ETR 500 was built at a scale factor 1:7.5 (frontal area 0.174 m²). The ETR 500 model was composed by the locomotive and two trailer cars. The moving belt in the test section could drive in rotation the wheels of the model. The trailer car next to the locomotive was instrumented to measure the longitudinal force. Tests were carried out both with the moving belt off and working. Finally, the turbulent conditions on the tunnel boundary layer could be modified to simulate the flow conditions when the trailer car is at the rear of the train.

The bogies of the ETR 500 model allowed to mount different type of fairings. A configuration without fairings and three different fairing configurations were tested. The first fairing type is optimised for drag; the second fairing shape can be retrofitted on the existing ETR 500 bogies and includes the openings needed to avoid interferences; finally, the third fairing configuration is the retrofittable type with taped openings.

![Figure 2 – Effects of bogie fairings on the wind tunnel tests of the ETR 500](image)
The figure 2 compares the measurements of the trailer car Cx in tests with both the airflow speed and the moving belt speed at 140 km/h. As can be seen, the drag coefficient of the trailer car with the optimised fairings is lower nearly 17% than the standard value without fairings, while the fairings which can be retrofitted on the real bogies produce a yet high reduction of about 15%.

These promising findings enabled the advancement of the project to the phase of full scale tests with the multi-voltage ETR 500.

4 The bogie fairings

The bogie fairings were designed and manufactured by AnsaldoBreda, one of the partners of the ETR 500 manufacturer consortium. The fairing geometry was designed to respect the gauge limits and to avoid interference between bogie and car elements such as yaw dampers, doors, etc. In addition, openings on the fairings were necessary to allow, for instance, the view of the brake indicators. As a result, it was not possible to design a fairing surface optimised to reduce the aerodynamic drag.

Different fairing geometries were realized for the bogies of the locomotives and of the trailer cars.

The 8 fairings for the two locomotives are made by a single element fixed to the car frame. The figure 3 shows the fairing (the grey element) mounted on the first bogie of the locomotive. A central big opening for the yaw damper and the two small openings for the brake indicators can be seen in the picture.

The figure 4 shows a side view of the standard configuration of the bogie without fairing.

The figure 5 shows the side view of the locomotive. It can be seen that the fairing surface is perfectly aligned with the locomotive surface.

The 32 fairings for the trailer cars are made by two elements, the first one fixed to the car frame and the second one to the bogie frame. Both elements are shaped to enable the door motion. The figure 6 shows the fairing (the grey element) mounted on the bogie of the trailer car.

The figure 7 shows the same view of the bogie of the trailer car for the standard configuration without fairings. As can be seen, the bogie area is uncovered up to the height of the wheel.

Finally, the figure 8 shows the side view of the trailer car fairings. A large niche shaped to allow the opening of the door can be seen on the fairing surface.

5 The full scale tests and the measurements

The test-runs were carried out on the Direttissima line, the Italian high speed line between Florence and Rome, within the section linking Arezzo to Florence. In this section the maximum allowed speed in operations is 250 km/h, but speeds up to 300 km/h can be achieved under test conditions.

Drag measurements have been undertaken on a test section which has a length of about 10 km. The maximum slope within the test section does not exceed 7.5‰ and the minimum curve radius is about 3000 m.

Three different train configurations have been tested for a total of 95 test-runs.

The first configuration is the standard train of 2 locomotives and 8 trailer cars without bogie fairings. A total of 32 test-runs has been undertaken on both directions of the line at speeds covering the range from 120 km/h to 300 km/h.
Figure 3  Locomotive first bogie with fairing

Figure 4  Locomotive first bogie without fairing

Figure 5  Side view of the locomotive fairing
Figure 6  Bogie of the trailer car with fairing

Figure 7  Bogie of the trailer car without fairing

Figure 8  Side view of the trailer car fairing
The second configuration is the same train of 2 locomotives and 8 trailer cars with bogie fairings. A total of 37 test-runs has been undertaken on both directions of the line at speeds covering the range from 140 km/h to 300 km/h.

A third configuration has been tested to verify the effect of the train length on drag. This train was composed of 2 locomotives and 8 trailer cars and the bogies were without fairings. A total of 26 test-runs has been undertaken on both directions of the line at speeds covering the range from 100 km/h to 220 km/h.

The train speed, the train location and the wind speed have been measured to examine the train drag. The train speed and the train location have been measured by FS on the test train; the wind speed has been measured by DB AG on the ground at two different locations along the test section.

All the drag measurements have been carried out according to the coasting method. In this method the train is accelerated as far as it achieves the target speed. This speed is maintained as far as the train enters the test section; then the train coasts all along the test section. When the target speed is not reached at the entering of the test section, the train continues to accelerate up to the target speed and then the train coasts as far as the end of the test section. In this case the track length where the drag data are available is lower than the test section.

6 The drag calculations

The train drag is generated by the friction in the wheel rail contact, the friction in curve riding; the aerodynamic forces and the gravity force when there is a gradient on the track. The train drag $R$ is defined as the sum of wheel rail forces and aerodynamic forces. It is usually described by the following function of the train speed:

$$R = A + B V + C V^2$$

[1]

where $A$, $B$ and $C$ are constant coefficients. This section presents the method applied to calculate the coefficients of the drag curve.

When the train coasts on a track section with slope $i_n$, the train speed changes from $V_n$ at the initial location of the section to $V_{n+1}$ at the final location. On the straight track the energy equation of the train can be approximated as below:

$$( T - R - m g i_n ) l_n = \frac{1}{2} ( m + m_{et} ) ( V_{n+1}^2 - V_n^2 )$$

[2]

where the symbols mean:

- $i$ slope of the track section (positive if the track climbs);
- $g$ gravity acceleration;
- $l_n$ length of the track section;
- $m$ train mass;
- $m_{et}$ translating mass equivalent to the rotating masses of the train;
- $T$ traction force;
- $V_n$ train speed at the initial location of the track section;
- $V_{n+1}$ train speed at the final location of the track section.

As the drag is measured by the coasting method (traction equal to zero), the estimated value of drag $R_h$ on the section $h$ can be calculated from the relation [2].

Defining the rotating mass coefficient $k$ as follows:

$$k = l + m_{et} / m$$

[3]
the relation \[ 2 \] finally becomes:

\[
R_h = - \frac{1}{2} k m \left( V_{n+1}^2 - V_n^2 \right) / l - m g i_n
\]

[4]

The drag value \( R_h \) is associated with the speed value \( V_h \) defined as follows:

\[
V_h = ( V_n + V_{n+1} ) / 2
\]

[5]

Therefore the method generates the distribution \( R_h(V_h) \) of drag data which enables to estimate the coefficients A, B and C of the drag curve by the least square method.

It can happen that the distribution \( R_h(V_h) \) produces a negative B coefficient. In this case the train drag is described by a two coefficient curve:

\[
R = A + C V^2
\]

[6]

The coefficients A and C of the curve \[ 6 \] are again calculated from the data distribution \( R_h(V_h) \) by the least square method.

For each test-runs the distribution of drag data is computed on the same set of track sections. The initial and the final locations of each section are chosen so that the whole train rides on a track with constant slope. The figure 9 shows a scheme of the method used to define the initial and the final locations of the track sections.

![Figure 9  Track section exploited in drag calculations](image)

As the speed changes between the final and initial locations of the track section depend on the length of the section, a numerical effect can exist on the drag calculations (linked to the fact that the speed changes within the section are usually small). In order to verify if the dimension of the sections affects the drag curves, the calculations have been repeated for three groups of sections with different lengths. The drag data have been calculated for a set of 20 sections with lengths of about 400 m, for a set of 11 sections with lengths of about 800 m and, finally, for a set of 7 sections with lengths of about 1200 m. No significant effect of the section length was found in the calculations.

As the component of the wind speed on the track direction was null or negligible in all the test-runs, no wind correction has been performed on the drag calculations.

7 The effects of the bogie fairings on the train drag

A large database of drag data was achieved by means of the high speed test-runs of the ETR 500. In this section the drag of the standard configuration with bogie fairings is compared with the configuration without fairings.
Measurements recorded in 30 test-runs on both directions of the test line are available for the configuration without bogie fairings (2 locomotives and 8 trailer cars). The database covers a speed range from about 120 km/h to 300 km/h. The distribution of the drag data has been computed on the three categories of track sections. For the sections with a length of about 400 m a distribution with 460 drag values are available, for 800 m sections 246 values and for 1200 m sections 150 values.

The figure 10 shows the distribution of the drag data on the sections of about 1200 m. For this distribution a two coefficient curve has been computed with the least square method. The figure shows also the drag curves which refer to the three data distributions calculated on the sections of about 400 m, 800 m and 1200 m. As can be seen, the curves and also the coefficients A and C are very close for the three distributions; therefore, the effects of the length of the track sections can be ignored.

The following relation gives the drag coefficients for the ETR 500 configuration without bogie fairings, calculated on the sections of about 1200 m:

\[ R = 8.98 + 0.000674 V^2 \]  

In the relation \[ 7 \] the units of drag and velocity are respectively kN and km/h. As no drag value is available at low speed, the curve gives a satisfying approximation of the train drag at velocities higher than 120 km/h.

Measurements recorded in 34 test-runs on both directions of the test line are available for the configuration with bogie fairings (2 locomotives and 8 trailer cars). The database covers a speed range from about 140 km/h to 300 km/h. The distribution of the drag data has been computed on the three categories of track sections. For the sections with a length of about 400 m a distribution with 551 values is available, for 800 m sections 299 values and for 1200 m sections 184 values.

The figure 11 shows the distribution of the drag data on the sections of about 1200 m. For this distribution a two coefficient curve has been computed with the least square method. The figure shows also the drag curves which refer to the three data distributions calculated on the sections of about 400 m, 800 m and 1200 m. Also in this case the curves are very close and the effects of the section length can be ignored.

The following relation gives the drag coefficients for the ETR 500 configuration with bogie fairings, calculated on the sections of about 1200 m:

\[ R = 4.25 + 0.000669 V^2 \]  

Also in this case, the curve gives a significant approximation of the train drag only within the speed range where the drag data are available, that is, at a velocity higher than 140 km/h. As better seen later, the values of the coefficients A and C for both configurations can be corrected to take into account the lack of data at low speed.

The figure 12 shows the data distributions and the drag curves with and without fairings on the sections of about 1200 m. The data distribution for the configuration with fairings is well separated from the configuration without fairings and has lower values in the whole speed range.

Obviously, also the drag curve for the configuration with fairings stands below the curve for the standard configuration. The drag reduction generated by the fairings is about 5 kN within the whole speed range between 150 km/h to 300 km/h, while the reduction in percentage changes with the speed from 20% at 150 km/h to 7.5% at 300 km/h. The table 2 shows the values of the drag curves \[ 7 \] and \[ 8 \] at different speeds.
Section length about 1200 m - Distribution of drag data

- Standard configuration without fairings

- Standard configuration with fairings

Figure 10  Drag data of the standard ETR 500 without fairings

Figure 11  Drag data of the standard ETR 500 with fairings
The drag reduction generated by the fairings is about 5 kN within the whole speed range between 150 km/h to 300 km/h, while the reduction in percentage changes with the speed from 20% at 150 km/h to 7.5% at 300 km/h. The table 2 shows the values of the drag curves \[ 7 \] and \[ 8 \] at different speeds.

<table>
<thead>
<tr>
<th>Velocity [km/h]</th>
<th>Standard train [kN]</th>
<th>Fairings [kN]</th>
<th>Drag difference [kN]</th>
<th>Drag difference [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>24.2</td>
<td>19.3</td>
<td>-4.9</td>
<td>-20.1</td>
</tr>
<tr>
<td>200</td>
<td>36.0</td>
<td>31.0</td>
<td>-5.0</td>
<td>-13.8</td>
</tr>
<tr>
<td>250</td>
<td>51.1</td>
<td>46.0</td>
<td>-5.1</td>
<td>-10.0</td>
</tr>
<tr>
<td>280</td>
<td>61.9</td>
<td>56.7</td>
<td>-5.2</td>
<td>-8.4</td>
</tr>
<tr>
<td>300</td>
<td>69.7</td>
<td>64.4</td>
<td>-5.2</td>
<td>-7.5</td>
</tr>
</tbody>
</table>

It has been already noticed that the drag curves \[ 7 \] and \[ 8 \] are less significant in the low speed range. As the running resistance at very low speed is not affected by the bogie fairings (the small weight variation caused by the fairings is negligible for the ETR 500), the experimental drag values for the configuration with and without fairings have to be the identical at zero speed and have to be very close at low speed. As a consequence, the A coefficients of the drag curves have to be equal, while the deviations in drag with and without fairings are given only by the C coefficients.

In order to take into account this fact, the drag curves for the standard and the fairing configuration have been again computed imposing as A coefficient the mean value between the A coefficients of the curves \[ 7 \] and \[ 8 \] and calculating the C coefficients of each curve by the least square method.

The drag curve for the ETR 500 configuration without fairings becomes:

\[ R = 6.62 + 0.000720 V^2 \] \[9\]

The drag curve for the ETR 500 configuration with fairings becomes:

\[ R = 6.62 + 0.000627 V^2 \] \[10\]

The figure 13 shows the distribution of the drag data for the two configurations and also the drag curves with the corrected coefficients. Also in this case the drag curve for the fairing configuration is lower than the curve for the standard configuration. The drag reduction increases with the speed from 2.1 kN at 150 km/h to 8.4 kN at 300 km/h, while it changes in percentage from 9.2% at 150 km/h to 11.7% at 300 km/h. The table 3 shows the values of the drag curves with the corrected coefficients at different speeds.

<table>
<thead>
<tr>
<th>Velocity [km/h]</th>
<th>Standard train [kN]</th>
<th>Fairings [kN]</th>
<th>Drag difference [kN]</th>
<th>Drag difference [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>22.8</td>
<td>20.7</td>
<td>-2.1</td>
<td>-9.2</td>
</tr>
<tr>
<td>200</td>
<td>35.4</td>
<td>31.7</td>
<td>-3.7</td>
<td>-10.5</td>
</tr>
<tr>
<td>250</td>
<td>51.6</td>
<td>45.8</td>
<td>-5.8</td>
<td>-11.3</td>
</tr>
<tr>
<td>280</td>
<td>63.0</td>
<td>55.8</td>
<td>-7.3</td>
<td>-11.6</td>
</tr>
<tr>
<td>300</td>
<td>71.4</td>
<td>63.0</td>
<td>-8.4</td>
<td>-11.7</td>
</tr>
</tbody>
</table>
Drag data on 1200 m sections - Fairing configuration
Drag data on 1200 m sections - Standard configuration
Curve $4.25 + 0.000669 V^2$ - Fairing configuration
Curve $8.98 + 0.000674 V^2$ - Standard configuration

Figure 12  Drag data of the ETR 500 with and without fairings

Drag data on 1200 m sections - Fairing configuration
Drag data on 1200 m sections - Standard configuration
Curve $6.62 + 0.000627 V^2$ - Fairing configuration
Curve $6.62 + 0.000720 V^2$ - Standard configuration

Figure 13  ETR 500 drag data with and without fairings – Corrected coefficients
Both the representations of the drag (analytical or corrected coefficients) give the evidence that the bogie fairings can produce a significant reduction on the train drag. The amount of drag reduction in the high speed range between 280 km/h and 300 km/h is higher than 8% for the drag curves with the analytical coefficients and higher than 11% for the drag curves with the corrected coefficients.

8 The effects of the train length on drag

As the drag measurements were carried out on two train configurations with different numbers of cars, it is possible to estimate the drag amount added by each vehicle of the ETR 500. The longer train is composed of 2 locomotives and 8 trailer cars and its length is 249.7 m; the shorter one is composed of 2 locomotives and 3 trailer cars and its length is 119.2 m. Both trains were tested without bogie fairings.

The figure 14 shows the distributions of the drag data on the sections of about 1200 m for the trains with 8 and with 3 trailers cars. The figure shows also the two coefficient curves computed with the least square method. As obvious, the longer train generates the higher drag.

The relation [9] in the previous section has already given the drag coefficients (the corrected ones) for the longer configuration.

The following relation gives the drag coefficients for the configuration with 3 trailer cars, calculated on the sections of about 1200 m:

\[ R = 3.43 + 0.000440 V^2 \]  \[ 11 \]

![Figure 14 Drag data for the standard and the reduced configuration](image-url)
Using the relations [7] and [11] and by means of a simplified drag model it is possible to estimate the drag coefficients for the configurations with a different number of cars. The hypothesis is that the drag coefficients vary linearly with the number of cars. It corresponds to assume that the friction component of the drag (covered mainly by the a coefficient) is proportional to the number of bogies and that the aerodynamic component (covered by the c coefficient) is proportional only to the wet surface of the train. This rough approximation neglects the effects that the length of the train generates on the pressure drag.

The figure 15 shows the diagrams of the drag coefficients as functions of the number of trailer cars. The graph shows also the experimental values of the drag coefficients which are available for the trains with 8 and with 3 trailers cars.

The following relations, where n is the number of the trailer cars, give the values of the coefficients A and C for the two coefficient curve of the configuration without bogie fairings:

\[ A = 1.51 + 0.638 n \]  
\[ C = ( 2.71 + 0.560 n ) \times 10^{-4} \]

![Figure 15 ETR 500 drag coefficients as functions of the number of trailer cars](image)

The relations [12] and [13] have been used to compute the drag curves for different train lengths. The figure 16 shows the graphs of the drag curves of train configurations with different number of cars (up to 11, the number of trailer cars used in the current operations of the ETR 500). The two curves for the trains with 3 and 8 trailers cars are the experimental ones calculated by the drag measurements.

The drag curve for the ETR 500 configuration with 2 locomotives and 11 trailer cars operating on the Italian routes is the following:

\[ R = 8.53 + 0.000887 V^2 \]
9 Conclusions

The full scale tests of the new ETR 500 high speed train with experimental bogie fairings have shown a strong effect of the fairings on the aerodynamic drag. The drag of the ETR 500 with fairings is approximately 10% lower in the high speed range than the drag of the standard configuration without fairings.

The drag reduction achieved by the experimental fairings could be further increased if the fairing design was aimed for the aerodynamic optimisation and not only for the retrofitting on the existing bogies. The success of this research project joining DB, SNCF and FS proved that the optimisation of the external surface in the bogie area can strongly affect the aerodynamic drag of the high speed trains.

BIBLIOGRAPHY
