# SWISSMETRO - Energy Balance Of The Basle-Zurich Link

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**Abstract**

The idea behind Swissmetro is a public transportation system between the main cities of Switzerland, designed for a speed up to 500 [km/h] in two tubes (tunnels) under partial vacuum. Each 6 [min], a vehicle, carrying 200 passengers, would travel without contact to the infrastructure through an application of linear motor technology, magnetic levitation and guidance. The energy consumption of the system will be low, due to the reduced air resistance.

This publication describes the electromechanical component consumption and more particularly the energy balance applied to the Swissmetro Basle-Zurich link.

The energy balance considers different parameters such as the vehicle length, the speed or travel time, the mechanical motor maximum power. Specific aspects such as: the motor distribution; the power supply; the energy of the stations and the vacuum pumps are parts of the evaluation.

## 1 Introduction

The Swiss central plateau is a region with a high density of population, spread over a distance of 300 km, with city centers. The Swissmetro project is based on four technologies:

- a subterranean infrastructure in the form of two tunnels of approximately 5 meter inside diameter, with underground stations connected to the public transport surface networks;
- a partial vacuum maintained in the tunnels, to reduce the energy requirements for propelling the pressurized vehicles which are based on the airframe principle;
- a propulsion system using linear electric motors interdependent of the tunnels themselves;
- a magnetic levitation and guidance system allowing high velocities of around 500 km/h.

## 2 Basle-Zurich Link: Main Characteristics

### 2.1 Infrastructure Profile

The proposed Basle-Zurich link is situated between the beginning of the Jura mountains near the Basle city and ends at the Zurich city railway station, which is very closed to the Zurich lake. The Swissmetro two tunnels correspond to a total length of 89664 [m]. The tunnel slope is a minimum 0.003 [-] up to a maximum of 0.0103 [-]. The tunnel inside diameters are 5 [m]. The tunnels are under partial vacuum of 8000 [Pa]. The complete link has 10 intermediate shafts: Ariesheim, Bubendorf, Rümlingen, Wölflinswil, Zeihen, Rüfenach, Aaretal, Unterndingen, Dielsdorf, Chöchenrüti.

### 2.2 Vehicle

Independently of the on going studies of the Swissmetro project, the vehicle length and consequently its capacity were optimized for this particular link only, without considering the existence of the complete network [1, 2, 6, 13]. The optimization of the Basle-Zurich link, for itself, leads to a vehicle of 130 [m] length with 400 seats and a total mass with the passengers varying from

110 to 170 [ton], depending on the motor variants and the transfer of energy to the vehicle variants. This differs from the previous published studies, which were considering vehicles of 80 [m] length with 200 seats.

### 2.3 Aerodynamic Drag Force

In this framework [13], the best configuration for this long-range (89.664 [km]), high blockage ratio tunnel network, seems to consist in two coupled tunnels connected by a number of pressure relief ducts. These connections allow both a reduction of the piston effect generated by the moving vehicle and a positive mutual interaction of vehicles moving in opposite directions.

Side effects of these connections are not always desirable: sudden increases in aerodynamic drag and strong lateral wind loads on the train can be generated. A solution to this problem can be found by placing pressure relief ducts only in proximity of the stations, where the high-speed vehicle is in its accelerating/decelerating phase.

### 2.4 Magnetic Drag Force

As for the Swissmetro Main Study, the magnetic drag force is considered as a percentage of the total moving mass: 1% is chosen here.

### 2.5 Speed Profile

The speed profile is defined by the total accepted time for one travel, which is admitted to be 15 [min], based on the study of the exploitation network. The corresponding top speed is 400 [km/h] with a variation of 5%. The maximum admissible acceleration and deceleration are 1.3 [m/s^2]; this value is defined by the comfort of the passengers.

### 2.6 Exploitation

The study of the demand leads to a daily traffic definition as follows:

- 6 hours – 10 travels per hour, per tunnel;
- 12 hours – 6 travels per hour, per tunnel;
- Total: 18 hours – 132 travels per tunnel.

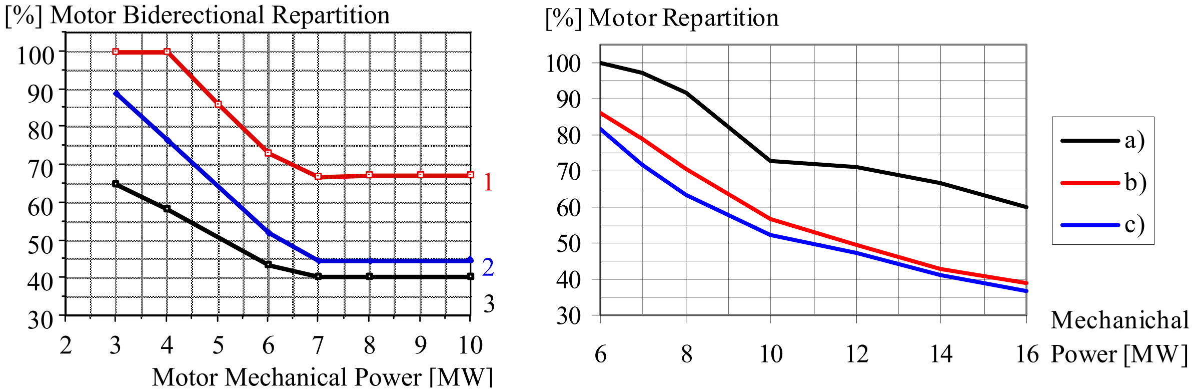
## 3 Motor Bi-directional Repartition

### 3.1 Design Consideration

The motor bi-directional repartition is defined by the case corresponding to the specified design of the tunnels to be able to admit vehicle motion in both directions. Of course, during normal operation one tube is uni-directional. For all electromechanical components, the design case corresponds to the full capacity of the vehicle. The determination of the necessary motor mechanical power is based on the satisfaction of the specified speed trajectory and the travel time. Consequently the motor mechanical power is considered as a design parameter. From the initial values given in the Swissmetro Preliminary Study and the "Demande de Concession" and the actual studies, some values changed as the chosen partial vacuum down to 8000 [Pa] and a slight increase of the ratio: mass per vehicle length.

Furthermore, for the Basle–Zurich study the vehicles are formed of 10 cells (nose, eight intermediate cells, trail), where the nose and the trail are about 15 [m] length each, for a complete vehicle length of 130 [m]. Applying a speed trajectory, mainly defined by the maximum acceleration and deceleration and the nominal speed including its variations, leads to a spatial repartition of the motors with short stators in a dissymmetry manner for the Basle-Zurich direction and the Zurich-Basle direction. This is due to the vertical slope of the tunnel profiles, which are not symmetric. This phenomenon clearly implies that for motors with short stators fixed with the tunnel, an optimization of the speed trajectory is necessary in order to minimize the number of motor stators along the track.

Figure 1 represents the two cases: the Geneva-Lausanne link corresponding to the Swissmetro Preliminary Study and the on going study of the Basle-Zurich link. For a vehicle of 80 [m] length (nose, 4 intermediate cells, nose), a mechanical power of 6 [MW] is proposed. For the Basle-Zurich link, considering a vehicle of 130 [m] length, the mechanical power must higher than 10 [MW]. Figure 1 shows that the bi-directional motor repartition is slightly different from the motor repartition going from Basle to Zurich than the one going from Zurich to Basle. The bi-directional repartition is the superposition of the two direction results. Figure 1 shows that for motors with short stators, a clear optimization of the speed trajectory should be considered in order to decrease the bi-directional motor repartition. This optimization is not presented here. The proposed mechanical power for a vehicle of 130 [m] is 12 [MW], corresponding to the maximum mass of 130 [ton]. Indeed, it means that the mechanical power is directly proportional to the number of intermediate vehicle cells, the nose and trail having no motor active component.




Geneva – Lausanne: Demande de Concession
Case: Vehicle 50 m (+2*15)m, 50 t + 20 t (200 pass.)
1. blockage ratio: 0.5, pressure 10000 Pa
2. blockage ratio: 0.4, pressure 10000 Pa
3. blockage ratio: 0.3, pressure 10000 Pa

Basle - Zurich
Case: Vehicle 100 m (+2*15)m, 130 t +40 t (400 pass.)
1. blockage ratio: 0.4, pressure 8000 Pa
a) bi-directional repartition; b) direction Basle – Zurich;
c) direction Zurich - Basle

Fig. 1 Motor Bi-directional Repartition

# 4 Direct Energy Balance

## 4.1 Motor Variants

The active energy necessary for the propulsion of the vehicle depends on the rate of occupancy of the vehicle. As the speed profile has to be guaranteed, the active energy of the propulsion varies inside a small range. This is due to the fact that the mechanical energy depends mainly on the aerodynamic drag force and on the magnetic drag force. As 50% of the kinetic energy is recuperated during the breaking mode, the influences of the total mass in motion and consequently of the vehicle rate of occupancy are low. Figure 2a shows the influence of the mass on the active energy necessary for the propulsion. Three motor variants defined the total masses:

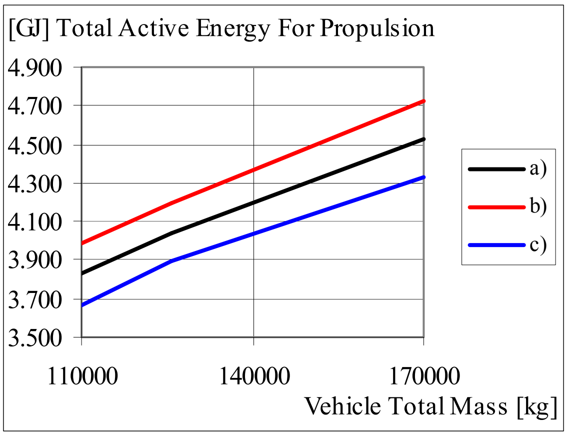
- **Variant A**: Stator fixed with the tunnel track, transfer of energy to the vehicle by linear transformer;
- **Variant B**: stator on the vehicle board, transfer of energy to the vehicle by mechanical contacts;
- **Variant C**: stator on the vehicle board, transfer of energy to the vehicle by linear transformer.

## 4.2 Vehicle Occupancy Rate

Figure 2b represents the active energy for the propulsion versus the vehicle occupancy rate. For this case the mass of the vehicle, without passenger is considered as the maximum mass of 130 [ton].

## 4.3 Motor Spatial Repartition

Figure 3 represents the motor distribution along the track Basle – Zurich, considering the maximum vehicle mass with all the passengers: total 170 [ton]. This case represents the maximum installed mechanical power for the propulsion. Figure 4 shows the different characteristics, which defined the major parameters of a vehicle travel.



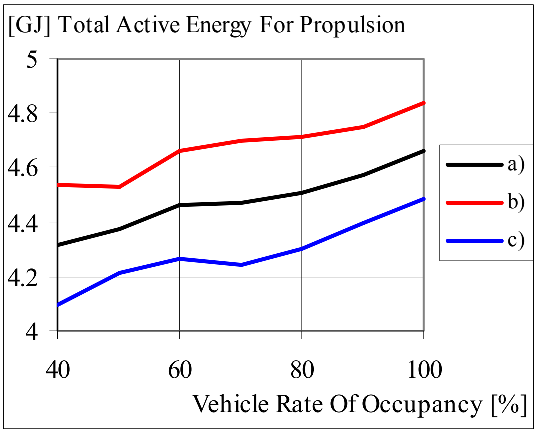




Fig. 2a Fig. 2b

Fig. 2a Total Active Energy For Propulsion Versus Total Vehicle Mass
Fig. 2b Total Active Energy For Propulsion Versus Vehicle Rate Of Occupancy
a): Average Value; b) Direction Basle – Zurich; c) Direction Zurich – Basle

## 4.4 Total Active Energy

The total active energy can determined. The total direct energy involves the *complete Basle – Zurich Swissmetro System*: the two stations, the intermediate shafts, the complete maintenance of the vacuum, the sas, the ripage circulaire and the propulsion. The consumption per passenger*kilometer shows that high speed system must be used at their best possible occupancy rate.

| **Exploitation** | | | | | |
|---|---|---|---|---|---|
| Number of exploitation days per year | **365** | **365** | **365** | **365** | **365** |
| Number of travels per day, two tunnels | **240** | **240** | **240** | **240** | **132** |
| Vehicle occupancy rate | **1** | **1** | **0.75** | **0.5** | **0.6** |
| Maximum frequency, one tunnel | 10 | 10 | 10 | 10 | 7.333 |
| Vehicle length [m] | 80 | 130 | 130 | 130 | 130 |
| Seats | 200 | 400 | 400 | 400 | 400 |

| **Yearly Consumption Two tunnels** | **Geneva Lausanne** | | **Basle** | **Zurich** | **Basle** | **Zurich** | **Basle** | **Zurich** | **Basle** | **Zurich** |
|---|---|---|---|---|---|---|---|---|---|---|
| | [TJ/an] | [%] | [TJ/an] | [%] | [TJ/an] | [%] | [TJ/an] | [%] | [TJ/an] | [%] |
| 1. Stations without lifts | 14.3 | 6.8 | 14.3 | 2.5 | 14.3 | 2.6 | 14.3 | 2.6 | 14.3 | 4.3 |
| 2. Lifts in the stations | 7.8 | 3.7 | 7.8 | 1.4 | 5.8 | 1.0 | 3.9 | 0.7 | 2.6 | 0.8 |
| 3. Intermediate shafts | 3.4 | 1.6 | 7.8 | 1.4 | 7.8 | 1.4 | 7.8 | 1.4 | 7.8 | 2.3 |
| 4. Pumps, vacuum maintenance | 29.0 | 13.8 | 46.3 | 8.3 | 46.3 | 8.3 | 46.3 | 8.4 | 46.3 | 13.8 |
| 5. Vacuum creation in the station, Sas | 0.8 | 0.4 | 0.8 | 0.1 | 0.8 | 0.1 | 0.8 | 0.1 | 0.4 | 0.1 |
| 6. Sas | 1.1 | 0.5 | 1.1 | 0.2 | 1.1 | 0.2 | 1.1 | 0.2 | 0.6 | 0.2 |
| 7. Circular lining track in the stations | 1.3 | 0.6 | 1.3 | 0.2 | 1.3 | 0.2 | 1.3 | 0.2 | 0.7 | 0.2 |
| 8. Vehicles | 41.2 | 19.6 | 119.5 | 21.3 | 119.5 | 21.5 | 119.5 | 21.7 | 65.7 | 19.6 |
| 9. Propulsion | 111.2 | 53.0 | 361.2 | 64.5 | 358.5 | 64.6 | 355.8 | 64.6 | 196.3 | 58.6 |
| **10. TOTAL [TJ/year]** | **210.0** | **100.0** | **559.9** | **100.0** | **555.3** | **100.0** | **550.6** | **100.0** | **334.6** | **100.0** |
| **TOTAL [10^6kWh/year]** | **58.0** | | **155.5** | | **154.3** | | **153.0** | | **93.0** | |
| **Direct consumption [Wh/(pas*km)]** | **58.0** | | **49.5** | | **65.5** | | **97.4** | | **89.7** | |
| **Direct consumption [Wh/(t*km)]** | **582.0** | | **495.1** | | **654.6** | | **973.7** | | **896.6** | |

Table 1 Direct Energy Consumption

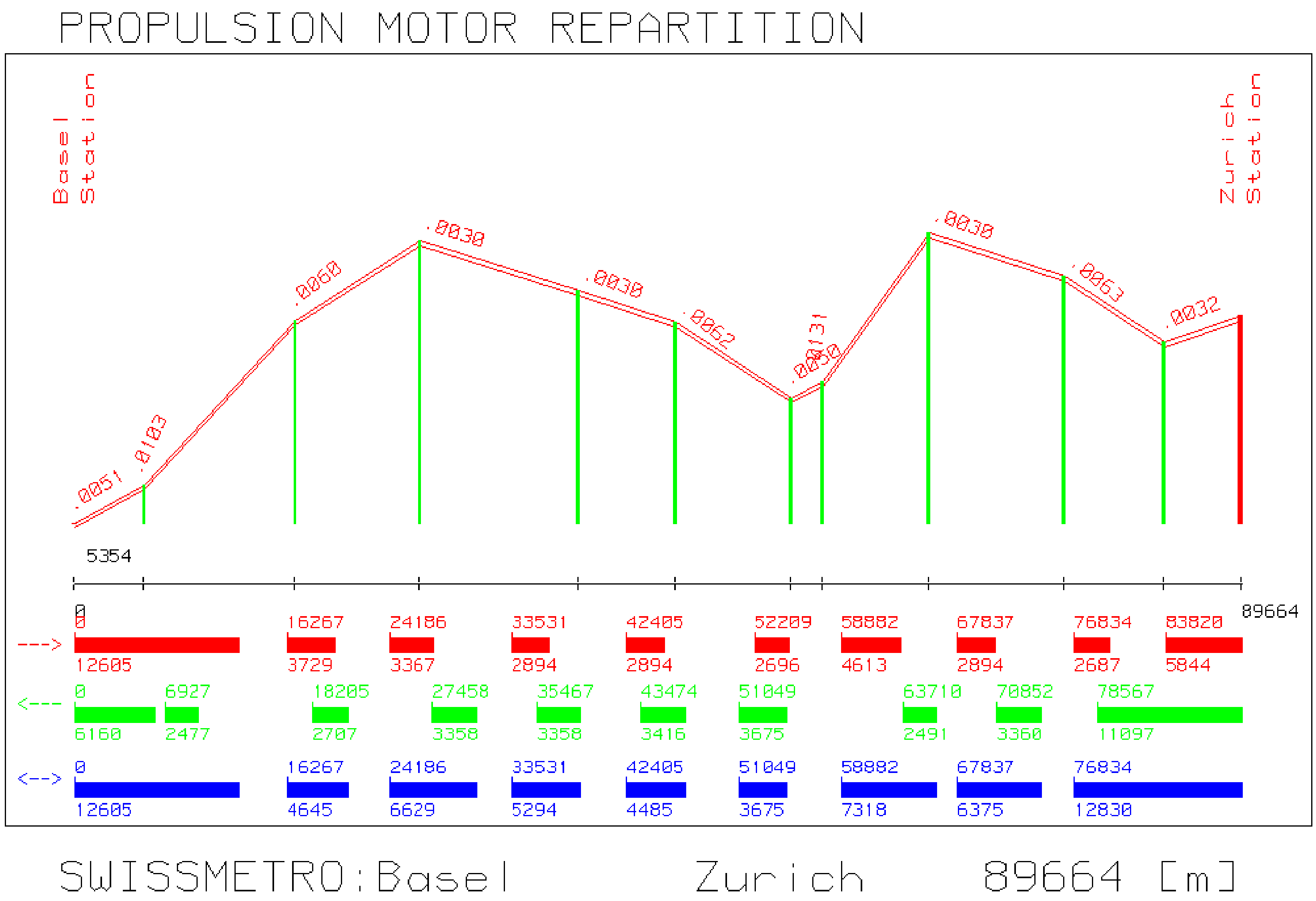



Fig. 3 Basle-Zurich Link: Motor Spatial Repartition

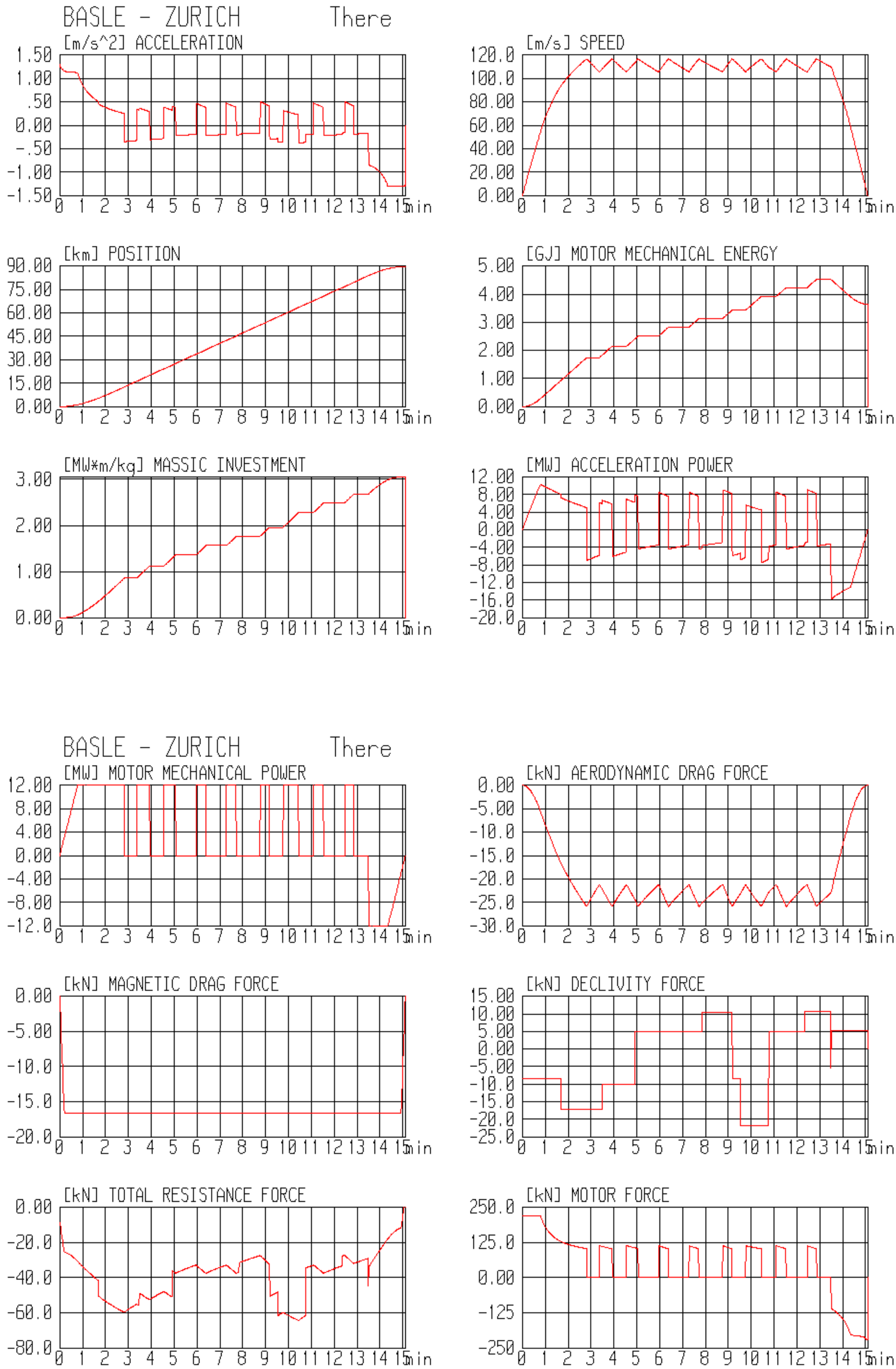



Fig. 4 Direction Basle-Zurich Link: Trajectory Characteristics

# 5 Conclusions

- The total active direct energy determined for the Basle – Zurich track, based on a vehicle length of 130 [m] is lower than the total active direct energy for the Geneva - Lausanne track, based on a vehicle length of 80 [m]. This difference can be explained by comparing the different energy components. The station consumption will certainly increase with the length of the vehicle, since the complete station civil infrastructure has to be designed in direct relation with the maximum possible vehicle length. Consequently the consumption for the Basle –Zurich track should certainly slightly increase.
- The ratio of the aerodynamic drag force between a vehicle length of 130 [m] and a vehicle length of 80 [m] is 2.13. This corresponds also to the double of the vehicle seat ratio.
- For high speed transportation system, the direct energy consumption varies slightly versus the total mass. Consequently, the consumption versus passenger*kilometer is very sensitive if the rate of vehicle occupancy is low.
- Optimization of the vehicle length to the exploitation requirements and to the passenger demand is a key issue of the complete system design.

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