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Cooling and ventilation of a high-speed ground transportation system

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Synopsis

This paper presents the special needs and difficulties concerning cooling and ventilation of the *SwissMetro* high-speed ground transportation system. *SwissMetro* is based on four complementary technologies: a complete underground infrastructure, a partly evacuated tunnel system to reduce the aerodynamic drag of the vehicle with a maximum speed between 400 and 500 km/h, linear electric motors and a magnetic levitation and guiding system.
Due to high internal and external heat loads permanent cooling and air-conditioning of the vehicle is required. Additional thermal problems may occur in the case of an emergency. The pressure level inside the tunnel has to be raised within a short period of time to guarantee the safety of the passengers and to avoid any health risks. This repressurization of long tunnel sections may cause shock waves and high temperatures inside the tunnel. The aim of the project is to analyse the spatial and temporal temperature evolution in the *SwissMetro* tunnels under different operating conditions and in emergency situations.

Introduction

With the introduction of the "TGV" in France, the new "Shinkansen" in Japan, the "ICE" in Germany and, to a lesser extent, the "Pendolino" trains in Italy, guided transportation systems which are commercially available, have reached their limits in terms of economy, comfort, speed and their potential for further development.
The *SwissMetro* is planned as a high speed transportation system for passengers only and within the first quarter of the 21st century is intended to contribute significantly to the linking of the major Swiss cities in an ultra high speed network. Fig.1 shows the foreseen pilot stretch, the different stages of the whole network and the connection with the European high-speed rail network.

The evolution of a new form of guided transportation for public use is an enormous, multifaceted and costly public utility project. Such a project requires several years of R&D and detailed design efforts to be completed. The nationwide project *SwissMetro* includes a variety of research activities at the Swiss Federal Institute of Technology and in the supporting Swiss industry.

Under the current ecological conditions, it would simply be impossible to construct a high-speed train system in Switzerland along the traditional lines, i.e., the TGV or the ICE. Even the German "Transrapid", which is partly based on a similar technology, would for the same reasons hardly be thinkable in Switzerland. Due to the legal and social restrictions resulting from high public sensitivity to environmental issues, the mountainous nature of the Swiss terrain and the high land values in Switzerland, the *SwissMetro* will have an entirely subterranean, tube-like infrastructure. Fig.2 shows a design study and Fig.3 shows the cross-section of the vehicle and tunnel structure.

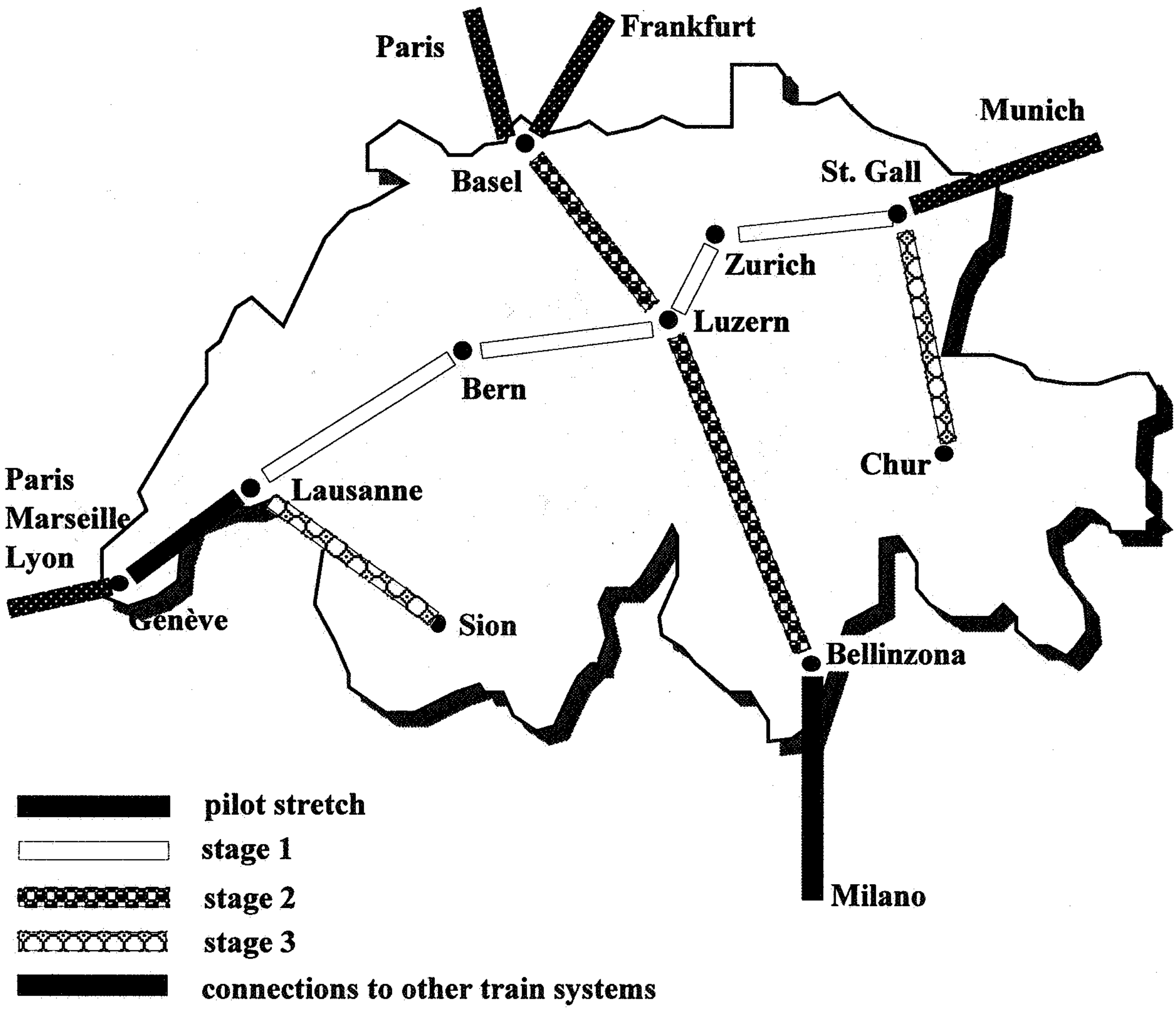

Fig.1: SwissMetro network

SwissMetro is designed to travel at speeds exceeding 400 kph. Subatmospheric operating pressures are thought to be required to reduce the friction and piston effect forces resulting from the use of very small diameter tunnels which themselves are supposed to keep tunneling costs low. The tunnel tubes will therefore be kept under partial vacuum. For SwissMetro, the classical wheel-rail system had to be dismissed, because it is difficult to master that technology at such high speeds. The vehicles will be held on track by a magnetic levitation and guidance system involving no surface contact. The propulsion force is supplied by stationary linear electric motors fitted to the track. This will ensure maintenance-free operation.

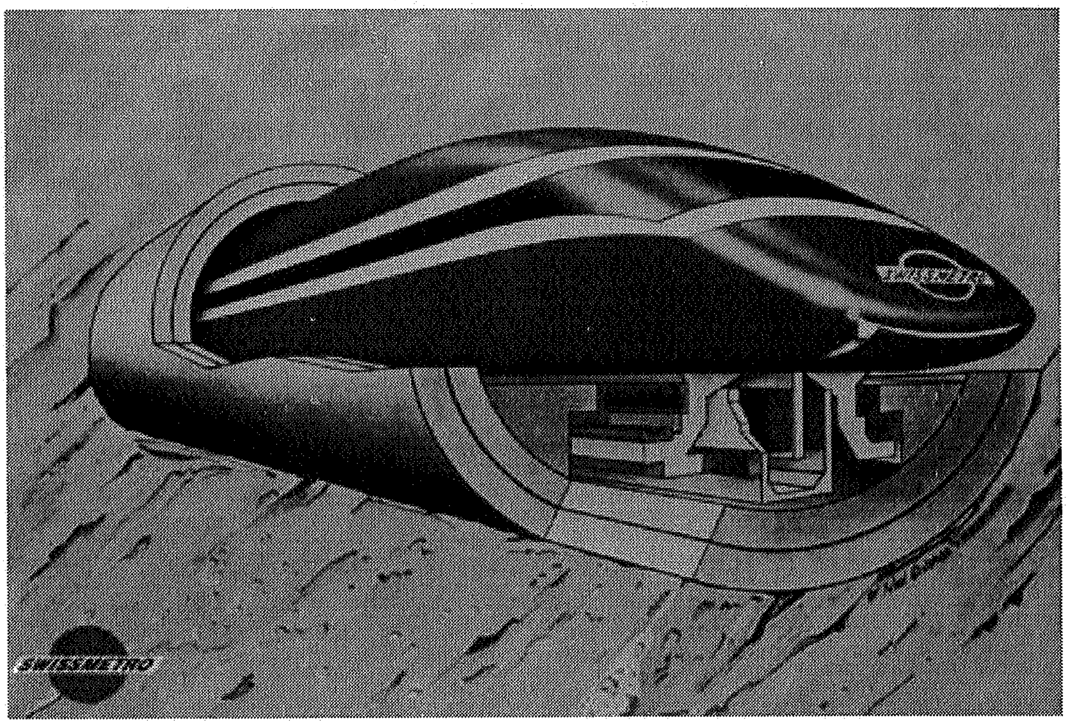

Fig.2: Design study of SwissMetro

Despite the fact that the entire system would be built underground and that very complex technology would have to be used, the costs remain comparable to those of other transport systems. A comparison of energy consumption has shown that *SwissMetro* will consume 35% less energy per person-km than an InterCity train, and some 65% less than the TGV.

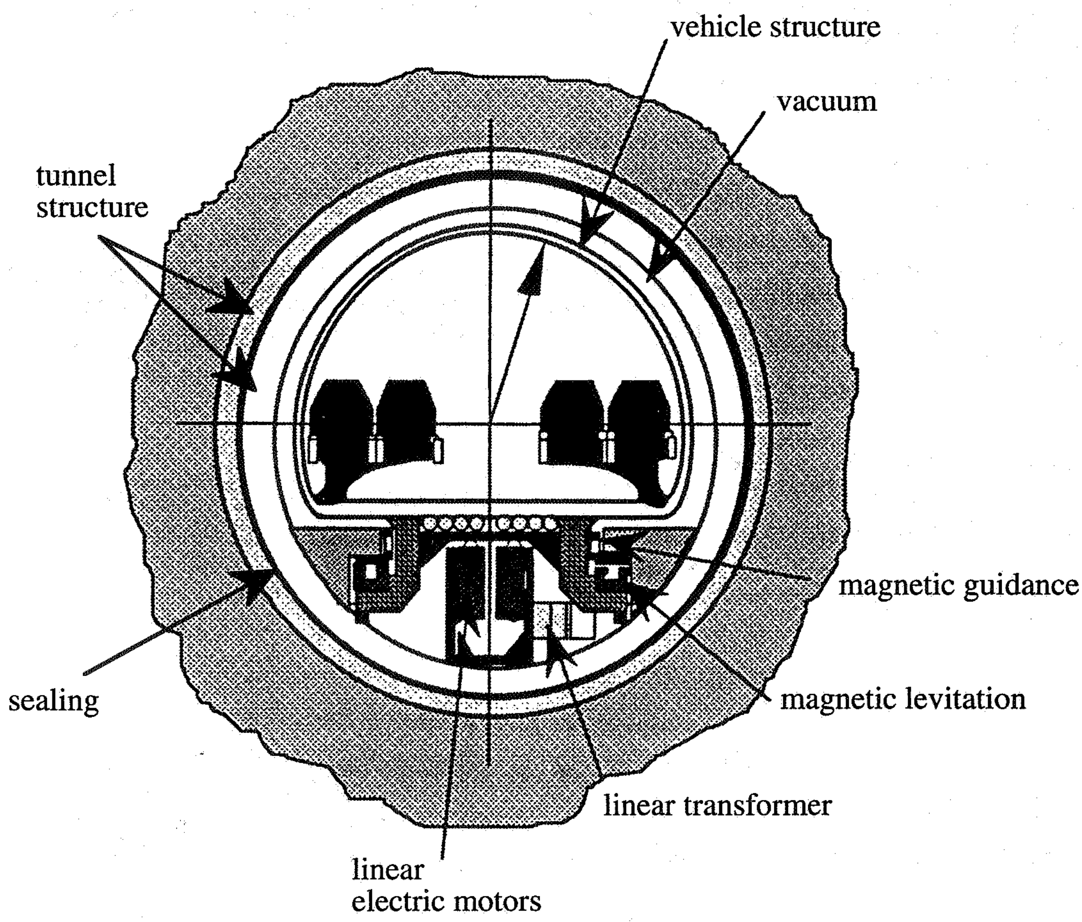

Fig.3: Cross-section of SwissMetro tunnel

Thermal conditions during normal operation

The new and unique technology of *SwissMetro* with the complete underground infrastructure and the partly evacuated tunnel system presents special challenges and difficulties concerning cooling, ventilation and air-conditioning.
Due to the reduced pressure level in the tunnels the vehicle has to be pressurized, similar to a commercial airliner. In this section the thermal balance of the vehicle and a global balance of the tunnel system are analysed.

Thermal balance of the vehicle

In this first step it is assumed that the isolation of the vehicle is very efficient. So the inside and the outside of the vehicle may be regarded separately. The air-conditioning system has to ensure thermal comfort and sufficient air quality, as well as a constant pressure level.
The main heat-sources are:

- the passengers (100 - 150 W per person)
- lighting
- the control system
- the heat-pump

These internal heat loads have to be removed constantly. In the current phase of the project, it is not determined whether the thermal energy is transferred to the rarefied tunnel atmosphere or removed during stops in stations. This requires an additional system to store the thermal energy inside the vehicle.

Global balance of the tunnel system

In contrast to the internal heat sources of the vehicle the external ones are not permanent. The most important ones are:

- Magnetic levitation and guidance
- Linear transformers
- Linear motors
- Electric power supply

The first step of this thermal analysis of the whole system (Monnier, Th.: "Bilan thermique du système Swissmetro") has shown that the tunnel and the surrounding rock will heat up during the operation and steady state temperatures may climb up to 40 °C within nearly 50 years of operation. This effect is today also visible in subway systems with a high vehicle density.

The results still contain some uncertainties, especially the aerodynamics which have a major influence on the dissipated energy of the linear motors, the most important heat source. Another critical factor is the heat storage capacity of the surrounding rock, mainly a question of geology. Also the heat transfer from the track and the tunnel air to the walls in the rarefied gas atmosphere is uncertain. As the study progresses the results have to be refined with the help of more precise input data to design a sufficient cooling and ventilation system for the vehicle, the tunnel with the electrical equipment, and the stations.

Thermodynamics of an emergency situation

Additional thermal problems may occur in the case of an emergency, especially if the vehicle body is severely damaged, a situation causing a dangerous pressure drop inside the passenger cabin.

The human body is very sensitive to any kind of pressure variation. The physiological effects are mainly a function of the pressure drop or increase rate and the lowest pressure levels.
In the case of *SwissMetro* the two most important health risks for passengers are Hypoxia and different forms of decompression sickness, also called Dysbarisms. They have a major influence on the safety aspect of the concept and will play an important role in the licensing by the safety authorities.

Hypoxia can be defined as a lack of sufficient oxygen in the body cells or tissues. It is usually caused by inadequate oxygen supply in the inspired air.
Decompression sicknesses or Dysbarisms are caused by gas expansion within or on the body and may be divided into two groups:

- Trapped gas: During increase and decrease of the pressure level free gas expands or contracts in certain body cavities. A person's inability to pass this gas may lead to abdominal pain or pain in ears and sinuses.
- Evolved gas: These conditions are produced by the low atmospheric pressures in the tunnel, similar to a flight at high altitude. Gases escaping from solution in the blood and other body tissues are responsible for conditions such as chokes, paresthesia and central nervous system problems.

These physiological effects give the time and pressure level limits which have to be observed in an emergency evacuation scenario. To avoid the negative impact of very low pressures on the human body the inside tunnel pressure has to be raised quickly. In case of a minor emergency without perforation of the vehicle, the tunnel does not have to be repressurized.

If the body of the vehicle is ruptured and the pressure inside the cabin has already dropped to the outside tunnel pressure, there is only limited time to repressurize the tunnel. In the current phase of the project it is planned to divide the tunnel into different sections which can be shut off separately. The remaining volume is either repressurized from a reservoir under atmospheric conditons, or from a high pressure reservoir. The main influence factors on the repressurization time are number, arrangement and diameter of the repressurization valves.

The results of Guigas "Etude de la repressurisation des tunnels du SWISSMETRO" have shown that shock-waves and a significant temperature raise during the repressurization may cause serious problems. To analyse the unsteady, compressible flow a 1D-model was used.
To verify and refine the results currently a commercial 3D CFD Code is used to calculate the transient temperature and pressure distributions in the tunnel.

References

Monnier, Th.
"Bilan thermique du système Swissmetro"
Internal report; SwissMetro Main study; EPFL 1994

Guigas, X.
"Etude de la repressurisation des tunnels du SWISSMETRO"
Internal report, SwissMetro Main study; EPFL 1996

Parlavantzas, C.
"Safety review of the SwissMetro public transportation system"
Internal report; SwissMetro Main study; EPFL 1995