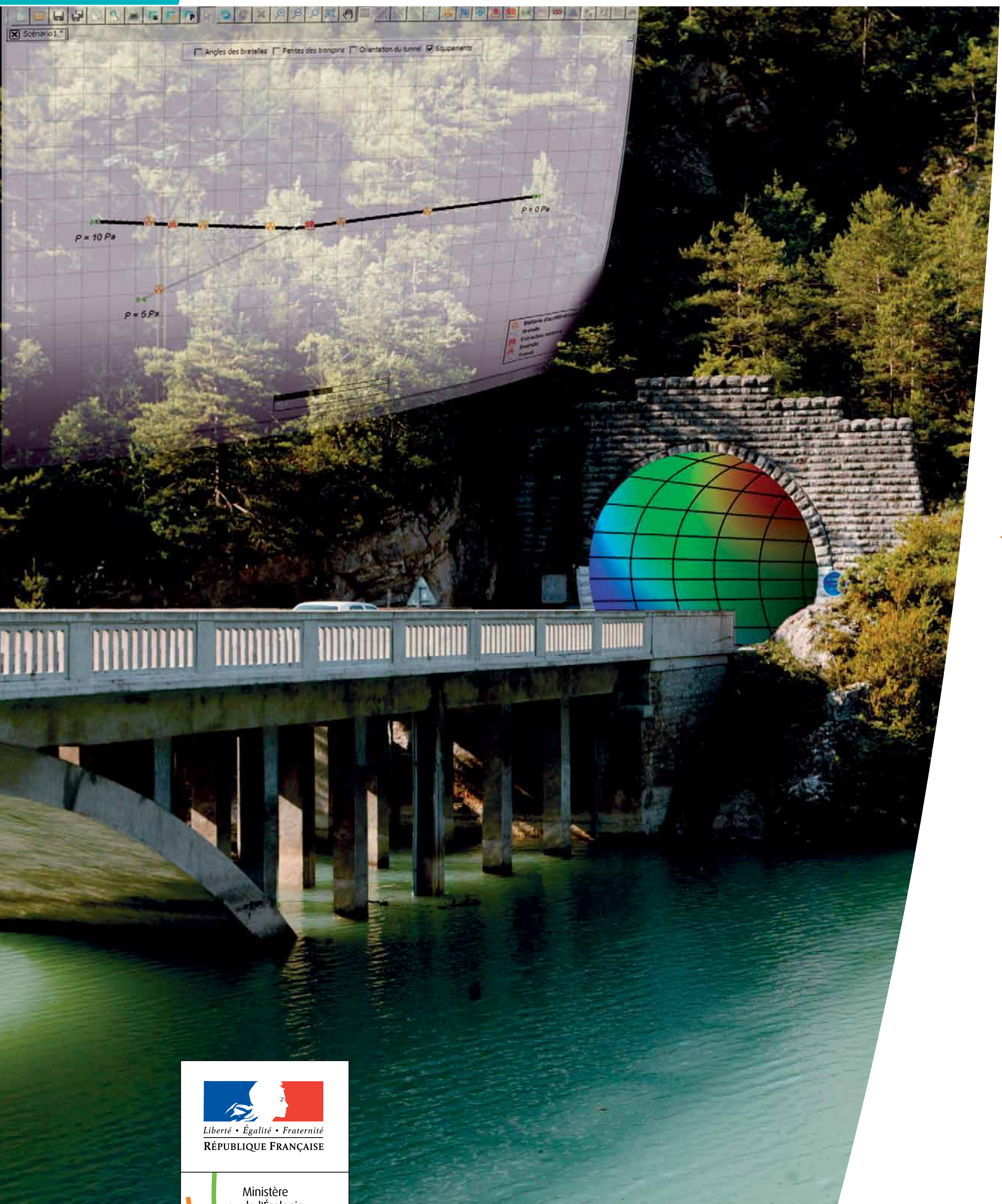
Guidelines

AIR FLOW MODELLING FOR TUNNELS
VOLUME 1: TOOLS AND CHOICE CRITERIA



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CONTENTS

INTRODUCTION

Ventilation and safety studies for tunnels require numerical simulations to assess the movement of air, and of smoke when applicable, under various circumstances. These simulations make use of software herein referred to as “numerical simulation tools”.

In the field of fire safety, the results provided by these tools are essential in assessing the safety level of a tunnel and may lead to substantial modifications in a project. In other fields of tunnel operation, the results of aeraulic simulations may also determine important investments, for example regarding the impact of tunnels on their immediate surroundings.

Therefore, the expectations regarding the reliability of the tools used and the interpretation of the results are high. These tools are only used by specialists. The owner or operator of the tunnel is unlikely to be able to evaluate the relevance of the choices made by their contractor. This situation may not be the best for carrying out a project given the stakes linked to aeraulic modelling.

This document is thus aimed at tunnel owners or operators and their advisers. Its goal is not to make the reader a specialist in modelling, but rather to explain the main choices to be made in the studies, provide project leaders with the essential notions related to the capabilities and limitations of modelling, and allow optimal use of human, financial and time resources. Since the stakes are generally significant, it is judicious for the project leader to seek assistance from an advisor with specific skills in the field of aeraulic modelling.

Two more volumes complete this guide. Intended for use by specialists, they are aimed at designers, numerical modelling consultants and those in charge of controlling their work. They deal with one-dimensional (volume 2) and three-dimensional (volume 3, to be published) simulations respectively.

1

AERAULIC MODELS AND THEIR APPLICATIONS

The flow of air in and around tunnels often has to be studied in a relatively detailed manner because its behaviour is crucial for safety, as well as for the quality of air in the tunnel and its close surroundings.

Regarding fire safety, tunnels over a certain length must generally (by law or from risk analyses) have a ventilation system. Its sizing requires calculations which may be more or less complicated depending on the case. Moreover, assessing the performance of the smoke control system in the exact configuration of the tunnel is crucial to validate its design and evaluate the general level of safety of the tunnel. This is done by studying fire scenarios, which also provide a basis for the definition of ventilation procedures. Modelling has therefore become a universal tool in this field.

Concerning the environment, polluted effluents from tunnels may be problematic in dense urban areas. Studies are then carried out to assess their impact more precisely. Different methods exist; numerical simulation of such problems is difficult but is more and more often considered because it is cheaper and faster than the more classic scale models.

The simplest form of aeraulic modelling consists in using equations describing the overall behaviour of the system being considered (called “integral equations”), which can be solved “by hand”. Unfortunately, the physical phenomena involved can only rarely be described by such equations with sufficient accuracy. The necessary simplifications are often quite rough and induce either a risk of excessive oversizing or unacceptable uncertainty regarding the safety level. More or less complex numerical tools are therefore used almost systematically; they are essentially of two types:

- one-dimensional models (often abridged as 1-D),
- three-dimensional models (3-D), often referred to as Computational Fluid Dynamics or CFD.

2

ONE-DIMENSIONAL MODELS

These models can only be used to describe the flow **inside a tunnel**. This location, however, represents the vast majority of the performed simulations. The fundamental assumption for these models is that all flow variables (pressure, velocity, temperature, concentration of toxic gases, etc.) are uniform over any cross-section of the tunnel. This assumption is generally fairly valid without a fire, for pollution calculations for example. It is, however, never strictly true in the presence of a fire, even in situations where so-called “destratified smoke” is present (generally corresponding to poor visibility in the lower part of the cross-section). By definition, the presence of stratified smoke cannot be predicted by such models. Other phenomena, such as the variation of the efficiency of smoke extraction in the case of transverse ventilation, are also ignored because of this assumption.

Despite their theoretical limitations, one-dimensional models can prove very useful. Their main use is to compute the average velocity of air at any given point in a tunnel in quite complex configurations : tunnels with ventilation devices, with traffic, branches, etc. **This is sufficient for the majority of ventilation design studies**, either longitudinal or transverse. In the latter case, design adjustments mainly concern the control of the longitudinal air flow.

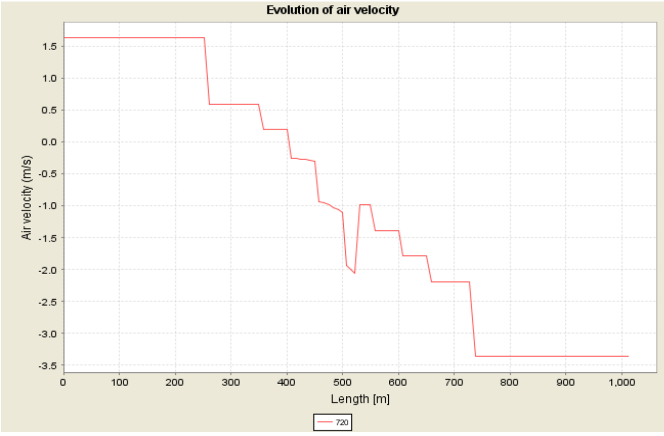

Figure 1: The velocity profile as a function of abscissa is a result of 1-D calculations which allows to assess the behaviour of a tunnel with transverse ventilation.

One-dimensional models employ simple formulations to describe phenomena such as head losses or the influence of traffic. These semi-empirical formulae often prove more accurate than three-dimensional simulations of the same phenomena, except if considerable resources are used for the latter. Including these formulae in the aerodynamic model in one dimension is straightforward and does not significantly slow down the computation.

Another advantage of 1-D models is that they require only very short set-up and computation times, even for long tunnels with many modelled devices. Simulating a fire in a tunnel of average complexity requires an hour at most to define the problem and a few seconds of computation for each fire scenario. Interpreting and formatting the results is often more time-consuming than the calculations per se. From the results, an engineer with good knowledge of the physics of tunnel fires can assess qualitatively the level of danger for people in a wide range of cases.

All these characteristics make 1-D models the most appropriate tool to size and study the general behaviour of a tunnel ventilation system, and to assess qualitatively the consequences of a fire in a majority of cases. The evaluation of risk can even be quantitative in simple situations. Some results are, of course, to be taken with caution due to the simplifications involved; the user’s expertise in fluid mechanics and tunnel fires is crucial.

The calculations being very quick to perform, it is cheap to carry out additional investigations such as sensitivity studies to uncertain parameters, for example:

- the pressure difference between the portals,
- the heat release rate of the fire,
- the reaction times,
- the leakages in the ventilation network,
- the installation efficiency of jet fans, etc.

Appendix A briefly describes a 1-D model developed and distributed by CETU, called CAMATT.

3

THREE-DIMENSIONAL MODELS

3.1 GENERAL CONSIDERATIONS

In this type of models, space is “discretised”, i.e. divided into elementary volumes or cells, forming a three-dimensional mesh. The physical variables are computed in each of these cells. The strongest assumption of 1-D models is therefore avoided. **It would, however, be illusory to think that 3-D models are a perfect representation of reality.** Indeed, in fluid mechanics, physical or chemical phenomena which have a strong influence on the flow occur at very small length or time scales. An ideal description of these phenomena would require such a fine mesh that no existing computer would be capable of performing the calculation in a reasonable time. Due to this constraint, one still has to make assumptions. The physical meaning of these hypotheses and their influence on the results are much more difficult to understand than for the 1-D flow hypothesis. Therefore, 3-D models, like their 1-D counterparts, have limitations of their own, but understanding them requires specific expertise. Moreover, there are many ways to model a given tunnel and **the modelling choices will, to a great extent, depend on the exact goal of the study.**

The uncertainties related to a 3-D modelling are generally impossible to quantify. It is therefore often judicious to choose a comparative methodology (between scenarios, technical solutions, etc.) than to seek an assessment of absolute performance. If the modelling is done properly, it can be very helpful to decision-makers.

The next section details the main choices to make to perform a reliable 3-D modelling, as well as the related stakes.

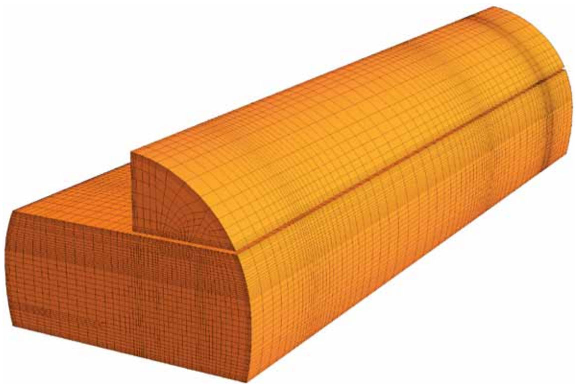

Figure 2: Example of mesh for a tunnel section and its extraction duct.

3.2 MAIN CHOICES IN 3-D MODELLING

G *denotes terms which are defined in the glossary on page 16.*

3.2.1 The calculation tool

The calculation tool used depends on the studied problem and the associated needs: geometry, most relevant output variables, permanent or transient regime, optimal modelling of a particular phenomenon, etc. For tunnel fires, the software *FDS* is more and more widely used (see Appendix B) but more general-purpose tools exist and may prove more appropriate in some cases. It would be impossible to list all uses for every available software, because the choice may be influenced by very case-specific considerations. The tools with the widest application range are also the most costly in terms of preparation and computation times.

3.2.5 Defining the modelled domain

This choice looks like the simplest of all, but it is essential because the optimisation of the usage of computational resources, as well as the relevance of the results depend on it. Indeed, if the domain is too large, one loses the possibility of using a fine mesh, which limits the accuracy of the results. On the other hand, if the domain is too small, important information may be lost. A typical case is a partially modelled tunnel in which smoke spreads beyond the modelled section.

The definition of the computational domain is a crucial step and must be properly justified, taking into account the physical problem under consideration, the expected general behaviour of the flow, and some constraints related to the physical and numerical models used.

3.2.3 Mesh and sub-models

The mesh[G] is the decomposition of the physical domain into a large number of cells. The shape of the cells is variable. The two most common mesh types are hexahedral mesh (6-faced cells, often parallelepipeds) and tetrahedral mesh (4-faced, pyramid-shaped cells). In the case of tunnels, the hexahedral mesh is more common because in a tube-shaped geometry, it allows minimising the number of cells for a given 'quality' of the numerical result. The number of cells varies from a few hundred thousand to several million. This number is the most influential parameter on computational cost (the duration of the computation and the amount of computer resources used). In order to obtain a realistic result, it is of course preferable to use as fine a mesh as possible. However, the geometrical scale of tunnels make it difficult to use cells smaller than 10 cm in edge length for applications other than academic research.

No information on the behaviour of the flow is available at length scales smaller than the mesh size. No phenomenon occurring at smaller scales can be described explicitly.

But several important phenomena, most notably turbulence[G], but also combustion and some forms of heat transfer, occur at very diverse length scales. In a turbulent flow, the size of eddies varies from about a metre to a few millimetres. It is impossible, in practice, to represent explicitly all these eddies, but their physical behaviour varies a lot with size. The relationship between small- and large-scale phenomena must therefore be assumed, whereas in reality, it can be very variable depending on the flow, and even between different regions of a given flow.

This is why sub-models[G] describing statistically phenomena such as turbulence or combustion must be chosen, taking into account the problem to be studied and the available mesh, from mainly empirical knowledge. For the same reasons, it is often impossible to quantify the uncertainty of a 3-D modelling. Expertise in the related scientific fields is therefore essential to build a consistent physical and numerical model.

Regarding the mesh, an important step of the process is the mesh sensitivity test. Different levels of fineness should be tested if possible. The mesh which is eventually used must ensure that the results are very close to what they would have been with a finer mesh. The limit of acceptability for a given mesh depends on the required degree of accuracy in the study and the available resources.

Finally, it should be noted that creating the geometry in the software, meshing and possibly testing sub-models can require a very significant amount of time in complex cases.

3.2.4 Boundary conditions

To perform a calculation, the model requires specifying the behaviour of the flow at the boundaries of the computational domain. Different types of boundary conditions exist: imposed velocity or pressure, smooth or rough walls, etc.

While there are various possible boundary conditions, it should be underlined that in practice, none of them can represent perfectly the real flow. The modeller should be aware of the influence of their choices, by performing preliminary tests if necessary. In numerous cases, moving the boundary condition away from the main area of interest reduces the sensitivity of the results with respect to this condition. This allows using "standard" conditions if no specific and sufficiently detailed data is available.

Boundary conditions have a determining influence on the results of a simulation. The physical validity of the modelling is largely based on them. The modeller should therefore know the consequences of the related choices they have to make regarding them, get as close as possible to the physical reality and use boundary conditions which are consistent with the definition of the domain and the sub-models.

3.2.5 Source terms and modelling of fires

The way the fire zone is modelled is obviously important for the quality of a fire simulation. Different, more or less realistic methods are available. It is, however, not always necessary to use the most accurate methods.

The simplest method consists in representing the fire as a simple **heat source** with a fixed geometry; it can be coupled with a pollutant source (recommended to analyse the evolution of visibility and toxicity). This source is distributed in the space surrounding the fire place. One has to make sure the simulated temperatures remain realistic. If the source is too "concentrated", very high temperatures are computed, leading to unrealistic heat transfer. The main advantage of this method is that it is fast (in set-up and computation); it is generally sufficient for smoke control studies on relatively large domains (a few hundred metres). It is, however, not accurate enough to predict temperatures close to the fire.

A **combustion model** may also be used. It computes the concentrations of fuel and oxidant at every mesh point and deduces the heat release from them. This procedure makes the computation significantly heavier (the case of the software *FDS* is particular, see Appendix B). It should therefore be employed only in cases in which relatively accurate prediction of temperatures near the fire is sought, for example to assess the thermal impact on the structure. It is also worth noting that most combustion models were originally developed for industrial applications (thermal engines, burners, etc.), not for accidental fires in which widely different physical processes are at stake.

In practice, even when a combustion model is used, **the heat release rate of a fire and the production rate of toxic compounds and soot should be specified explicitly**. It would be unrealistic, with current knowledge and equipment, to assess these values by modelling from the physical and chemical composition of the fire (vehicle type, size, cargo for example); this could lead to gross errors. The main goal of the combustion model is to predict the shape of flames, and therefore the temperature field, more accurately.

3.2.6 Permanent or transient regime

A fire is an event during which the conditions vary very widely. Therefore, it seems natural to perform simulations in transient regime[G]. However, these simulations are very long and costly. It can be interesting to restrict the study to permanent regime[G], for example when sizing a ventilation system, for which the dimensioning situation will be a sustained, fully developed fire. Specific methodologies involving both types of simulation can also be applied.

The software *FDS* cannot perform permanent regime simulations because of the type of turbulence model used, which is transient by nature. Time-independent (steady[G]) boundary conditions can be applied, and the flow can then be allowed to develop until a somewhat stationary state is reached..

For simulations outside a tunnel, the situations studied are generally steady (the boundary conditions do not depend on time). The permanent regime is therefore more suitable.

3.2.7 Specific applications

3-D models are theoretically capable of simulating any type of fluid flow. In the case of tunnels, the most classical application is a fire simulation inside a tunnel, for which modelling practice has been established for a number of years. Simulation tools are, however, more and more often applied to more complex situations, such as the study of the behaviour of a tunnel as a function of external wind, the dispersion of pollutants in the vicinity of a road tunnel, etc. These studies are very useful, especially because the physical phenomena are less well known qualitatively than the behaviour of fire smoke. They cannot, however, be considered common practice and they require specific expertise. The owner or operator should pay extra attention when choosing a contractor and demand proper justification of the modelling choices. It is especially judicious to seek external assistance in such cases.

4 CHOICE CRITERIA AND COMPLEMENTARITY BETWEEN MODELS

4.1 CHOICE CRITERIA BETWEEN 1-D AND 3-D MODELS

In practice, 1-D modelling, in combination with good physical knowledge of tunnel fires, is often sufficient to dimension a ventilation system. In the case of innovative systems, unusual geometries, etc., 3-D modelling can fill in some gaps. Regarding hazard studies, 3-D modelling generally yields more accurate results by giving information on the stratification of smoke and by computing the movement of smoke fronts reliably. However, depending on the geometry, the ventilation system and the accuracy of the hypotheses for other models (notably egress), a 1-D model may be sufficient. Finally, in some studies, only 3-D models are suitable (for example, the behaviour of a tunnel portal).

The choice criterion between 1-D and 3-D models is not always directly linked to the ventilation strategy (longitudinal or transverse). In transverse ventilation, the ventilation strategy is based on smoke stratification, which can be modelled in 3-D only. Representing it is, however, not always necessary. For example, if the feasibility of controlling the longitudinal air flow is considered, a 1-D model is sufficient and will probably yield more reliable results. Optimizing the geometrical set-up of extraction dampers, on the other hand, requires 3-D modelling.

In addition to the characteristics of the tunnel, the physical phenomena which are relevant for the particular problem under consideration should be taken into account to choose the most appropriate model.

Table 1 (overleaf) sums up the models generally used for different types of studies.

4.2 COMPLEMENTARY USE OF BOTH TYPES OF MODELS

In most cases, and particularly for hazard studies, the best compromise between the quality of the results and the resources used will be reached by combining both approaches. For example, the general aeraulic behaviour of a tunnel can be studied quickly and reliably using a 1-D model. A large number of scenarios can be analysed, and good physical knowledge allows the engineer to qualify those cases (acceptable, unacceptable, uncertain). The uncertainty in problematic cases can be related to the stratification of smoke, its confinement or the efficiency of extraction. 3-D modelling can then be used to dispel it.

The interest of a complete 1-D study before using any 3-D model is twofold: it allows the restriction of the 3-D study to those cases for which it is really needed; it can also provide reliable boundary conditions for the 3-D simulation, allowing a reduction in domain size and optimisation of numerical convergence. The time and money savings, as well as the improvement in the quality of the results, can be very significant.

In all cases, especially the most "classical" ones, it is important to assess the potential added value of 3-D simulations before performing them. Information of comparable interest can sometimes be obtained by less costly methods.

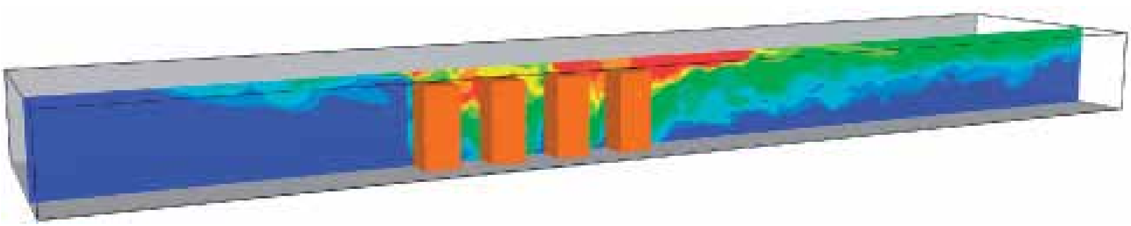

Figure 3: Example of 3-D result: temperature field in the vicinity of a fire.
Precise knowledge of ceiling temperatures can only be obtained by 3-D simulation.

Problem under study	1-D	3-D
Dimensioning of the system: jet fans or ventilation flow rates		
For longitudinal ventilation		
For transverse ventilation	✔ (a)	
Definition of basic scenarios for day-to-day ventilation and smoke control	✔	
Optimisation of the ventilation system		
Longitudinal positioning of jet fans	✔	
Fine-tuning of smoke control scenarios		✔
Geometry of extraction dampers (unusual)		✔
Fine-tuning of flow rates for smoke confinement (unusual)		✔
Transverse positioning of jet fans, improvement of efficiency (unusual)		✔
Hazard studies		
Longitudinal ventilation, in cases where control of the longitudinal air flow is not required	✔ (b)	✔
Transverse ventilation, or longitudinal ventilation in a scenario where control of the longitudinal air flow is required		✔
Reconstruction of real fires		
Reconstruction of ventilation scenarios	✔	
Reconstruction of conditions during the fire		✔
Fire safety engineering (for structural resistance)		
Computation of thermal sollicitations on structures		✔ + combustion
Impact on the environment and neighbouring tunnels		
Dispersion of pollutants at tunnel portals, of smoke, recycling between bores or neighbouring tunnels		✔

(a) In this case, modelling is generally used to size devices for controlling the longitudinal air flow.

(b) Section-averaged vaues (of toxicity, opacity) are generally insufficient to assess the conditions at user height for scenarios where users may find themselves surrounded by smoke (congested traffic, air velocity lower than the critical velocity).

Table 1: Type of model to be used for the various types of studies performed on tunnel, except specific cases related to the nature, the function or the complexity of the tunnel. A 1-D study is always recommended before any 3-D modelling.

5

CLAUSES TO CONSIDER IN CONTRACTS

Regardless of the model used, a numerical ventilation study is reliable only if it is carried out with a rigorous method and if the technical choices are suitable for the tunnel studied and the objectives of the study itself. Several types of clauses can allow improvement of the reliability of studies.

5.1 SPECIFICATIONS OF THE STUDY

The programme can include certain details about the objectives of the study, but also about the tools to be used. It is necessary, before ordering a study, to define precisely the questions to be answered. Then the exact nature of the most critical phenomena with respect to these particular questions will allow the choice of an appropriate tool, rather than, for example, the type of ventilation system. Defining a preferred tool at this stage, or specifiying methodological demands, leads to more easily comparable bids from a technical and financial point of view. Potential contractors should be discouraged from proposing 3-D simulations which would not add much value considering their cost, but which could look attractive to the tunnel owner due to their supposed technical superiority. The emphasis should be put on the methodology.

5.2 QUALITY CONTROL

Any modelling requires certain hypotheses which may have a great influence on the conclusions of the study. The results should also be interpreted rigorously. In order to guarantee this, several demands may be specified:

- Before performing any computation, to write a **note justifying the tool used and the hypotheses of the model**. Template lists can be found in the CETU guides dedicated to each type of model[1].
- **To have the calculations double-checked** by a person who is competent in the field of modelling, within the contracting company but distinct from the one who has carried out the study (external control).
- To present **raw calculation results**, to write a **methodological note on their interpretation** and then a note with the conclusions.

For any calculation inside a tunnel, it is strongly recommended to include in reports the evolution of the average longitudinal velocity of air with space and time. This result allows immediate qualitative verification of the consistency of the simulation with the scenario being studied.

1 : For 3-D studies, see volume 3 of this guide (to be published) or *Guide to road tunnel safety documentation*, booklet 4 — “Specific hazard investigations” (CETU, 2003), annex D, section D.3 which gives a list applicable to any 3-D calculation, even outside the scope of hazard investigations for road tunnels.

6 CONCLUSIONS

Numerical modelling of air flows in tunnels or their close environment has become widespread, notably in the field of fire safety. It remains, though, a technically complex subject.

Two main types of models exist: 1-D and 3-D models. Each offers different possibilities. It is therefore important to choose the more appropriate tool, and in numerous cases a complementary use of both types of models is likely to yield the best cost/quality ratio.

1-D models do not represent the stratification of smoke, which is often an important limitation for hazard studies or risk analysis. However, they are generally sufficient for sizing ventilation systems. They also remain the only practical tool to perform parametric studies with a large number of scenarios, and to include phenomena which are difficult to model in 3-D, such as the influence of traffic. Good physical knowledge of tunnel fires helps to conclude at least qualitatively on the safety level for a large part of the scenarios. Despite their theoretical limitations, 1-D models offer possibilities which should not be underestimated.

3-D models are useful to fill in the gaps in a 1-D study when uncertainty remains on specific phenomena, most notably the stratification of smoke when it is important for user safety. However, the modelling process is complex. Numerous choices have to be made and can greatly influence the final result. The reliability of the results is therefore more difficult to assess than in 1-D. Importantly, the contractor must be capable of justifying their choices with respect to the specific problem under consideration. Dedicated external assistance to the tunnel owner is useful.

Moreover, progress in phenomenological knowledge, along with the intrinsic uncertainty of 3-D simulation, leads to situations where the added value of 3-D simulation for “classical” scenarios (standard fire in a usual geometry) is low. The human and financial resources used for such simulations could be employed to obtained more valuable information, for example through sensitivity analyses using a 1-D model.

3-D models are also more and more often used to study the interactions between the tunnel and its environment (influence of wind on the air flow in the tunnel; dispersion of pollutants from the tunnel). These specific studies are often valuable but also very difficult given the lack of feedback and documented ‘best practice’. The level of expertise of the contractor is crucial for a successful study, and external assistance to the tunnel owner is even more useful.

APPENDICES

APPENDIX A – *CAMATT*

CAMATT is a French acronym for "one-dimensional aniso-thermal transient calculation in tunnels". It is a one-dimensional computer tool for modelling flows in tunnels, distributed by CETU.

Among other features, it takes into account the heating of the tunnel walls during a fire, a phenomenon which increases the air temperature in the tunnel and is not always included in 1-D models.

Today, *CAMATT* is the most widely used 1-D modelling software in France. Some consulting firms have developed their own tools, with comparable performance. As for any model, using a tool that is well known by the user is always preferable as long as minimum performance is guaranteed. Such minimal requirements are listed in Volume 2 of this guide.

APPENDIX B – *FDS*

Fire Dynamics Simulator or *FDS* is a 3-D simulation computer tool dedicated to fire simulation. This tool was developed by the National Institute of Standards and Technology (NIST), a US government agency. Within a few years, it has become the most widely used software in the field of fire safety worldwide. This success can be explained by several factors:

- The software is in the public domain and therefore available free of charge on the Internet.[2].
- It is quite easy to use by beginners.
- The calculations are fast (for a 3-D model).
- It comes with a good visualisation tool (*Smokeview*).
- Its source code is open and customisable.
- There is a large community of users and numerous validation cases are available.

These advantages come with a number of drawbacks:

- Geometry is limited to plane-parallel shapes.
- Only one model is available for turbulence, radiation and combustion phenomena.
- Permanent regime computation is not available.
- The numerical methods used are somewhat less accurate than those used in 'industrial' or research codes.

It is important to stress that *FDS* is originally a tool dedicated to fire simulation in buildings, and has been optimised for such cases. When tested on academic cases of tunnel fires, it yielded very acceptable results compared to 'industrial' tools. However, care should be taken when performing less classical studies. The simulation of flows outside a tunnel, in particular, is very different from the original usage of *FDS*.

It should also be pointed out that *FDS* uses a form of turbulence modelling which implies certain constraints, notably regarding the mesh. By default, it also uses a specific combustion model which adds only little to the computational cost but requires precaution.

From experience, the main advantages of *FDS*, namely its zero cost and ease of use, also turn out to be its most significant drawbacks. Indeed, users who are not sufficiently competent in numerical simulation can perform calculations yielding physically plausible results, but with little reliability from a quantitative point of view.

2 : http://fire.nist.gov/fds
3 : See A. Rahmani, *Simulation des Grandes Echelles pour les incendies en tunnel routier*, PhD thesis, Claude Bernard Lyon 1 University, 2006.

GLOSSARY

Boundary condition
A mathematical condition imposed at the boundaries of the computational domain. These conditions are necessary to solve the equations numerically or analytically.

Mesh
The set of points in space at which an approximate solution of the model equations is wanted. The aforementioned points are called computational nodes. A finer mesh, i.e. nodes which are closer together, generally yields better accuracy of the numerical solution.

The set of time values at which the approximate solution is computed is sometimes referred to as 'time mesh'.

Numerical model
A tool allowing approximate calculation of physical variables. The numerical model describes reality in a simplified manner. The physical hypotheses — i.e. those related to the phenomena seen as significant for the problem under consideration — lead to a description of reality through mathematical equations. These equations may be simplified using mathematical hypotheses — e.g., on the relative magnitude of certain terms — which may or may not be interpreted physically. Finally, if the equations cannot be solved analytically, which is generally the case in fluid mechanics, an approximate resolution is performed on a finite number of points in space and for a finite number of instants, by mathematical techniques referred to as 'numerical analysis'. This process introduces a certain amount of inaccuracy.

Permanent regime
The characteristic of a flow in which all variables (velocity, temperature, etc.) are independent of time. When the temporal evolution of a flow is negligible or is not relevant for a given study, assuming permanent regime allows the modeller to solve the equations only once.

The expression "steady regime" is also used. In order to avoid any confusion, it is not used in this guide, and the adjective "steady" only applies to the input variables of the model (see below).

Transient regime
The opposite of permanent regime; the characteristic of a flow in which variables evolve with time. Simulating a flow in transient regime require solving the equations for each simulated instant, hence much longer computation times than in permanent regime.

Sub-model
A set of algebraic or differential equations describing one of the phenomena at stake in the modelled flow. The most important sub-models are related to turbulence, chemistry (including combustion) and heat transfer.

Steady
Adjective applied to an input variable (boundary condition in particular) of the model which does not vary with time. A flow with steady boundary conditions is not necessarily permanent. The propagation of the smoke front from a fire of steady heat release rate is a typical counter-example.

Turbulence
A phenomenon consisting in a generalised instability of the flow, which arises beyond a certain velocity or length scale of the flow. For air flows in tunnels and the atmosphere, turbulence is always present. It is characterised by the random formation of eddies of various sizes. Turbulence and its effects on the flow (mixing, energy loss) can in theory be described statistically, but they depend strongly on the problem under consideration.

NOTES

NOTES

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