Project no. TST3-CT-2003-506437

ITARI

Integrated Tyre And Road Interaction

Specific Targeted Research or Innovation Project

Priority 6
Sustainable development, global change & ecosystems

ANNEX OF DELIVERABLE 2.2

Improvement of the air pumping CFD modelling

Start date of project: **2004-02-01**

Duration: **36 months**

Lead contractor for this deliverable: Centre Scientifique et Technique du Bâtiment (CSTB)

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draft 1
CFD model of air pumping

Objectives of WP2:
> To predict noise radiation from road/tyre interaction, providing a global model
> To integrate important parameters: tyre shape, contact patch geometry, porosity…
> To consider « air pumping » sources as well as tyre vibrations
> To carry out a parametric study
**Approach**

> **General approach:**

Spatial domain is divided into 3 zones

**Zone 3**
Acoustic propagation beyond the tyre (BEM, ray tracing...) and in the porous layer of the road

**Zone 2**
Acoustic propagation inside and near the contact patch (CFD)

**Zone 1**
Air pumping modelling in the contact patch (CFD)

> **Aeroacoustic sources (Air pumping) model:**

Build-up of a noise source model for each road texture profile, from a database of single cavity noise sources computed by CFD simulations

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**First results**

> Nonlinear effects in acoustic propagation near the tyre can be neglected

> A multi-domain module has been implemented in the BEM code MICADO and allows to simulate acoustic propagation in the porous layer of the road in 2D

> CFD simulations have shown that several type of aeroacoustic sources exist near the contact patch

> Air compression and release in road cavities during tyre/road interaction seems to be the main aeroacoustic noise source in high frequency

A first 2D CFD model has been made and provide correct trends
Outlines

1. Improvement and validation of the CFD model
   > Improvement of the compression modelling
   > Validation of the air resonance at the opening of the cavity in 2D
   > Full simulation

2. Study of simple cases
   > Study of the cavity shape effects
   > Simulation of cavities successions

3. Build-up of the noise source model

4. Conclusion

CFD modelling of air pumping

Approach:
   > Modelling of the fluid behaviour by solving the Navier-Stokes equations
   > The CFD (Computational Fluid Dynamic) solver FLUENT is used
   > Tyre and road surface are smooth
   > The reference frame is the tyre and the cavity slides
   > The displacement velocity is 80 km/h for all simulations
   > The cavity geometry is taken from Hamet experimental device
Improvement of compression modelling

Boundary conditions:
> Wall velocity is considered on the road surface (translation movement) and on the tyre surface (rotational movement) equal to the movement velocity (80 km/h)
> With or without airflow

Geometry:
> The static deformed shape of the tyre
> The discretisation of the sharp angle stops at a certain distance of the contact point
> Approximation of a the tangential velocity
> Local effects (boundary layer)
Improvement of compression modelling

**Turbulence model:**
- Turbulence modelling according to the configuration and the available data
- Several turbulence model (k-e, k-w...) were tested and the model k-w has been chosen
- The overpressure is created locally in the horn and the boundary layer effects are very important.

**Results convergence:**
- Meshing of the sharp horn near the contact point
- Effects only very close to the contact point
- Time step / cpu time
Results for a rectangular cavity (15x30mm):

- Effects of the different parameters

![Graph showing results]

Experimental result (Hamet, 1990)

$P_{\text{max}} = 1650 \text{ Pa}$

Validation of the cavity resonance at the trailing edge

Numerical models:

- Fluent: non viscous fluid, solving Euler equations
- Micado: BEM 2D + FFT

- 1st case: single rectangular cavity
  => Pressure signal at several distances
Validation of the cavity resonance at the trailing edge

Rectangular Cavity

The first positive part of the signal is missing in the BEM computations. That is probably caused by the source modelling in BEM.
Validation of the cavity resonance at the trailing edge

The first positive part of the signal is missing in the BEM computations. That is probably caused by the source modelling in BEM.

> 2nd case: triangular cavity (without movement) with a tyre
Validation of the cavity resonance at the trailing edge

Full simulation of Hamet experiments

Air compression and release in a rectangular cavity (15x30 mm) at 80 km/h have been simulated in a single simulation in 2D without airflow.

Pressure signal are shown at the leading edge, at the trailing edge, and at the bottom of the cavity.

The pressure wave at the leading edge was not expected a priori, but it can be seen in the measurements.

Pmax = 820 Pa
Full simulation of Hamet experiments

Measurements of Hamet for a cylindrical cavity (15x30 mm) at 80 km/h in 3D

- Pressure signal at the trailing edge before filtering
- Pressure signal from the leading edge predicted by the simulations
- Pressure signal at the bottom of the cavity
- Pressure at the trailing edge
- Pressure wave at the bottom of the cavity
- Pressure signal at the leading edge

- \( P_{\text{max}} = 1650 \text{ Pa} \)

Full simulation of Hamet experiments

2D simulation of air compression and release in a rectangular cavity (15x30 mm) at 80 km/h

- Pressure fields
- Pressure wave at the leading edge
- Pressure wave at the trailing edge
**Effects of the cavity shape:**

> Several simulations have been carried out with a rectangular cavity, a triangular cavity, and a cosine profile cavity
> The triangle and the cosine provide almost the same results
> The overpressure is bigger for the cosine than for the rectangle because of the volume change
Effects of the cavity shape

Scale effects:
> A cosine profile cavity 10 times smaller than the previous one (1.5x3mm => more realistic road cavity size)
> The overpressure is twice bigger but the pressure signal at the trailing edge is 5 times smaller

Interaction between cavities

Succession of 2 triangles:
> The 2 cavities have not the same behaviour

Succession of 10 cosines:
> The first and the last cavities have edge effects
> The cavities of the middle have almost the same behaviour
Interaction between cavities

Simulation of a succession of 10 cavities

Succession of 10 cosines:

> The main assumption to build-up of an equivalent noise source is that each successive cavity is independent
> The signal due to a succession of cavities is compared with the sum of signals from single cavities delayed
> The results show there are obviously interactions between cavities at the trailing edge
Interaction between cavities

Succession of 30 cosines:

> The cavities are, in this case, 3 times narrower (5x30 mm)
> There are 30 cavities on the same distance (15 cm) than with the previous case
> There are more interactions between the cavities at the air release

Interaction between cavities

Study of the linearity of the noise source related to the road texture profile (test of the validity of the Fourier decomposition assumption):

> A simulation has been carried out with a road texture profile corresponding to the sum of the two previous cosine profile
Interaction between cavities

Test of the validity of the Fourier decomposition assumption:

- The sum of the signals is not so bad (except a phase shift)
- The pressure signal recorded at the trailing edge looks like the signal from the 10 wide cosines

Spectrum of the signals at the trailing edge

Build-up of the noise source model

The general idea was to build the noise source model for a road texture profile from a database of computed single cavity noise sources according to the spectrum of the road texture profile (Fourier decomposition)

Some preliminary assumptions:

- A succession of cavities is equivalent to the sum of these cavities considered alone
- The use of spectral decomposition of the road texture profile implies the phenomenon has to be linear

The previous simulations show these assumption are not obvious!
Build-up of the noise source model

What description of the road texture profile should we use?

> It seems that only the volume and the depth of a cavity control the overpressure (only the coarse envelop of the texture is necessary?)

> At the trailing edge, cavities act as resonators. Do a succession of cavities act as a sum of resonators? From a certain length, there is no more interaction so can we sum short cavity successions?

Other remarks:

> The deformation of a single cavity is negligible but the tyre deformation due to a succession of cavities is probably not negligible.

Conclusion

> Improvement of the simulation of the air compression in the cavity

> Validation of the air resonance at the trailing edge in 2D comparing with MICADO results

> Full simulation of the phenomenon

> Study of geometric parameters effects for a single cavity

> Simulation of cavities succession

=> Building of a noise source model
> Continuation of the study of interactions between cavities
> 3D simulation with a cylindrical cavity to fit Hamet measurements
> Parametric study
> Building of the noise source model
> Porosity modelling in Fluent (?)

> MICADO 3D