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DYNAMIC RESPONSE OF PASSENGER CARS IN TURBULENT WINDS

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SUMMARY:

The objectives of the research are to investigate the dynamic response of passenger cars in turbulent winds with specific reference to the study and measurement of aerodynamic admittance using spectral methods for a typical vehicle shape. Previous work has been on simple shapes, principally in wind engineering. Experimental work will be undertaken in the RMIT and large Monash wind tunnel, which can test full-scale cars. Full-scale tunnel verification has not previously been undertaken. On-road testing is also scheduled. An expected by-product of this work will be an assessment of the minimum flow quality necessary for satisfactory measurements in a wind tunnel.

OBJECTIVES:

The scope of this project is currently limited to gaining an understanding of the aerodynamic response of passenger cars in turbulent winds under low, medium and strong winds, excluding extreme conditions (>10 m/s). It is estimated that 95 % of driving occurs under these conditions.

The research well address the comfort and also partly the safety criteria, because typical passenger cars can exhibit significant dynamic response under turbulent crosswinds. After driving under strong crosswinds, the driver would be tired and start to represent a safety hazard on the road. This problem has been identified by the American Society of Automotive Engineers Crosswind Response Sub-Committee and also by the RMIT Vehicle Aerodynamics Group, a member of the Sub-Committee, in initial tests at the RMIT/Monash Wind Tunnel. Normally this car behaviour would also strongly attributed to tyre or the road-surface characteristics. However, these initial tests showed it was principally an aerodynamically-driven phenomenon.

The objectives of the research are to :

1. Consider an appropriate analytical model of the dynamics of passenger cars;

2. Investigate and experimentally determine the aerodynamic inputs in smooth and turbulent flow using the aerodynamic admittance approach (aerodynamic admittance relates the incident turbulent fluctuations of the wind to the fluctuating forces on the cars);

3. Measure the dynamic response of passenger cars and passenger-car shapes in smooth and turbulent winds in the wind tunnel and on the road;

4. Compare the outputs (response) of the model (1) using the inputs in (2) with tunnel and road response data (3)

5. Suggest the minimum flow quality necessary for satisfactory simulation of the on-road environment for car dynamic response in a wind tunnel.

RATIONALE:

To save energy, cars are becoming lighter and more streamline. As a result, cars become less aerodynamically stable. Therefore, the vehicle companies are increasingly interested in studying vehicle dynamic response under turbulent winds.

An existing analytical approach (aerodynamic admittance) commonly utilised in determining building vibrations will be further developed with the consideration of components relevant to passenger cars.

This work will extend previous studies which measured aerodynamic admittance functions of a square plate, a rectangular cylinder and a slabbed-sided commercial vehicle. In these studies there have been few full-scale vehicle measurements or work specific to car shapes.

The successful results of this research would be valuable for automotive design to increase safety and driving comfort. As a side benefit, the dynamic wind load on structures is a common but complex problem and the research would also contribute to its better understanding and estimation.

PROGRAM SEQUENCE:

The program sequence is as follows:

Literature Search including CD Rom and international data base search; understanding existing methods in aeronautical, vehicle and wind engineering (structures).

Analytical Approach: Review existing dynamic car models and apply spectral methods with aerodynamic admittance approach to 3D car shape.

Experimental Planning: Design appropriate experiments for wind-tunnel (models and turbulence simulation) and on-road studies. This includes studying modification of full-scale car suspension, recording and analysing data methods, wind-tunnel calibration ...

Preliminary Experiments: Undertake first wind-tunnel and on-road tests to evaluate data quality and determine experimental refinements required, consideration of experimental hypotheses.

Refined Experiments undertaken to assess hypotheses.

Writing Reports, Papers and Thesis will occur in parallel

APPENDICES :

THE AERODYNAMIC ADMITTANCE OF A SINGLE-DEGREE-OF-FREEDOM (SDOF) SYSTEM TO RANDOM EXCITATION

Similar to an approach detailed by Scruton, the SDOF system under consideration is shown schematically in Figure 1.

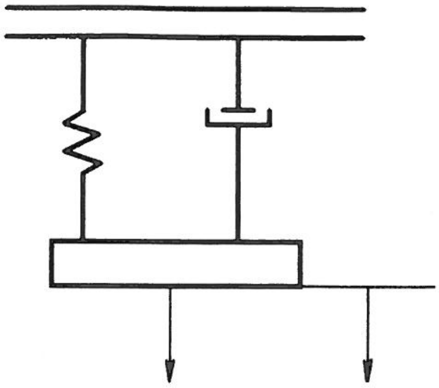

Fig.1 Single degree of freedom system

The equation of motion is

$$M\ddot{Y} + C\dot{Y} + K_s Y = F(t) \qquad (1)$$

from which we can separate a time-average response of $\bar{Y} = \bar{F} / K_s$ and for the fluctuating component we can write

$$M\ddot{y} + C\dot{y} + K_s y = f(t) \qquad (2)$$

If $f(t)$ is expressed in terms of a power spectral density function S_f(n) such that

$$\sigma_f^2 = \overline{f(t)^2} = \int_0^\infty S_f(n)dn \qquad (3)$$

the response is given in terms of another spectral density function $S_y(n)$:

$$\sigma_y^2 = \overline{y(t)^2} = \int_0^\infty S_y(n)dn \qquad (4)$$

$$= \frac{1}{K_s^2}\int_0^\infty |H(n)|^2 S_y(n)dn \qquad (5)$$

$$S_y(n) = \frac{1}{K_s^2}|H(n)|^2 S_f(n) \qquad (6)$$

Where $|H(n)|^2$ is the transfer function between the power spectral density function for $y(t)$ and $f(t)$ and is termed the structural admittance.

An expression for the fluctuating force on a small area A immersed in a turbulent incompressible stream is

$$F(t) = \frac{1}{2}\rho V^2(t) A C_D + \rho \frac{\delta V(t)}{\delta t}\frac{A^2}{d} C_m \qquad (8)$$

where $V(t) = \overline{V(t)} + u(t)$, A and d are typical area and linear dimensions, C_D is the drag coefficient, and C_m is a virtual mass coefficient.

Substituting $V(t) = \overline{V(t)} + u(t)$ and neglecting the virtual mass term C_m and the term in $\{u(t)\}^2$, this yields

$$\overline{F} = \frac{1}{2}\rho\overline{V}^2 AC_D \qquad (9)$$

$$f(t) = \rho\overline{V}Au(t)C_D \qquad (10)$$

$$\sigma_u^2 = \overline{u(t)^2} = \int_0^\infty S_{uu}(n)dn \qquad (11)$$

and a relation between the force spectrum and the gust spectrum

$$S_f(n) = 4\overline{F}^2 / \overline{V}^2 S_{uu}(n) \qquad (12)$$

This expression is only valid for a point area where the scales of turbulence are much greater than the typical dimension of the body. For the more practical case where the dimensions of the structure and the turbulence scales are of the same order, another function $|X(n)|^2$ termed the aerodynamic admittance is introduced and

$$S_f(n) = |X(n)|^2 .4\overline{F}^2 / \overline{V}^2 .S_{uu}(n) \qquad (13)$$

The final expression for the spectrum of the response for a generalised displacement Y *is*

$$nS_y(n) = 4|H(n)|^2 |X(n)|^2 .\overline{Y}^2 / \overline{V}^2 .nS_{uu}(n) \qquad (14)$$

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