WIND CALIBRATION OF MICROWAVE CAVITIES

by

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1. Introduction

The calibrations to be performed were supposed to yield information on the following questions.

a. How does the steady state pressure inside the cavity vary as function of velocity and angle of mean wind direction and cavity axis?

b. How does the steady state flow rate through the cavity vary as function of velocity and angle of mean wind direction and cavity axis?

c. How does the refractive index of the cavity respond to turbulence?

For the last question only supporting data are given, which NBS personnel have to evaluate.

2. Equipment and Procedures

The experiments were performed in the wind tunnels of Colorado State University. These have a test section cross-section of 6' x 6' which is sufficiently large to avoid throttling of the flow by the cavity.

The measurements consisted of pressure, mean velocity and turbulent intensity data. Pressures were measured with a micromanometer (Flow Corporation Type MM-2) which uses butyl alcohol (specific gravity of 0.81) as measuring fluid and which can be read to a smallest reading of 0.0002 in. of measuring fluid.

The mean velocities were measured by means of a pitot-static tube of standard (Prandtl) design. This was connected to the above manometer. The accuracy of the manometer and the stability of the flow is not sufficient to permit measurements of velocities below 4 mph, the values for 1 to 3 mph are only approximately right, with a possible error of $\pm$ 10 to 30% (the larger error corresponding to the lower velocity).

The turbulent intensities were measured only with the refractometers rather than the model cavities in the tunnel. Since the requirement was of a large turbulence structure in the tunnel, a vane system consisting of 2 x 12" lumber louvres, which could be adjusted for decreasing the obstructed area, was installed into the entrance of the test section.

The turbulent intensities were measured with a hot wire anemometer of the constant temperature type. The wire was made of 0.0002" diameter tungsten with a total resistence of about 6 Ohms. The electronics was of the type Hubbard. The typical calibration curve for the hot wire is given in Fig. 1. The turbulent intensity is equal to

$$\sqrt{\overline{u'^2}} = A\sqrt{\overline{e'^2}}$$

where $\sqrt{\overline{e'^2}}$ is the rms value of the fluctuating voltage (about a not recorded mean) as measured by a Bruel and Kjaer true rms - meter, and A is the slope of the calibration curve at the point on the curve corresponding to the local mean velocity. Spectra of turbulent energy were taken with a spectrum analyses type Bruel and Kjaer 2109.

For evaluating the residence time of the fluid inside the cavity, two series of experiments were performed in CSU's wind tunnel flume-combination (WFC). The model cavity was placed on a metal stand into the slowly running water in the bottom part of the WFC. Dye was inserted upstream of the cavity, and photographic color pictures were taken of the flow in and around the cavity, with the cavity at different angles to the flow. The residence time can be estimated from the time it takes for the water inside the cavity to loose any trace of dye. The evaluation of the photographs was left to NBS; the films have been turned over to the personnel of NBS. The water tunnel data should compare with wind tunnel data taken at the same Reynolds number, or, if the flow is fully turbulent, (Reynolds number above critical) should be independent of velocity, if made nondimensional in the following way.

We can define a "clean out" velocity for the cavity to

$$v_c = \frac{L}{T_r}$$

where L = length of the cavity and

T_r = residence time of dye inside the cavity.

A non-dimensional number

$$h_c = \frac{v_c}{u_c}$$

where u_c = flow velocity in obstructed portion of WFC

can be defined, which should, for large Reynolds numbers, depend only on the angle of inclination θ between cavity axis and flow direction.

3. Results of pressure measurements

The pressure measurements were made with the intention of obtaining an estimate of the difference between the pressure inside and outside of the cavity, and of obtaining an estimate of the relative flow through the cavity as function of angles between the direction of the mean wind and the axis of the cavity.

The pressure p_i inside the cavity was measured with respect to the hydrostatic pressure p_s. The hydrostatic pressure was taken from the static taps of the pitot static tube. With these pressures, a pressure coefficient C_p was defined to

$$C_p = \frac{p_i - p_x}{1/2\ \rho\ u^2}$$

where ρ is the density of air, and $1/2\ \rho u^2$ is the pressure reading obtained between the two ports of the pitot-static tube.

The results are shown in Fig. 2. There appears to be a large variation for the pressure coefficient at low speeds, the absolute pressure changes are, however, only small. For large velocities, the distribution attains a shape independent of velocity, bearing out the fact that due to the sharp edges of the cavity opening a velocity effect (or Reynolds number effect) should not exist, except in the regions near laminarflow or in the transition between laminar and turbulent. Since the cavity is of rather peculiar shape and does have flow through it which is obstructed by the front and rear plates, it is not possible to define an expected critical Reynolds number; from the experimental evidence one might speculate, however, that in the average for all angles the laminar flow region becomes unstable somewhere between u = 2 and 3 mph, while fully developed turbulence starts between about 5 and 10 mph.

4. Results of qualitative flow measurements.

Qualitative estimates of the flow rates were made by measuring the pressure difference between the pressure p_f against the front center of the front cavity plate and the pressure p_r against the rear center of the rear plate. The reason for this is that in a crude approximation the total pressure can be assumed constant for across the front end of the cavity as well as across the rear. Then Bernoulli's equation for the front end yields

$$p_f = 1/2\rho u_1^2 + p_{fs}$$

where u_1 is the velocity through the front holes of the cavity, and p_{fs} is the static pressure at the front end (which is not necessary equal to the static pressure in the wind tunnel, but not very far off). For the rear end one obtains

$$p_r = 1/2\rho u_2^2 + p_{rs}$$

where u_2 is the velocity through the rear holes of the cavity, and p_{rs} is the static pressure at the downstream end of the cavity. Now, the flow through the cavity can be considered to resemble the flow through an orifice under the effect of a pressure gradient $p_{fs} - p_{rs}$; and since from the condition of continuity follows $u_1 = u_2$, one obtains

$$p_{fs} - p_{rs} = p_f - p_r = C_D \cdot 1/2\rho u_1^2$$

where C_D is a discharge coefficient which should for turbulent flow and sharp edged openings be independent of velocity. Thus, for the discharge follows:

$$Q = u_1 \cdot A = A\sqrt{\frac{p_f - p_r}{1/2C_D\rho}}$$

where A is the area of openings.

Due to the crude assumptions involved, this result can be used only qualitatively. Its value lies in the fact that it shows that Q depends only on the pressure difference, if other quantities are equal. Thus, for the same velocity, if the pressure difference is the same, then the flow through the cavity should be the same also.

Applying this conclusion to the experimental results, which are plotted in Fig. 3, it can be seen that the rate of flow through the cavity does remain approximately constant from angles from 0 to 20° for all except the lowest velocities, while it decreases rapidly beyond about 25° until it readies essentially zero at 90°.

A second conclusion can be drawn regarding improving the reponse time of the cavity. This can be done by increasing the size of the holes in the front and the end plate, but there exists also the possibility of rounding the edges of the openings to converge the flow more gradually.

5. Turbulence Measurements

Three different turbulence levels were generated with the vanes described in 2. The vanes cause disturbances with frequencies essentially from almost dc to 5000 cps. Low frequencies are associated with large eddies, thus, it was thought necessary to provide for frequency information by means of an oscillograph recording of the signal obtained from the hot wire set.

The recordings are attached in a separate folder. (Note: do not expose recordings to direct sunlight). The oscillograph trace does not contain the complete signal. The oscillograph, a Honeywell Visicorder Type 1406, has a frequency response flat to only 200 cps. Also, the output of the hot wire set has a low frequency cut off at about 0.2 cps, so that all energy below this frequency remained undetected.

In order to provide information at high frequencies, the spectrum analyser was used which gave the spectral distributions associated with the different grid sizes as shown in Figs. 4 to 6. Since the spectrum analyser works only for frequencies above 10 cps, the oscillograph recordings have to serve the purpose of filling in the information between 0.2 cps to 16 cps. The total turbulent energy is recorded for different velocities and grid sizes in Table 1. The values are estimated to be accurate within ± 20%.

TABLE I

TURBULENCE MEASUREMENTS

Grid No. 1		Grid No. 2		Grid No. 3	
u_a (mph)	$\frac{u'^2}{u_a}$	u_a (mph)	$\frac{u'^2}{u_a}$	u_a (mph)	$\frac{u'^2}{u_a}$
22.6	0.212	25.6	0.104	25.6	0.029
19.4	0.20	19.4	0.113	19.4	0.028
10.3	0.16	10.3	0.113	10.3	0.016
5.0	0.093	5.0	0.025	5.0	0.006
2.6	0.043	2.6	0.013		