Dynamic and thermal interference effects on two neighbouring building models

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Abstract. The paper considers the dynamic and thermal interference effects on two neighbouring building models in the form of square prisms arranged at a short distance from each other. It is shown how relative positions of the models affect the specific phenomena caused by the airflow interactions.

1. Introduction

It is worth noting that engineers and researchers have always shown a lot of interest in the problem of wind loading. The learning potential and technical feasibility promote opportunities to study the wind flows and their effect on different objects. The recent years have seen remarkable advances in the knowledge acquisition concerning the wind effect on such objects as prisms, pyramids, cylinders, etc. In each case, the air motion has specific features. Similar methods have been used for several objects, including their mutual effect on the airflow and its turbulation.

There are two main research trends of the wind loading. The first is the wind loading on a building, which is an integral action resulting in multiple phenomena, such as static load which includes air pressure and rarefaction; dynamic load which includes airflow pulses causing vibrations of an object; and many others. Second, the air motion is a source of the convective heat exchange of a building. The latter also includes many research trends among which are heat loss and heat exchange between several objects.

The slipstream effect is the best example of changes in the dynamic airflow and the rate of heat transfer in the studied arrangement of the building models (beyond the disturbing barrier).

It is found that the slipstream which occurs near a group of buildings affects both the heat loss and wind loadings which, in turn, govern the internal microclimate of building, its operating parameters and safety.

Determination of the direct dependence between the heat loss and the wind pressure is still a complicated and multiple-factor problem that can be solved through the analysis and comparison of the dynamic and thermal interference effects based on the systematic experimental studies.

This work aims at the experimental study of the dynamic and thermal interference effects on two building models or square prisms depending on their relative positions.
2. **Research tasks. Pilot model and measurement technique**

Research tasks were based on the experimental data on the wing loads and convective heat exchange. The results of multiple experiments being collected for the last few years and their comparison with those obtained by other researchers [1–17] allowed us to distinguish general tendencies in the behavior of the interference factor. At the first stage, the building models were prepared to explore the fields of pressure applied to different sides and the local and average heat transfer coefficients in the conditions of the forced convection. The second stage included the combined exploration of the wind (dynamic) load and thermal flows and finding common changes caused by the relative positions of the building models. Due to the large data volumes [18–20], we present the experimental results under the following conditions:

1. The square prisms have the relative height \( H/a = 6 \), where \( a = 50 \text{ mm} \) is the size of the cross-section.
2. The square prisms are arranged on one axis relative to the slipstream (figure 1).

![Figure 1. Plane view of building models arranged on one axis: 1 – obstruction model; 2 – model of interest. \( a = 50 \text{ mm} \); \( U_0 \) – airflow velocity; \( L_1 \) – axial displacement.](image)

3. The longitudinal pitch is accepted to be \( L_1/a = 0.5; 1; 1.5; 3, 4.5 \) and 6.

The final data processing and the analysis of results were based on a comparison of the identical parameters. The initial parameters of the air pressure and rarefaction \( C_p \) and the heat transfer \( \text{Nu} \) did not allow us to compare properly the changes in these parameters because of the difference in the units of measurement. On that basis, we used the interference factors \( \text{IF}(C_p) \) and \( \text{IF}(\text{Nu}) \) as parameters describing the rate of the dynamic and thermal interaction.

\[
\text{IF}(C_p) = \frac{C_p}{C_{p_0}} \quad \text{IF}(\text{Nu}) = \frac{\text{Nu}}{\text{Nu}_0},
\]

where \( C_p \) and \( \text{Nu} \) are respectively the pressure coefficient and the Nusselt number for one of the sides of the downstream Model 2; \( C_{p_0} \) and \( \text{Nu}_0 \) are respectively the pressure coefficient and the Nusselt number for the whole surface of the Model 1 in front.

Figures 2 and 3 illustrate two prismatic models with the different structure for measurements of the pressure and the heat transfer coefficients. On the side of the model for the pressure measurement there are channels for the air motion that was recorded with the multichannel pressure sensor switch. A set of thermocouples was placed at the respective points on the side of the model for measuring the heat transfer coefficient.
Measurements of the static pressure and the heat transfer coefficient as well as a study of the air motion are performed on a specific aerodynamic test bench. This test bench consists of the wind tunnel, the multichannel pressure sensor switch for recording changes in the heat transfer coefficient using the downstream model and the model of interest.

The wind tunnel is an open exhausting tube, the schematic view of which is presented in figure 4. The range of speeds in the working chamber is 1–30 m/s; the turbulent stream rate is 0.5 %.

The working chamber of the wind tunnel is 1200 mm long, its cross section is $400 \times 400$ mm$^2$. One of the lateral sides of this chamber has two windows made of organic glass. One window is intended
for the model assembling and the other is for observations and locates above the model. The chamber housing is made of steel.

The gages are placed in the working chamber via an aperture at the bottom of the channel. The aperture is sealed with a fluoroplastic band. Branch tubes are connected to the type VO-5U2 mine fan with a 7.5 kW motor. The airflow speed is varied by the speed control system using a frequency converter. The velocity profile in the flow core is uniform; the thickness of the boundary layer at the model placement is ~20 mm.

Air in the wind tunnel is supplied from the outer space through the laboratory rooms. During the experiment, the air temperature is rather constant (~20°C).

The multichannel pressure sensor switch (1 mm graduation) is manufactured to vary the difference in pressure. The readout of information from the pressure sensor switch is provided by a digital camera, and the results are digitized in a GetData Graph Digitizer. The reference value is selected to be static pressure in the channel of the undisturbed flow.

Electric current is passed through a nichrome coil to provide the surface heating in the model for the heat transfer measurements. Thermocouples were placed on one side of the model covered with a stainless steel plate 1 mm thick. The thermal boundary condition on this surface matches the stable thermal flow, i.e. \( q = \text{const} \). In order to reduce the heat flowing along the model, a number of slots are made as shown in figure 3. The model is subsequently rotated to the proper angles for the heat transfer measurements on other sides.

As a result of these measurements, we obtained the coefficients of the pressure distribution and the heat transfer, which were used to calculate the Nusselt number. Besides mean values, the dynamic component of the wind loading allowed us to detect the maximum and minimum values of the resulting parameters. Thus, the interference factor was calculated using not only mean but also maximum and minimum values of \( Cp \) and \( \text{Nu} \).

3. Results and discussion

Firstly, the effective analysis is necessary for grouping the diagrams by the model sides and types of measurements (dynamic and thermal). Secondly, the individual analysis of medium, maximum and minimum values is required. Thirdly, the mutual analysis should be conducted for the dynamic and thermal interference depending on the distance \( L1/a \) between the wind tunnel models at the airflow angle of attack. Let us discuss the results obtained.

![Figure 5. Distribution factor of dynamic (a) and thermal (b) interferences along the side A–B of Model 2.](a) (b)

According to figure 5, the dynamic interference factor on the front side \( A–B \) of Model 2 strongly depends on the relative position of the models (figure 5, a). The interference factor is higher for the lowest values of the pressure coefficient \( Cp \) than for the mean (integrated) or maximum values. This is
because the air rarefaction enabled by the model in front. The highest interference factor is observed at a relative distance $L_1/a = 4.5$, when the measuring model is exposed to the horseshoe vortex [13].

Unlike the dynamic, the thermal interference effect shown in figure 5, b is less dependent on the distance $L_1/a$ between the models. At the same time, their mean, maximum and minimum values do not significantly differ from one another. The highest values of $\text{IF}(\text{Nu})$ are observed for the integrated value of the interference factor.

The dynamic interference effect along the sides $B–C$ and $D–A$ of Model 2 (figure 6, a) is higher at $L_1/a = 0.5…3$. This is caused by the accelerated airflow along the sides of Model 2. At $L_1/a = 3…\infty$ this effect is lower.

The thermal interference effect in figure 6, b continues to be constant at all values of $L_1/a$. The maximum $\text{IF}(\text{Nu})$ values match the integrated values in most cases.

According to figure 7, the interference effect on the back side $C–D$ of Model 2 is less dependent on $L_1/a$ distance and seems not to be significantly changed. It should be only mentioned that the interference changes at $L_1/a = 1.5$ (figure 7, a), when the vortex zone formed by the front Model 1 affects the side of Model 2 and is strengthened by slipstreams from edges $B$ и $A$.

**Figure 6.** Distribution factor of dynamic (a) and thermal (b) interferences along sides $B–C$ and $D–A$ of Model 2.

**Figure 7.** Distribution factor of dynamic (a) and thermal (b) interferences along the back side $C–D$ of Model 2.
Conclusions
This study showed that the factors of the dynamic and thermal interferences observed beyond the disturbing building model differed strongly. The thermal interference effect was rather conservative as compared to the dynamic. The highest values of the thermal interference effect were observed on the back side $C-D$ in the vortex zone beyond the model.

Based on the description of the dynamic and thermal interference effects it can be concluded that the dynamic interference is more subjected to changes depending on the distance between the building models, i.e. at $L_1/a > 3$ the changes occurred on $A-B$ side, and at $L_1/a < 3$ they were observed on other sides.

Using the interference parameters one can easily analyze the extreme values of the pressure and thermal flows on the model surfaces depending on many factors, including their relative positions.

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