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Experimental study of the motion of small-sized models through a two-phase medium

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The paper presents the results of a study of the features of small-sized model motion through a two-phase medium (a thin stream of water in still air). The created ballistic setup is briefly described. Methodical experiments have been performed that have demonstrated the operability of the setup and the developed methods of synchronizing the model's flight through the measuring section and its photo and video recording. The first results concerning the features of the interaction of the model and the stream of water have been obtained. The main tasks of further research have been formulated.

Keywords: motion of bodies, interaction of the model with a stream, two-phase media, cloud of drops, synchronization of flight and photo fixation.

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The problem of interaction of two-phase flows with immersed bodies arose in the context of study of the motion of various aircraft in the atmosphere [1–3] containing solid soil-dust formations, raindrops, etc. The issues of flight of small-sized aircraft through two-phase media are currently becoming increasingly relevant. The present study is the first to set the objective of examining the features of motion of small-sized models in a two-phase medium (a thin stream of water in air). The aim was to investigate the features of interaction of a small-sized model and a two-phase medium.

A ballistic setup was constructed to study the characteristics of flight of bodies through various two-phase media (water streams, droplets, particles). The diagram of the experiment is presented in Fig. 1. A chamber made of plastic is the key element of the setup. The model (*1* in Fig. 1) thrown by a special device (not shown in the figure) moves inside the channel during the experiment and is caught at the exit from it. The main parameters of the designed ballistic setup are as follows: (1) the mass of the thrown model is 0.2–1 g; (2) the initial velocity of the model is up to 270 m/s. In the present study, we examined the interaction of the moving model with a thin stream of water (*3* in Fig. 1) 0.8 mm in diameter produced by a specialized device designed for this purpose (*2* in Fig. 1). Water was collected in a container (*4* in Fig. 1).

The system of video recording of the model, the water stream, and the droplet cloud by means of high-speed filming (Photron Fastcam SA4 and other options) and photographic imaging (Canon EOS 1D X Mark III Body and other options) forms the core of the diagnostic complex. Several techniques ensuring synchronization of the model's flight through the measurement section and its photo (video) recording were devised. Only the results of photographic imaging of the model are discussed in the present study.

Let us describe briefly one of the mentioned methods. The instruments used include a photostart apparatus, which was constructed based on an infrared (940 nm) optical interrupter; a CoB LED array (with an approximate power of 350 W) producing a flash; and a photo camera. The principle of operation is as follows: the model released from a thrower crosses the photostart line with a certain known (measured in each experiment) velocity, triggering the LED flash delay circuit. The flash is activated after a certain time interval (it depends on the parameters of the delay circuit). By this point in time, the model (travelling with a known velocity) enters the photographic recording chamber.

Thus, the system allows one to adjust the number of flashes and their duty cycle. The number of flashes was set to four, and the duty cycle was 72 μs. The flash duration was 18 μs. It should be clarified that these four flashes were used to produce an overall „pattern“ containing four superimposed images of the model and various regions of droplet dispersion that are of interest to us.

Lead models with a diameter of 4.5 mm and a hemispherical end were used in the experiments. Their mass was 0.55 g.

Figure 2 shows sample photographic images of the interaction of models with a stream of water obtained at two time points: 10 and 82 μs. Time was counted from the moment the model came into contact with the stream of water.

For example, three positions of the model at different moments in time are seen clearly in Fig. 2, *a*. The first two images of the model correspond to the first two „actuations“

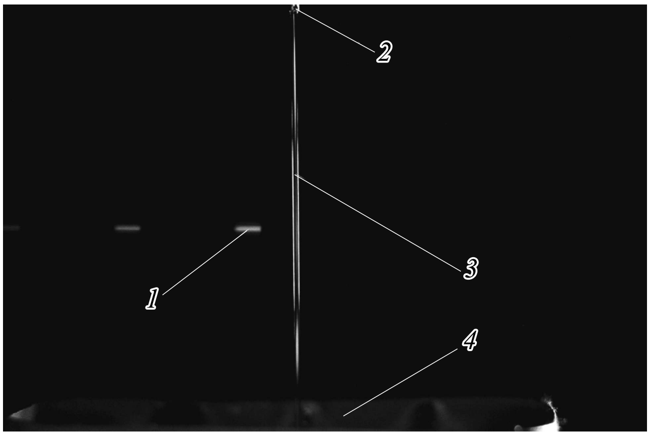

Figure 1. Diagram of the experiment (the image size is 98×65 mm). *1* — Thrown model, *2* — stream-producing device, *3* — water stream, and *4* — container for water.

of the flash. A „cloud“ of droplets (their trajectories), which formed when the water stream was disrupted, is also visible. The model moving at a high velocity (260 ± 10 m/s) breaks up the water stream into a multitude of droplets, which start to move in the process of momentum exchange. The process of blurring of the droplet dispersion region over time, which was recorded in the experiments, provides very important information, since it allows one to estimate the axial component of droplet velocity.

All four positions of the model are visible in Fig. 2, *b*. The initial region of droplet dispersion is also seen clearly. It is also possible to distinguish the peripheral and frontal regions of droplet dispersion. These are the transformation of the initial dispersion region (Fig. 2, *a*) within the elapsed time ($72\,\mu$s). Experiments revealed that the maximum axial velocity of droplet dispersion in the frontal region was 220 m/s. It was these droplets that were the result of interaction of the stream with the axial region of the model and were imparted the maximum momentum. The maximum axial velocity of droplet dispersion in the peripheral region was significantly lower (120 m/s).

The first methodological experiments were carried out, and the performance capabilities of the designed ballistic setup and methods for synchronizing the flight of the model through the measurement section and its photographic imaging were demonstrated. The first photographs of the thrown model and the resulting dispersed phase „cloud“ were obtained.

Let us conclude by formulating the main objectives of further research: (1) examination of the features of gas-dynamic interaction of models of various shapes with various two-phase media (water streams, droplets, particles); (2) study of the characteristics of droplets and particles (concentration and velocity fields) near the model; (3) study of the loss of momentum of the model in interaction with two-phase media; (4) study of the mass loss and other characteristics of the model.

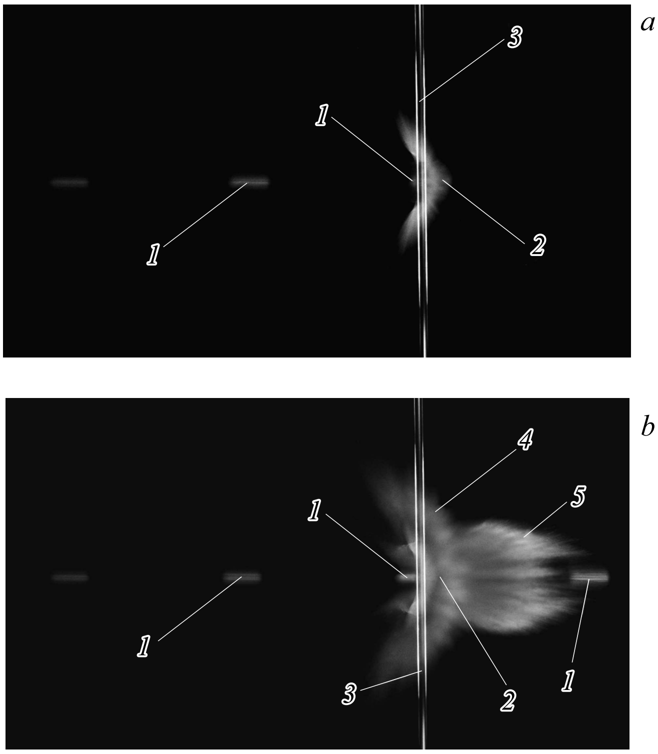

Figure 2. Typical photographs (the image size is 66×37 mm) of the interaction of the model with a water stream at time points $t = 10$ (*a*) and $82\,\mu$s (*b*). *1* — Thrown model (at different points in time), *2* — region of droplet dispersion, *3* — water stream, *4* — peripheral region of droplet dispersion, and *5* — frontal region of droplet dispersion.

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Conflict of interest

The authors declare that they have no conflict of interest.

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