ON A MECHANISM OF INTRAPHASE INTERACTION IN NON-RELAXING TWO-PHASE FLOW

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1. Introduction

Nature of intraphase interaction lies in the aerodynamics of closely-spaced bodies at their common airflow. Any spatial configuration occurs in a big ensemble with occasional particle positioning. Restricting the attention to "close" interactions, it is possible to reduce the problem to pairwise interactions, where only two main types are selected both by geometrical and physical features. From geometrical viewpoint these two types of positioning present: 1) transverse; 2) lengthwise positioning of the bodies as related to the velocity vector of a non-disturbed flow. From physical viewpoint these are 1) a wave interaction through shock waves; 2) a force interaction through a disturbed turbulized particle trail. The wave interaction of the particles has already been studied by us [1]. The main feature of such a structure is as follows: a downstream flow gets a nature of the alternate trails and currents across the flow – the trails behind the particles and currents between them. So, the influence of the windward particle on the lee one through the trail is of fundamental importance even for the transverse geometry.

This paper deals with the experimental simulation of the intraphase interaction in a particle cloud through a turbulized trail. The simulation is carried out with the aid of a lengthwise system of spheres in the stream after the shock wave.

2. Experiment and data analyzing

The structure of a turbulent flow in the wake is omitted in this paper, and the fact that the flow is turbulent is assumed on the basis of relative Reynolds numbers $>10^4$. The strong shock waves followed with a supersonic stream are of interest. The experiments were carried out in a shock tunnel with a channel of square cross section of 52x52 mm, equipped with the windows for the shadow vizualization. The body interaction through the wake was simulated by a chain of free accelerating spheres of 5 mm diameter and was fixed by distinguishing their acceleration. For this purpose, a moving-image camera registered on 20 – 30 pictures with interval of $\Delta t = 30$ μs the consequent motion of the free spheres in the flow from the moment of the shock wave appearance. The shadow method of registration based on a laser stroboscopic light source was used.

Quantitatively the interaction of the bodies is characterized by the difference in their drag. This difference was defined as follows. The data about the motion obtained after processing the shadow pictures, were approximated by a function:

$$S(t;\ \sigma) = ut - \sigma \ln\left(1 + \frac{ut}{\sigma}\right),$$

founded from the motion equation of the particle in the flow behind the shock wave [1]. This technique, realized by parameter σ, with the known gas velocity u and residence time in the flow t, allows one to determine the coefficient of drag C_d averaged over the time of observation, since, as is shown in [1]:

$$\sigma = \frac{4}{3}\frac{\rho_p}{\rho}\frac{d}{C_d},$$

where ρ is gas density; d and ρ_p –are the particle diameter and density. Figure 1 presents the samples from a series of shadow pictures of a system of free bodies in the stream behind the shock wave.

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As is evident from the experiments, at Mach numbers of the undisturbed flow M = 1.2 – 1.6, when the distance between the spheres is 0.5 – 0.7*d*, one may observe a sharp (more than double) jump of the coefficient of aerodynamic drag of the leeward sphere. With smaller distances, the drag is weak and constant, whereas at big distances an asymptotic increase of the drag rises up to the value correlating to the undisturbed flow. But down to distances l = 5 – 6*d* the lack of drag still takes place. It means, as applied to the cloud of particles behind the shock wave, that a particle that occurs in a turbulized wake will be compulsory "gravitated" to a wake' source, which has permitted us to term this effect intraphase *force* introduction. In addition to the quantitative data, the high-speed shadow visualization yielded the following information

A. When the distances between the spheres is more than critical, the bow shock is formed on both spheres, and the spheres approach results in situation B.

B. When the distance between the spheres is less than critical, the bow shock occurs only on the front sphere, and the spheres approach up to collision.

In Fig. 1 one can see an infrequent case when both regimes are registered in one experiment. In the first pictures the bow shock is seen ahead of both spheres, with a trailing shock behind the first body (TS) crosses the bow shock of the second sphere in 50 μs after the shock wave appearance and forms a triple point (TrP). This point is observed during 180-200 μs up to picture No.6 but then, from picture No.8 the triple point disappears together with the bow shock near the second sphere. The shock wave joined to the second sphere related to the local supersonic transitions (LST) disappears with them, and by 300 – 350 μs of particles being in the shock wave the shadow scheme registers the only pressure jump – a bow shock wave near the first body (picture No. 12)

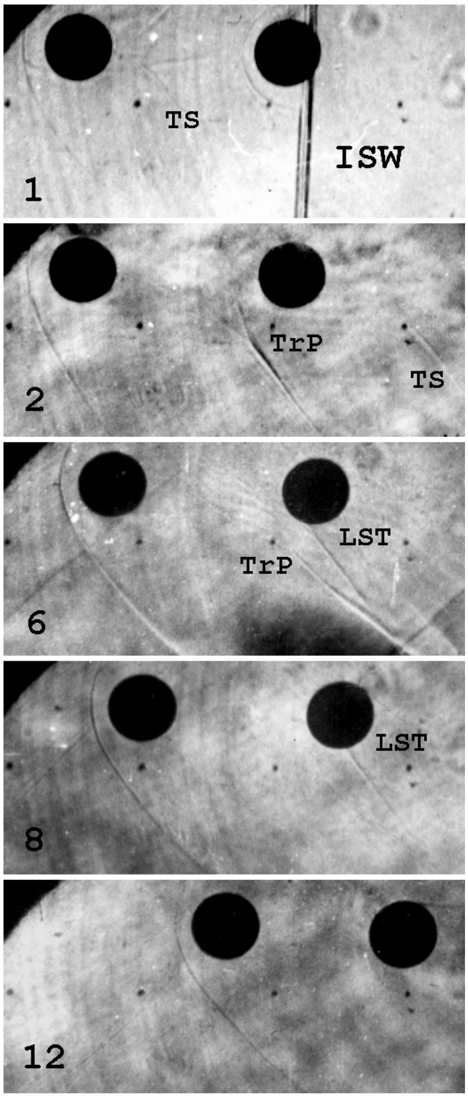

Fig. 1 The samples from a series of shadow pictures of velocity relaxation of the lengthwise system of spheres in the stream behind the shock wave. The interval between the sequenced frames is 30 μs.

Such a dramatic change in the wave pattern of the flow may be caused only by flow reconstruction as the distance between free bodies varies, one of these bodies moves in the other's aerodynamic wake. The analysis of references has demonstrated that turbulized wakes at separated flow around bodies were intensively studied in the 1960-70 (see, for example, [2]). At the same time the lengthwise systems of bodies were studied too. The approaches developed in these lines of investigations can also be used for two-phase streams. Figure 2 illustrates two flow schemes, each being known individually, and the transition from one scheme to another is connected with the varying distance between the spheres due to the lower drag of the second one.

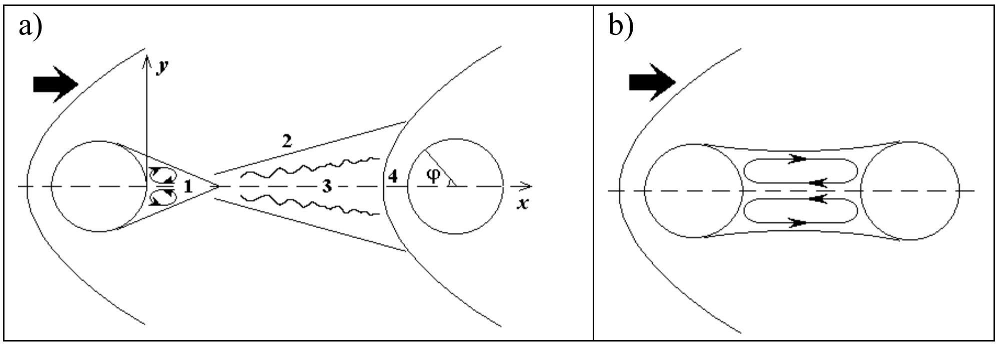

Fig. 2. Flow scheme near the lengthwise system of spheres: a) flow scheme with the shock wave ahead of both bodies; b) separated flow scheme; 1 – re-cycling region; 2 – trailing shock; 3 – turbulent wake center; 4 – the region of the bow shock unseen in the shadow pictures.

It is possible to check the correctness of such an interpretation of the flow pattern only indirectly – with a numerical experiment. The accurate solution of a three-dimension problem with a configuration changing in time, separated flow around the bodies, boundary layer streaming down, complicated system of shock waves and rarefaction waves is difficult. The most realistic approach in such problems is the engineering methods of computation, the more so as some experimental data, empiric relations and even ready models are available within the studied parameter range. In this work these computations were carried out by the following scheme: the equation of leeward sphere motion was solved numerically together with the empiric relations by Chapmen – Corst model for the parameters of the flow in the other sphere wake. Figure 3 shows the drag coefficient of the leeward sphere calculated by this scheme related to the distance to the windward one, Mach number of the undisturbed stream being of M = 1.5.

The experiments were also carried out with a three-body chain. It was shown that the intraphase interaction, strangely enough, spreads out only on the first two bodies. For example, Figure 4 presents frames Nos. 1, 10, and 15 from the shadow series, and, as the distances

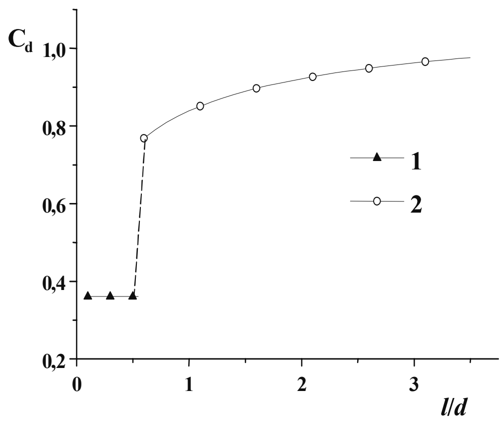

Fig. 3. Drag coefficient of the sphere situated in the other sphere wake related to the distance between them. 1 and 2 – experiment, line – calculation.

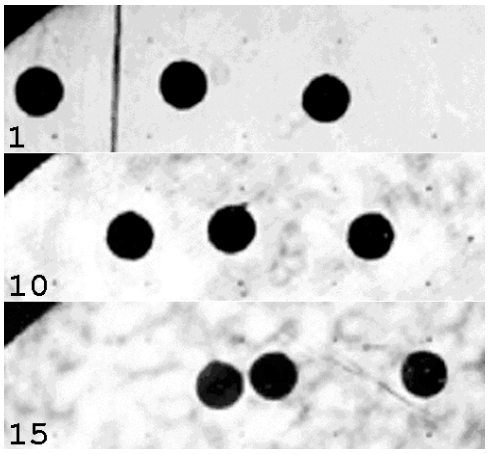

Fig. 4. Samples from a series of shadow pictures of the system from three free accelerating spheres. The intervals between pictures are 270 and 120 μs.

between free accelerating spheres vary, it is evident that the second and third bodies do not affect each other. The other, more obvious interpretation, which is that the second and third spheres are under the same conditions of flow around because of big length of the turbulized wake of the windward sphere, calls for further investigations.

3. Conclusion

In the flow behind the shock wave at a Mach number M = 1.1-1.6 the dynamics of acceleration of sphere chain, one being situated in the other's wake, has been studied. Two schemes of flow have been observed: a separated flow scheme, and the flow with the shock wave ahead of the back sphere. Basing on the wave pattern, the flow scheme has been reconstructed whose drag computed by engineering methods has happened to be close to the measured one. It has been demonstrated that the dynamics of acceleration of the chain from three and more spheres differs from the dynamics of two spheres.

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