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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM 111

AERODYNAMICS AND BALLISTICS.

By Eng. Filippo Burzio, of the Aeronautical Laboratory,
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June, 1921.

1.1.23

July, 1922.

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There is a tendency to insist on the affinity between these two sciences and still more an idea of utilizing them together in a sort of collaboration. These ideas are recent, owing their rise essentially to the war and to the consequent diffusion of ballistical knowledge among technicians.

From a scientific point of view, it is enough to enunciate the idea of such a comparison to understand the possibilities opened up. Ballistics is a science hundreds of years old and during its long life it has accumulated a valuable stock of theoretical and experimental material. This has now to be considered under a new aspect and placed at the disposal of a new science which has not much material of its own because, in former times, there was not much interest in making aerodynamical experiments and also because the knowledge of aerodynamics was mathematical rather than physical. This theoretical material consists of the mass of studies for the integration of the differential equation of the movement of the projectile which has contributed to the development of the integral calculus and which has found its practical culmination in the Siacci method for determining the trajectory. The experimental material, perhaps still more valuable, the fruit of old tests and new, is of use to artillery men in almost all parts of the world and is summarized in the curve of head resistance which gives the values of the so-called <u>func-</u>

tion of resistance, corresponding to the aerodynamical coefficient K_x for speed values increasing from 100 to over 1200 m/sec. We cannot rate too highly the importance of such experimental data in solving physico-mathematical problems relating to the mechanics of fluids by a knowledge of how the air behaves and of the disturbances set up in it at different velocities. These data, while revealing the existence of an important critical point corresponding to that of the velocity of sound, about 330 m/s, prove by the sharp variation of the laws of resistance, that K_x, from being approximately constant as is freely assumed in aerodynamics for a velocity lower than 240 m/sec., for a velocity from 240 to 460 m/sec., becomes linear, then cubical and then again linear attaining a maximum at about 500 m/sec., diminishing according to an approximately hyperbolical law at higher velocities. About this critical point of resistance, when the speed of the object moving in the air attains the speed of formation of disturbances foreseen as occurring in the medium, that is, at the speed of sound, we find ourselves at the beginning of other interesting studies founded also on other accompanying experimental results.

Photography of projectiles on flight has revealed the existence of waves both in front of and behind the moving projectile - the so-called Mach waves of condensation and rarefaction showing certain relations between acoustical phenomena and phenomena of resistance. Moreover all ballistic curves of resistance in the particular form revealed by firing tests have been recently subjected to tentative interpretations, especially to the theory of vortices due to Sommerfeld, which, supposing a law of resistance of the air similar to that of an electron which has a velocity greater than that of light, deduces a theoretical curve similar to the experimental curve. We are thus dealing with laws which aerodynamics and perhaps physics in general owe to ballistics.

From a purely theoretical point of view, however, this cannot suffice, and the fact that airships and airplanes on the one hand and projectiles on the other are all objects moving in the air, appears to give a relationship too remote since they are separated by such great differences of velocity. But the rapid increase of velocity in the first category is causing such differences to be gradually reduced. Some have already attained a speed of 80 m/sec. 177 mph. near the ground and flight at high altitudes will probably increase this figure greatly; this means that we shall soon reach the velocity of some mortar shells which is lower than 200 m/sec. 440 mph.; this establishes the fact that the two categories are continuous and are governed by the same laws. This opens up a vast field of problems and studies in which the collaboration of ballistics and aerodynamics will be useful, even technically. I will touch only on two questions which have already been examined.

In an interesting paper published some months ago, Col. Guidoni dealt with the problem of the form of optimum penetration, that is of least resistance, to be given to the parts of a high speed airplane for which low head resistance was of capital importance, and he riveted his attention on the fact that ballisticians, or rather, constructors of artillery, while at once recognizing the suitability of the pointed nose which gives length to the cylindrical-ogival form of the projectile, considered the shape of the tail of the projectile as of no importance and made it straight, and he asked himself whether this difference of form did not indicate a true intuition of the variations of aerodynamical laws. Examining the ballistic curve of resistance and interpreting the fact that, at over 200 m/sec., K_x was no longer constant, but first increased rapidly up to the critical point and then decreased, Guidoni, considering that the resistance consisted of two parts, positive pressure at the nose, negative pressure at the tail, maintained that the behavior of K_x was in relation to the importance of the second part, the negative tail pressure, which decreases gradually as the speed increases. Such negative pressure would reach a constant value, corresponding to absolute vacuum, when the particles of air rushing in the wake of the projectile at a known velocity of an order of magnitude of 400 m/sec. are not able to reach the object itself, which, moving at a greater speed, leaves vacuum behind it. One can understand that in such a case the shape of the tail is of no importance. On the basis of such considerations and others, which I omit, Guidoni thought himself justified in concluding that the form of least resistance depended as such on velocity and altitude; but that from 200 m/sec. this would be reversed, rendering it necessary to give a streamline form to the nose, leaving the tail rounded; the maximum cross section will be displaced to the rear rather than to the fore. Finally, if we design airplane projectiles flying at 400 m/sec. and upwards, we shall not need to pay any attention to the shape of the tail. It will perhaps be necessary, however, to have recourse to a pusher propeller in order to avoid enlargement of the nose of the fuselage; the struts and tension members will have a triangular section, etc. It will also be necessary to have other wing sections for it has already been proved in tests that when a speed of 200 m/sec. is attained, special phenomena begin to appear which ~~show~~ the inefficiency of the present wing sections.

These conclusions, which if confirmed, would be very important, if not for the immediate future, at least for a more distant future of aviation, would be of equal importance to the artillery, since they would solve the ancient problem of the best form to be given to projectiles, leaving the tail straight as at present, instead of tapering as was attempted during the last years of the war.

Against the ideas of Guidoni we have the opinions of Mata and other ballisticians who hold that in the wake of the projectile is a fluid, the pressure of which decreases with velocity but never reaches zero. Jacob, in one of his recent works, adduces in confirmation of this opinion some semi-experimental results, deduced from a study of the photographs of Mach waves which, for a velocity of 600 m/sec. give a pressure of 0.6 atmospheres to the air in the wake of the projectile. This, however, gives the deductions relative to the form of least resistance and does not weaken the position, and in any case discussion cannot fail to be fruitful.

A second point which I should like to deal with is the particular case of an important problem, and that is, how aerodynamical laws vary with velocity. This brings up also the theoretical problem which flight at high altitudes is making practical and actual. Established by laboratory tests carried out at very low speed, it is not certain that these laws are the same for higher speeds. The first data we possess indicate just the contrary: K_x, considered as constant in aerodynamics, is, on the contrary, shown by the ballistic curve of resistance to vary greatly. Another important magnitude of which we know nothing from an aerodynamical point of view as regards the way it is influenced by velocity is the aerodynamical efficiency ϵ of the lifting surfaces. The question may also be of importance to flight at high altitudes and ballistics gives some indications concerning it which, with due reservations, are perhaps worth considering.

While the attention of ballisticians was formerly usually turned to the solution of the first problem, the trajectory of the center of gravity of the projectile, important progress has recently been made in the solution of the second problem which includes the first, being the study of the movement of the projectile relative to its center of gravity. This problem, which is really that of the stability of the projectile along the trajectory, is analogous to the problem of the stability of an airplane, and we gather from the requirements that the incidence of the axis to the direction of flight, that is to the tangent to the trajectory of the center of gravity must not be more than a few degrees, beyond which the movement will be unsteady even if there is not an actual upsetting. As is known, a projectile is rendered stable by the rotary movement imparted to it by a suitably rifled bore. The main object of the second problem is to determine the value of the incidence of the axis of the projectile along the trajectory and this appears somewhat as the connecting link between ballistics and aerodynamics, since it takes into account an incidence of the projectile which the first problem assumes to be zero, but which may reach over 10°, that is, of the same order of magnitude as the incidence of the lifting surfaces. The phenomenon studied in the second problem has an important experimental consequence, since it can be measured and is actually measured in the construction of ballistic range tables. This phenomenon is the drift of the projectile, that is, its deviation from the initial plane of fire which may reach high values from a few hundred meters to several kilometers. The theoretical link between the phenomenon of drift and the data of the second problem is a very close one, since from the accepted values of the former we can find, approximately, the values of the latter. These latter values are essentially two: the distance l from the center of gravity of the projectile to the center of pressure, and the ratio K the angles of which, with the axis of the figure, give respectively the thrust of the air and the velocity. The approximate result is $K = \frac{\epsilon}{i} + 1$.

For a mean value of the incidence i, K thus varies as the aerodynamical efficiency of the projectile. In the first outlines and applications of a method which links up the data of the second problem with the phenomenon of drift, I have endeavored to find what values of K would be satisfactory for the various types of projectiles, at the values of drift given by ballistic range tables. For velocity varying from 200 to 550 m/sec., I found that the mean values of K decreased from 3.5 to 2 and 1.4.

In a series of tests carried out in the Aeronautical Laboratory of the Royal Polytechnical Institute, Turin, I found, for a velocity of 35 m/sec., K = 4.5. It was necessary to distinguish between the influence of the form and the influence of the incidence and for that purpose I compared my results with those of the Göttingen Laboratory on streamline shapes without fins, and was able to come to the conclusion that, approximately, other things being equal, for a velocity of the order of a few dozen meters, K would vary from 6 to 7 while for a velocity varying between 200 and 550, it would fall to 3.5, 2, and 1.4. Of course, aerodynamical efficiency would decrease in the same ratio; that is, we conclude that while K_x increases considerably with the velocity, K_y would increase less. This is the sum of the indications given by ballistics. The task of aerodynamics will be to verify the indications given. This can be done by establishing high speed wind tunnels in aerodynamical laboratories. In the Turin wind tunnel is now being built a Venturi tube of small section, diameter 0.80 meters, in which it is hoped to obtain a velocity of at least 80 m/sec., when it is inserted in the existing tube. That is not much.

America is working along this line. From the latest news received, tests on projectiles have been carried out in a tunnel having a speed of 75 m/sec. In the small tunnel at McCook Field it appears that a velocity of about 200 m/sec. will be attained. With special devices, and with a relative airstream flow obtained by powerful centrifugal compression, and with a projectile thrown into such an airstream by a whirling arm, it may be that we shall obtain a speed greater than that of sound. Such potent methods of ballistic-aerodynamical research cannot but lead to great and rapid progress in the solving of the problems common to both sciences. Scientific and technical writings are already directed towards this end, and, unlike the old treatises, new works like those of Jacob on the resistance of the air, are continually appearing and proving the full interdependence of the two sciences by their conception of data, problems, and researches which concern both.

Translated from the Italian by N.A.C.A., Paris Office.