THE MECHANICAL PRINCIPLES OF THE AEROPLANE

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BY

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PREFACE

The Dynamics of the Aeroplane is a subject now being taught at several of our universities and colleges; there can be no doubt that before long it will form part of the curricula of pass and honours schools of mathematics or engineering at most institutions of university rank. The student who approaches the subject from the mathematical point of view must get a clear grasp of the principles underlying the theory of resisted motion, three-dimensional dynamics, and the theory of fluid motion with free stream lines. Although several excellent books on aeroplanes have already been published, notably Bairstow's monumental treatise on *Applied Aerodynamics*—a veritable mine of information on all subjects aeronautical—there should yet be room for the present work, in which an attempt has been made to deal with the subject in such a way as to emphasise the fundamental ideas on which the theory of aeroplane motion is built. It is for this reason that so much space has been devoted to such questions as the theory of dimensions, moving axes, and the hydrodynamics of a perfect fluid in two dimensions. The *a priori* study of aeroplanes in Chapter VII., obviously inspired by Bryan's classical work, should help to make clear the reasons for the forms of aeroplanes now in use.

As the subject is yet in its infancy, and there is great scope for further research, several investigations have been included with a view to indicating lines along which much mathematical work can be done. Many of the exercises have been set for this purpose.

The notation employed in this book is one that has been carefully devised in consultation with Professor Bryan, so that it may be used with comfort in such complicated investigations as arise in connection with the general motion of the aeroplane. Appendices have been added to Chapters III. and IV. indicating the notation used in the *Technical Reports of the Advisory Committee for Aeronautics*, where so much that is fundamental in the behaviour of aerofoils and aeroplanes has been published.

My sincere thanks are due to Professor Bryan for his inspiration, and for his help in many respects. My best thanks are also due to my colleague, Mr. C. W. Gilham, M.A., to Mr. D. Williams, B.Sc., of the National Physical Laboratory, and to Dr. H. Levy, of the Imperial College, South Kensington, for their kind help in reading the proofs. I cannot hope that all errors have been eliminated; but, while assuming sole responsibility for the views expressed, I feel that the numerous hints given me by these friends have helped to make the presentation clearer and more correct. I also wish to thank Messrs. Constable for their kind permission to use the phugoid chart from Lanchester's *Aerodonetics.*

S. BRODETSKY.

THE UNIVERSITY, LEEDS.

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THE MECHANICAL PRINCIPLES OF THE AEROPLANE

INTRODUCTION

POSSIBILITY OF FLIGHT IN A HEAVIER-THAN-AIR MACHINE

1. If a body is held at rest in still air it experiences a certain pressure on every part of its surface exposed to the air. In elementary books on hydrostatics it is shown that the pressure on any small portion of the surface is in a normal direction, its amount per unit area being, however, independent of the direction of this normal and equal to the so-called pressure of the air in the immediate vicinity. To find the resultant pressure on the body we must add up vectorially all the pressures on the large number of small areas into which the surface of the body can be divided.

The problem becomes very simple in ordinary cases, for if the body has some moderate size we can assume the air density to be constant all round it, and then we use the **Principle of Archimedes** which states that *the total pressure exerted by a homogeneous fluid on a body, both being at rest, with the latter totally or partially immersed in the fluid, is an upward vertical force or buoyancy equal to the weight of the fluid displaced.* Thus the buoyancy is obtained by multiplying the volume of the immersed part of the body into the weight of unit volume of the fluid.

The principle of Archimedes is sufficient to enable us to discuss the condition for the equilibrium suspension of a body in still air, as, *e.g.*, in the case of a balloon at rest. We have only to equate the weight of the balloon, including the gas it contains and all its appendages, to the weight of an equal volume of air of a density equal to that of the air in the vicinity of the balloon. Or, if a ship is at rest in still water, the weight of the ship and all it contains must be equal to the weight of a volume of water equal to the volume of the part immersed. (In the case of a heavy body like a ship, the buoyancy of the air can be neglected.)

But the problem is entirely different when we wish to consider the case in which a body is moving through a fluid. We can either have the body at rest and the fluid in motion or both the body and the fluid can be moving. The latter includes what is often loosely described as the case of "a body moving through a fluid at rest," since, of course, the motion of the body must, and does, cause motion in the fluid.

Mathematically speaking, we can calculate the force exerted by the fluid on the body by adding up vectorially the pressures on the various parts of the exposed surface. But this is generally of little help to us, because in most cases we are quite ignorant of the pressures set up in the fluid. But of one thing we can be certain *a priori*, namely, that *the force exerted by a fluid on an immersed body when there is relative motion is in the nature of a resistance, tending to reduce the relative motion.* This is the inference derived from such ordinary experiences as walking against a wind, or trying to keep a boat still in a current of water.

2. **Aerodynamics: Mathematical.**—It is the problem of **aerodynamics** to investigate the pressure experienced when a body moves through the air, or, more generally, when there is relative motion of the body with reference to the air, which may have a motion of its own. Two main methods are available. We can attempt to solve the problem by means of **mathematical analysis.** As is generally the case in the application of mathematics to a physical problem, we are forced to introduce assumptions with regard to the nature of the fluid, the shape of the body, and the type of relative motion, that may not be quite justifiable, in order to make a solution by mathematical methods at all possible. We shall see that the application of hydrodynamical methods to air pressures in aerodynamics is at present very restricted in scope, and that considerable progress has yet to be made in the development of powerful mathematical instruments of investigation before we shall be in a position to attack the problem adequately.

Experimental.—Recourse must therefore be had to another method, which consists of **experimental research** on the air pressures on bodies of different shapes and sizes under various conditions of relative motion. Experimental aerodynamics has the advantages and disadvantages of all experimental methods. On the one hand, very elaborate apparatus, involving considerable expense, is required, and long series of careful observations are necessary. But, on the other hand, the results obtained can be made applicable to actual conditions of flight by reproducing these conditions as nearly as possible in the experimental research. It is, of course, clear that experimental investigation is possible no matter what shape is given to the body under discussion, whereas the mathematical methods at present yield results only in very simple cases.

3. **Rigid Dynamics.**—If now we have sufficient information aerodynamically to be able to write down the forces due to air pressure acting on a given body possessed of given relative motion in air in a stated condition of density and motion, we can at once write down the mathematical formulation of the *dynamical problem* of the motion of the body. We now have a purely dynamical investigation to carry out: *a body is moving under forces that are known at any instant and in a given position—to find the motion.* In practice we have a problem in rigid dynamics, and it is the function of the **Rigid Dynamics of the Aeroplane** to investigate the motion of the aeroplane, assuming the knowledge supplied by theoretical and experimental aerodynamics.

4. **Uniform Motion: Statical Equilibrium.**—Let us examine