TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 772

THE DENIS-GRUSON SIX-COMPONENT WIND-TUNNEL BALANCE

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INTRODUCTION

The aerodynamic study of a model in the wind tunnel necessitates, as a rule, the measurement of six components: the three components of the general resultant and the three components of the resultant moment.

These six components, measured with respect to a system of wind (or tunnel) axes, are as follows: lift, drag, sideslip, pitching moment, rolling moment, and yawing moment. (For reasons of clarity the pitching, rolling, and yawing moments are referred to a system of wind axes and not to a system fixed in the model.)

Thus, to be suitable for all experimental cases, a wind-tunnel balance must be able to measure these six components.

PARTICULAR CHARACTERISTICS OF AERODYNAMIC FORCES

Quite often the wind-tunnel measurements are beset with great difficulties because of the very peculiar characteristics of the phenomena in play. Briefly, these characteristics are:

a) The existence of unstable or transient phenomena with rapid changes (instability of certain airfoils at zero lift, multiple and transient regimes (velocities) at high angles, appearance of moments of instability at high angles, alternating turbulent flow, etc.);

b) Variations in the nature of the phenomena, particularly in the case of successive experiments (changes in air-stream turbulence, response to unstable phenomena at high angles);

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*"Balance dynamométrique à six composantes Système G."

c) Direct relationship between the forces and the quite often not very stable speed of the air stream;

d) Human element.

These factors preclude the idea of using a balance employing weights or sliding weights or any other balance of similar characteristics, but favor the use of recording devices with relatively small natural period and concurrent and continuous recording of the loads, angle of attack, and the air speed.

WIND-TUNNEL BALANCES

The most elementary kind of such a balance consists in the juxtaposition of the following six balances:

Two balances for the front lift

One balance for the rear lift

Two balances for the drag

One balance for the sideslip

Hereby the lift and the total drag are obtained by adding the readings from the corresponding balances; the rolling moment is obtained by deducting the readings from the front lift balances, etc.

Unfortunately, the practical disadvantages of such a balance tend to its rejection. For example, the loads in rolling are in the majority of cases small as compared to the forces of the front lift; nevertheless, they are measured with the same front lift balances. The relative instrumental accuracy is thus much lower in rolling than in lift, and certain changes in rolling moment may even pass unnoticed in certain cases.

These facts have led to the attempt of measuring the rolling and yawing moments with balances operating differentially on the front lift wires and the drag wires, these balances being supported by the front lift and the drag balance.

PRINCIPLE OF BALANCES USED

The balances employed (Gruson balance) are of two types: the simple and the parallelogram.

Both types are based on the principle of flat springs with low rate of deflection (0.4 to 0.01 mm).

The simple balance (fig. 1) consists of a spring R clamped at one end and actuated at the other by the force to be measured F. This spring has an extension, a rigid piece P, which forms the amplifying lever. The end of this piece actuates the thin spring r (in form of an arch) which carries the concave mirror M. The different parts are linked by clamps; thus the whole can be shifted without friction.

An oil dashpot with adjustable port is fitted between the amplifying lever and the base. The plunger of this dashpot, clamped in the lever, moves in the cylinder without friction; sufficient clearance is provided between the plunger and the cylinder.

The light beam from a lamp with straight filament is thrown on the concave mirror, and its reflection is photographed on the recording cylinder (fig. 1).

For the purposes of measuring a force in a certain direction, or even to superpose two balances (parallel displacement of the balance carried by the other), the diagram of the elastic balance has been modified to give the balance with elastic parallelogram (fig. 2).

This balance consists of two flexible plates R and R' clamped at their two ends in such a manner as to form a parallelogram with clamping pieces. One of these clamping pieces is integral with the base; the force to be measured is applied at the other.

Under the action of the force the plates R and R' are elastically displaced in the form of an S, presenting an inflection point at mid-length.

The stiff piece P forming the amplifying lever effects the tangent of the inflection to one of the plates; as in the simple balance, this piece actuates a secondary spring carrying the concave mirror M. A dashpot is fitted between piece P and the base.

The 6.C.1 type balance.- This balance is diagrammatically illustrated in figure 3. It comprises six balances for measuring the forces and one balance for speed regulation, a device for angle-of-attack changes controlled by electric motor with an electrical system for recording the angle-of-attack changes on two drums, and two spot lamps with straight filament.

The combination - balance and angle-of-attack changing device - is mounted on a cast-iron base supported by three jacks and arranged so as to be readily orientated about the vertical axis of symmetry of the forward lift wires. A post fastened to the base carries the clamps of the drag balance, of the front and rear lift balances, as well as the fixed points of the angle-of-attack levers.

The drag balance and the front lift balances are on the parallelogram principle and support the yawing and the rolling balances. The latter are differentially actuated by the drag and the front lift wires by means of transverse bars and small oblique rods. The linkages are ensured through elastic clamping.

Lastly, in order to promote instrumental accuracy at low drag ($C_{x_{minimum}}$, for example), a very sensitive balance is automatically connected to the main drag balance; the two balances then record the drag simultaneously and at different scales. Starting with a certain drag value, the connection between the two balances is interrupted, leaving the main balance to continue the recording.

At the sides and fastened direct to the base are the balances for the sideslip and for air-speed regulation. The latter is actuated by means of piano wire and a paddle mounted normally to the tunnel speed. (The reading of the speed balance should not be considered as a record of the air speed but rather as a control of speed uniformity, this uniformity being of prime importance in the interpretation of the recordings.)

The incidence-control device consists of two levers forming a parallelogram and mounted on ball-bearing joints. The lower lever, hinged to a fixed point on the post or column, is actuated through rack and pinion and an electric-control motor (motor with regulator).

The upper lever, engaged through the lower, by means of small vertical rods, is linked at the front to the rear lift balance; at the other end it is actuated by the rear lift wire connected to the model. A convenient device actuating the angle-of-attack mirror is fastened at the hinge of the lower lever.

The recording drums and the spot lamps are mounted on a small pedestal attached by means of a steel tube of large diameter. One drum records the drag with normal sensitivity, the drag with great sensitivity, the front lift, the rear lift, the speed, the setting of the model; while the other drum registers the yawing moment, the rolling moment, the sideslip, and the setting of the model.

The drums are simultaneously controlled by the electric motor; the recordings are conjugated either through the angle-of-attack recording curves or through stop marks made by the operator during recording with a special lamp. Such a balance may, obviously, be linked to the model through any system of wires. In the drawing (fig. 4) we show an especially simple arrangement which has proved very satisfactory.

The 6.C.1 balance lends itself, moreover, to arrangements which may be valuable. In particular, its angle-of-attack changing mechanism permits of ready linkage of the weighed model to a secondary model. The latter, fastened to a separate support (special set of wires), may in fact be actuated by the lower angle-of-attack lever. (This lever does not enter in the weighing.) Then the angle-of-attack changing mechanism controls concurrently the setting of the weighed model (upper lever) and the secondary model (lower lever). This arrangement is applicable in the very interesting case of tests in plane flow between panels for the control of guard tips, in biplane tests, in tests on wings with fuselage, etc.

The polars may also be established with this balance by simply rotating the balance and the upper attachment points about the vertical axis situated in the plane of the front lift wires. This axis is, moreover, realized on the balance by a centering piece fastened below the base.

All controls of the balance are assured through five push buttons and a reversing switch located along with the control lamps to the rear of the base. The operation of the balance for one record is limited to starting the motors, lighting the lamps, and reverse maneuvers when the limit of the angle of attack is reached. (The whole operation takes from 3 to 10 minutes.)

This wholly automatic operation of the balance permits it to be mounted in an airtight case and to be controlled from the outside, which renders it particularly suitable for high-speed or variable-density wind tunnels (compressed or rarefied air).

CONCLUSION

The 6.C.1 balance (fig. 5) is the first fully automatic balance assuring a continuous and simultaneous record of the aerodynamic characteristics of an airfoil in the wind tunnel (fig. 6).

The necessity of simultaneous records is well understood by all who have searched to determine the unstable phenomena of aerodynamics, such as at high angles of attack, for example.

The continuous record, only one parameter being variable (angle of attack, for instance), likewise presents an indisputable advantage over the "point by point" measurements which, no matter how close the experimental points are, must be graphically interpolated, which constitutes a source of error.

The 6.C.1 balance permits very quick wind-tunnel work with less personnel, which proportionally augments the efficiency of the laboratory.

Because of the rapidity of the measurements a complete polar (six components) requires only about three minutes of wind, that is to say, of motive power, which is of interest for wind tunnels with high efficiency factors and may lead to the economical design of large-size wind tunnels.

Data received from Paris Office, N.A.C.A.

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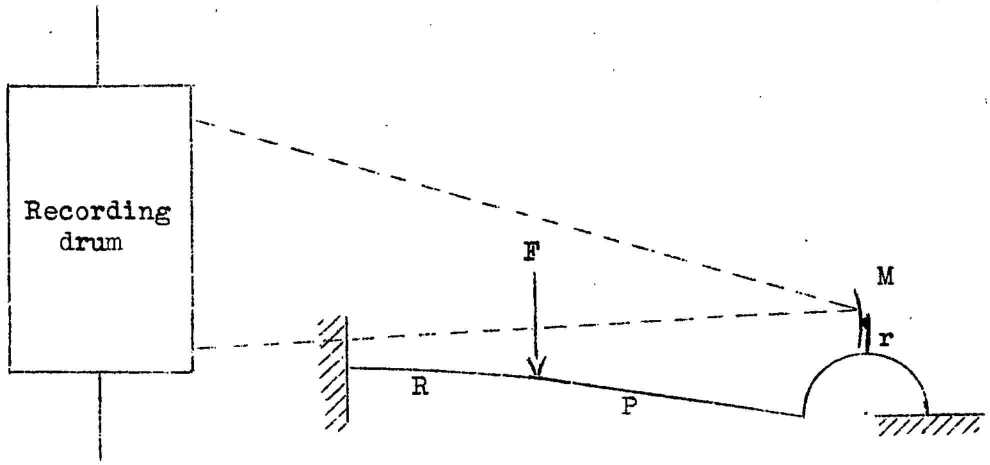


Figure 1.- Simple balance.

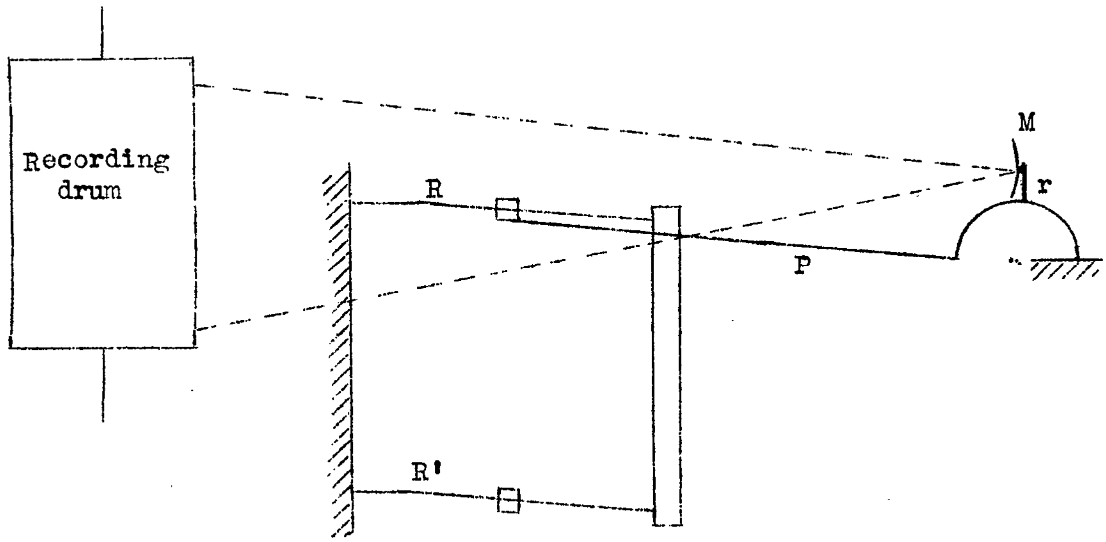
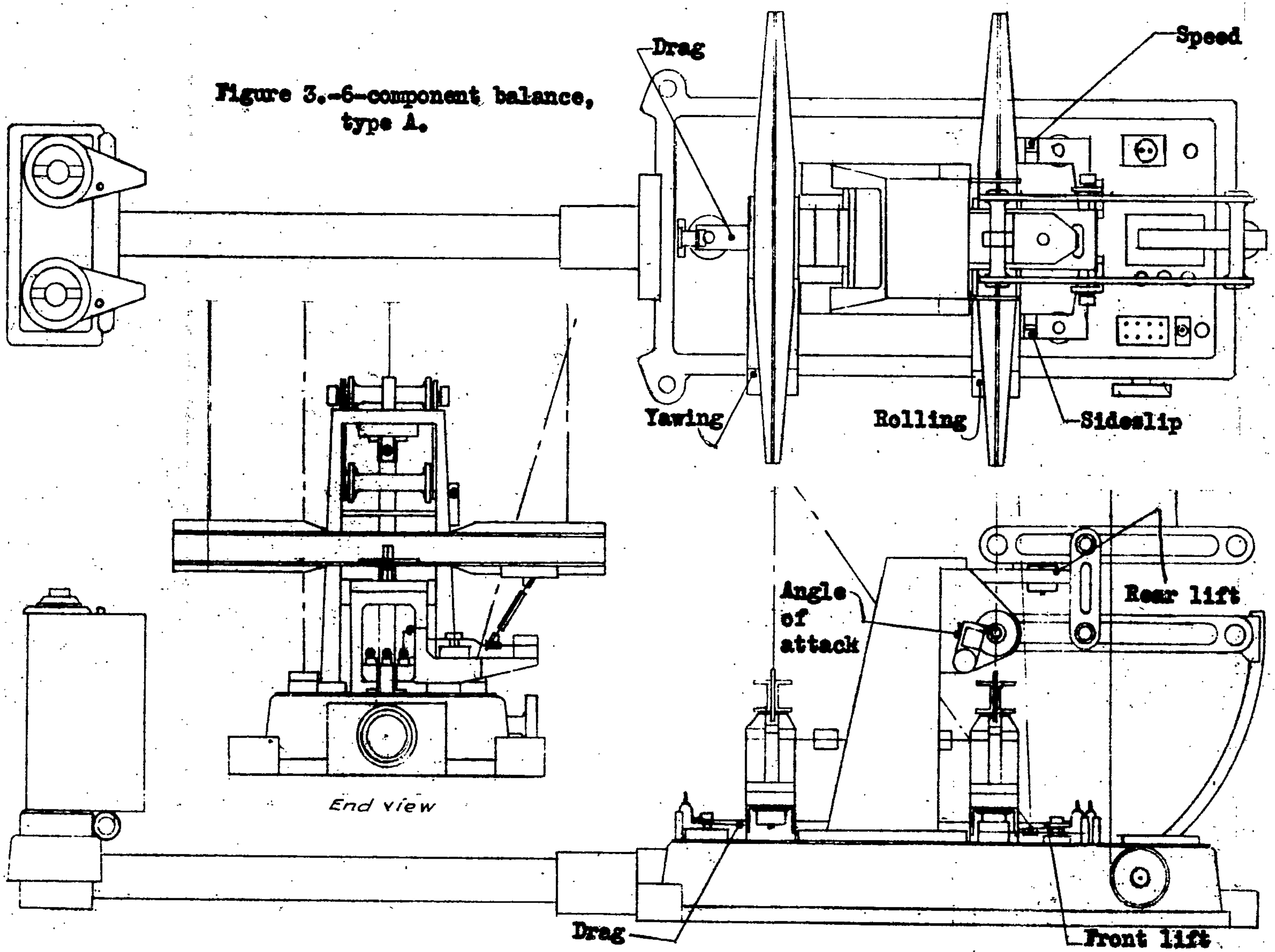


Figure 2.- Parallelogram balance.

Figure 3.-6-component balance, type A.



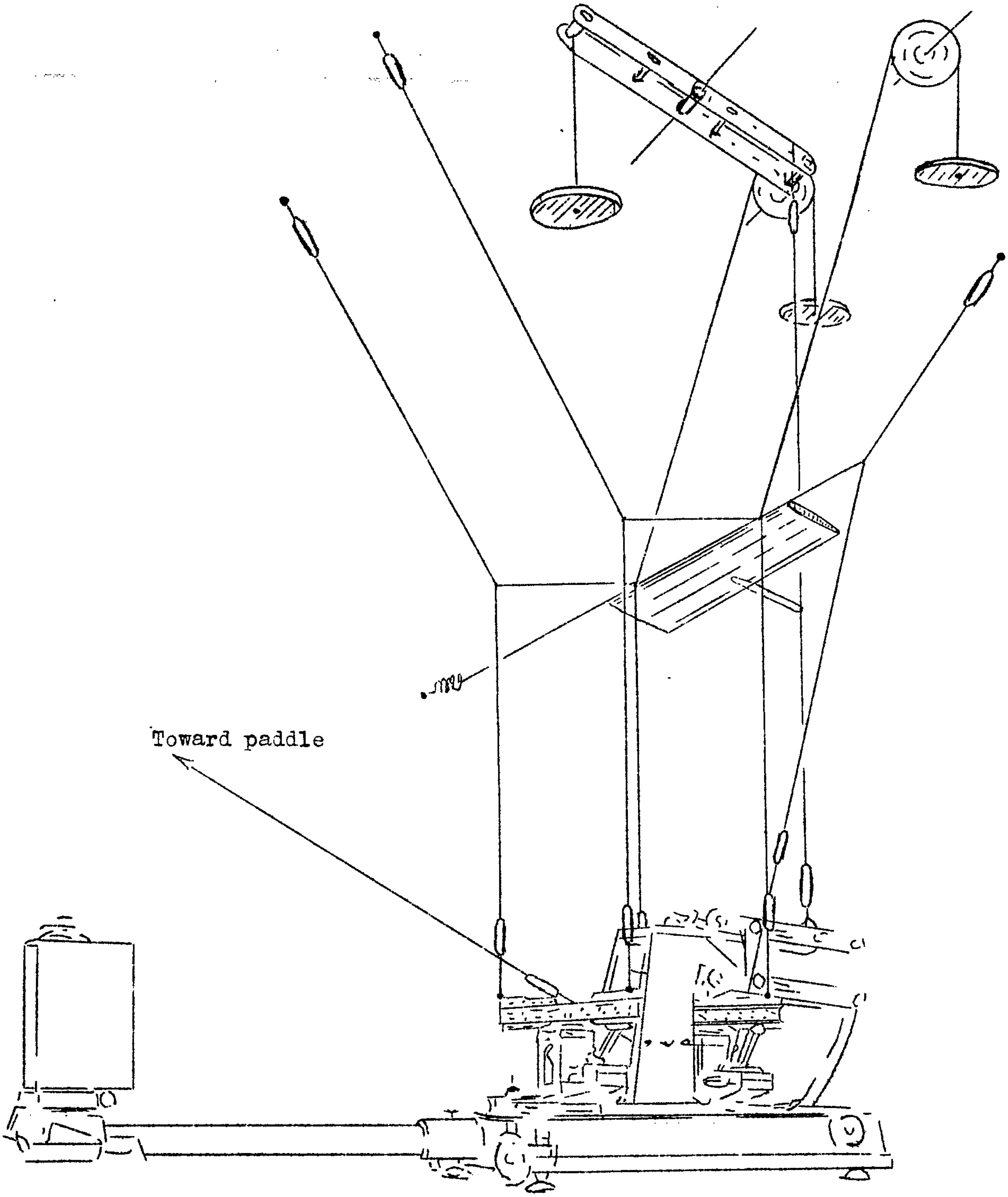


Figure 4.-Type 6 C.1 balance. System of wires.

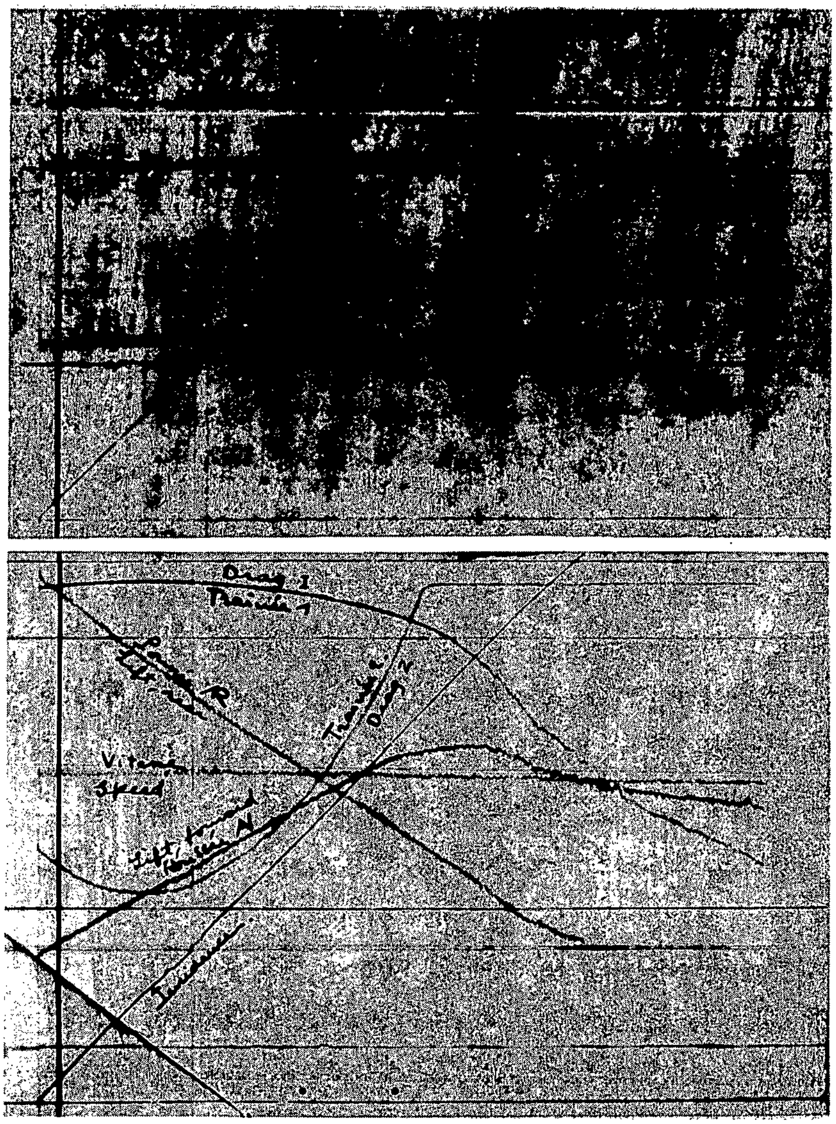


Figure 6.- Record of characteristics of airfoils.

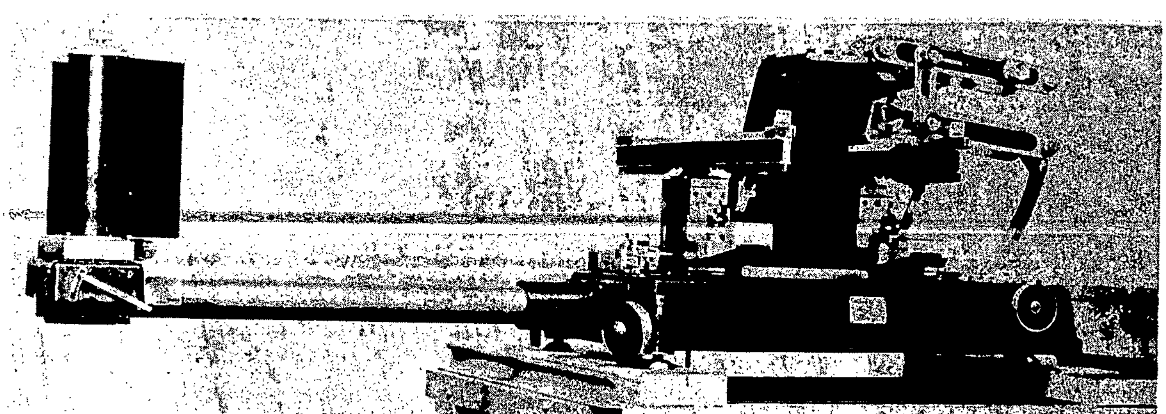


Figure 5.- The 6.C.l. balance.