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No. 251

THE VECTOR RULING PROTRACTOR

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THE VECTOR RULING PROTRACTOR.*

By A. F. Zahm.

In a previous paper** the present writer described a vector slide-rule for determining a vector in magnitude and position when given its components and its moment about a point in their plane. In wind-tunnel work frequently only the line of the vector has to be found. Given, for example, the lift, drag and pitching moment on an airfoil or a complete airplane model, only the line of the resultant air force is to be drawn. This can be done without knowing the magnitude of the force, as will be shown, by use of a circular protractor and guiding straight-edge along which it can move.

The theory, structure and working of an instrument of this kind are presented in the following text, slightly revised from a report written for the Bureau of Aeronautics in November, 1921, when the protractor was devised by the present writer. The instrument was made in the winter of 1922, and since has been in constant service in the Aerodynamic Laboratory. The computations and drawings for it were made by Mr. L. H. Crook.

In Fig. 1, for any angle of attack α, of the wind on an airfoil of given chord line, let the lift L, drag D, and mo-

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** "The Vector Slide-Rule," Jour. Frank. Inst., April, 1921.

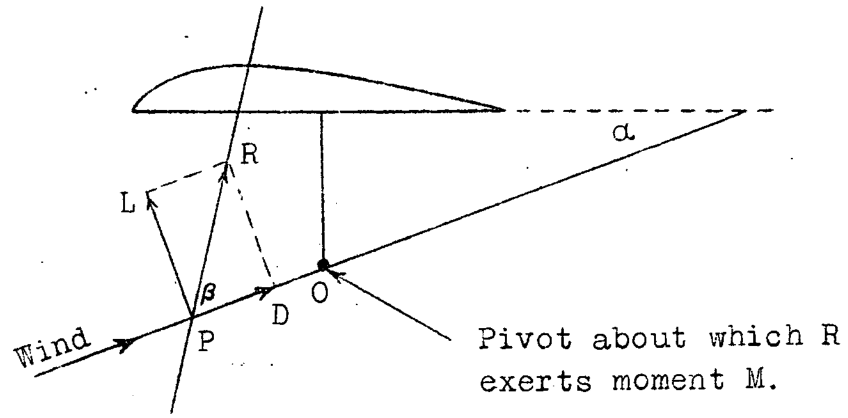

Fig.1. Scheme for drawing line of R when given L,D,M, the lift, drag and pitching moment for incidence α. Obviously OP = M/L; $\beta = \tan^{-1} L/D$.

ment M about the pivot O, be known. Then a line through O, parallel to the wind, cuts the line of the resultant air force R, at a distance OP = M/L. The slope of the air force to this wind line is L/D. To draw the line of R, therefore, one may first pass a construction line through O parallel to the wind, then intersect it at a point P, distant M/L from O, by a second line sloping L/D to the first.

The locating and drawing of this vector is conveniently done with the aid of the instrument shown in Fig. 2. It is simply a large Colby protractor with an L/D scale added to its inner circle. This L/D or slope circle, twenty-four inches in diameter, rotates within a holding circle graduated to degrees. The diametral ruler is divided in inches, tenths and fiftieths, up to ten inches each way from the center. The whole protractor is made of German silver, and slides along a horizontal guide at its base.

This guide should be movable parallel to itself for convenience in translating the protractor crosswise of the drawing table. To effect such translation quickly and accurately a cover straight-edge (Fig. 3) is made to slide along two oblique parallel grooves cut on a 20 per cent slope near the ends of a lower fixed straight-edge, which itself is bolted to the table and serves to clamp the drawing paper. To operate, one grasps a knurled clamping knob on the upper straight-edge, pushes to the right till the transverse displacement of the protractor is precisely correct, then twists the knob to clamp. The two straight-edges constitute, in fact, an accurate parallel ruler having a mechanical purchase of 5 to 1.

To use the protractor, rest it against the straight-edge, which previously has been placed on a sketch of the airplane or other model, and parallels the wing chord; shift the straight-edge cover till it pushes the center of the protractor up to a level with the center of moments used in testing the model, such as the point O in Fig. 1; incline the linear scale α degrees, to align it with the wind, and along it mark a guide point P, distant M/L from said moment center. Next give the linear scale a slope L/D to the wind, shift it to the guide point, and draw along it the line of R. This completes the operation for one vector.

The operator may sometimes find it convenient to locate the guide point for R from given values of D or R instead of L. It is therefore worth noting that $M = Lx = Dy = R\sqrt{xy}$, since the distance from the pivot O to the vector R is x along wind, y across wind.

For example, when the vector is nearly parallel to the wind, x becomes too large, and therefore one marks the guide point on R at the distance $y = M/D$ across wind from the pivot. Then, as beofre, the linear scale is sloped L/D to the wind, shifted to the guide point, and used as a ruler to draw R.

The usual text-book way to locate the line of R when given L, D, M, is to compute $R = \sqrt{L^2 + D^2}$, then at the distance $r = M/R$ from the moment center draw a line whose inclination β to the wind is given by $\tan^{-1}\beta = L/D$. The foregoing method is briefer.

Fig. 2 shows the protractor resting against its straight-edge, in the process of drawing the force vectors for a slotted wing with trailing-edge flap. The diametral ruler coincides with the line of resultant air force for an angle of attack of 30°, for which the lift drag, derived from the wind-balance readings, is about 4, and for which, therefore, the slope of the ruler to the wind must be 4. The point marked 4 on the L/D circle is accordingly set to 30° on the outer circle, which latter measures the angle of the wind to the wing chord. The ruler edge passes through a guide point previously marked on the paper at a distance M/L, measured along the wind direction, from the pivot or center of moments for the vector system. This center of moments, at the heavy dot in Fig. 2, has the same position relative to the wing as had the pitching axis during the wind-tunnel test.

In passing one may note that the little dots mark the successive guide points used in drawing the vectors. These dots outline a curve whose equation can be found if desired. Thus the polar equation is $r = M/L = f(\alpha)/f_1(\alpha)$, where r is the radius vector, drawn from the center of moments as origin, and α is both the angle of attack and the polar angle measured from a polar axis fixed parallel to the wing chord. Wind-tunnel tests usually give f and f_1 as linear functions of α for the more usual flying angles.

The envelope of the vectors is also a curve the form of whose equation is well known.

In Figure 4 is shown a typical vector diagram developed during the test of an airplane model, and superposed on the airplane sketch, made by pricking through a working blueprint then tracing with a pencil. The initial tailplane setting was slightly too low, causing the first trial vectors to fall too far forward with respect to the center of gravity. The stabilizer angle was therefore increased, and gave new trial vectors further aft, but not sufficiently so. A third setting, dictated by the previous results, gave a suitable vector grouping, and therefore was used for a complete set of measurements at many angles of attack. The actual moment axis used in the test is seen to be well below the nominal full-scale center of gravity indicated by the letters c.g. in the diagram.

Thus by employing a ready means of sketching the air forces on a model during a wind-tunnel test much time is saved from month to month. Formerly three days would be spent, with the indirectly measuring Eiffel balance, in making preliminary tests of an airplane model at various incidences and tail settings; three days more in computing the characteristics and drawing the vector diagrams; another day in writing a report and suggesting to the designing staff that the tailplane be raised or lowered by a small amount. Upon approval of the designing staff, communicated after due consideration, the wind-tunnel man would make a new tail setting and repeat the former operation. Today this preliminary measuring and adjusting, which used to consume more than a week, is effected by the engineer of tests in less than one hour.

Such vector diagrams, though not indispensable, are very useful and frequently employed. When they are required the present method of drawing them can be recommended.

Fig. 5 shows the operation of drawing the line of the wind force for an airship hull held at various angles of attack. The lift, drag and pitching moment of the wind on the model had just been measured in an air stream of forty miles an hour in the tunnel, thus enabling the tunnel engineer immediately to furnish the designing staff a vector diagram for the bare hull. The test was then repeated with the same hull provided in succession with manifold types of tail fins and rudders. A new diagram was drawn for each combination, so that the most suitable control could be chosen.

The contour in Fig. 5 represents the hull of the Shenandoah, America's greatest airship. The wind forces and moments on the model were measured first with the hull bare, then in succession with nine different sets of tail fins and rudders. In the complete test several angles of attack were used, and wind speeds of 20, 30, 40, 50, 60 miles an hour. The laboratory report comprised about seventy tables and diagrams giving the air forces and moments acting on the ship, under manifold conditions, and disclosing the relative merits of the different types of control surface. Thus the designing staff was supplied with data enabling it to forecast the stability of the great ship in flight, and the power required to propel her at all available velocities.

Fig.2.

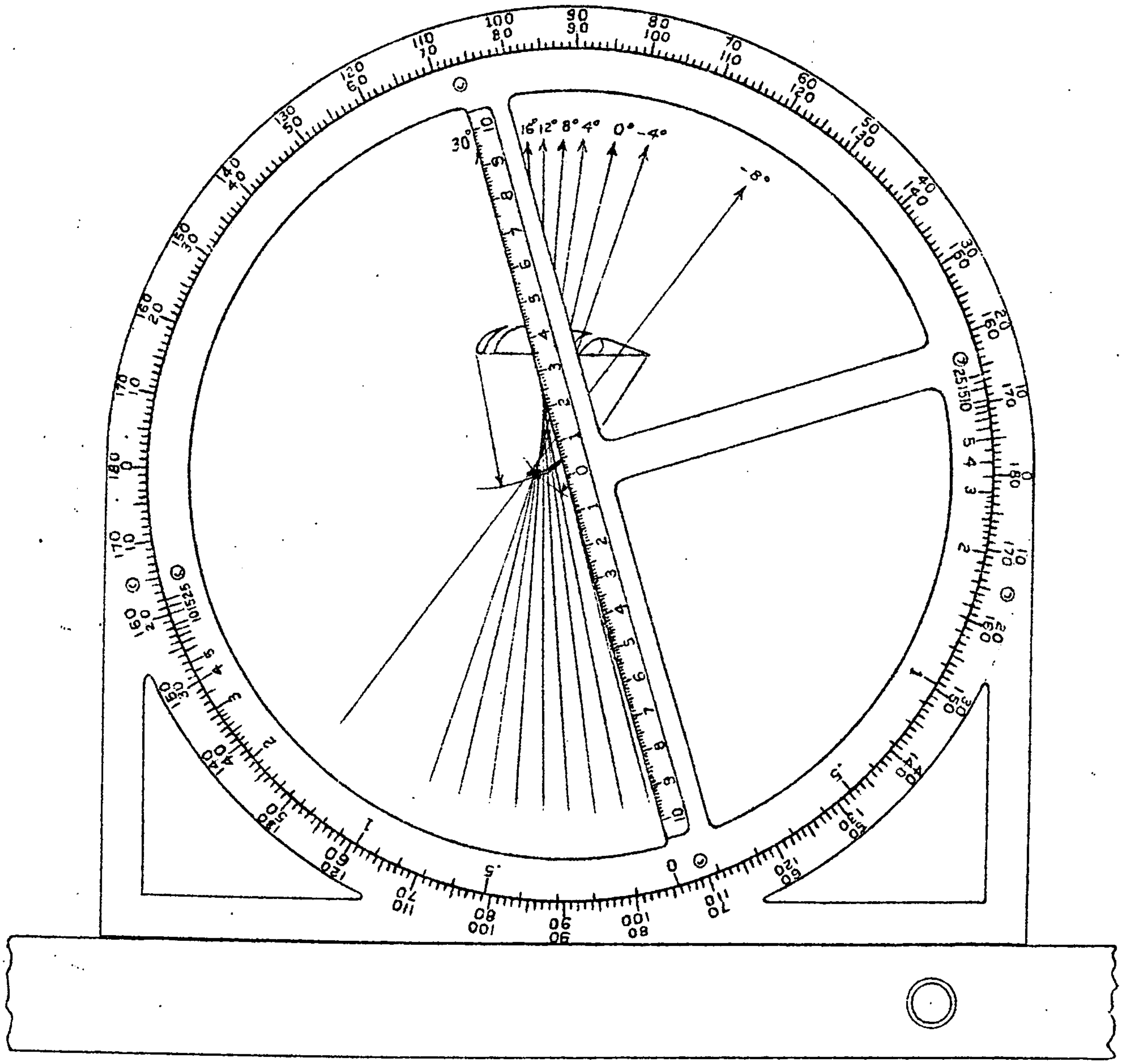

Fig.2. The vector protractor used for drawing airfoil vectors.

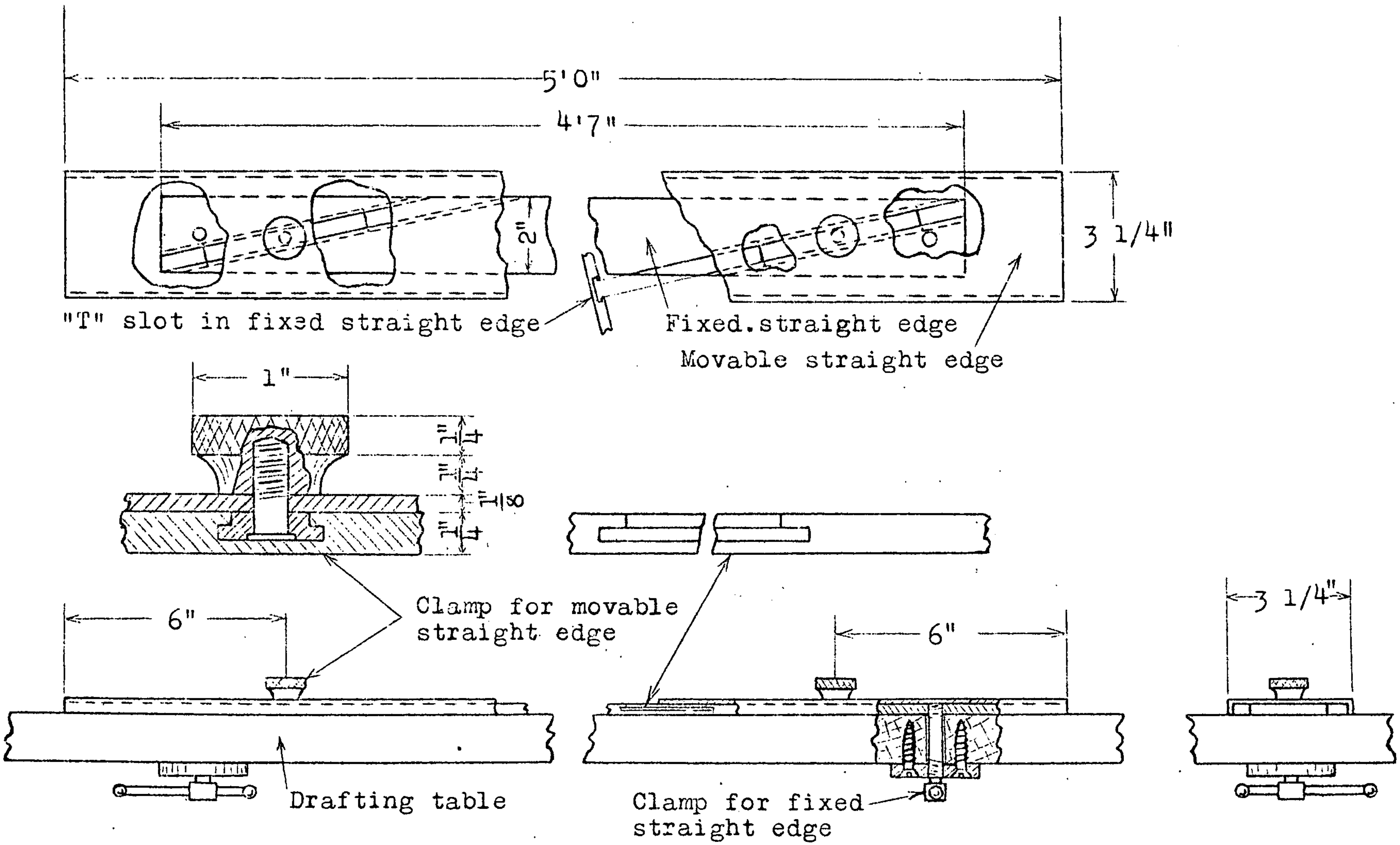

Fig.3 Translating guide.

Fig.3

Fig. 4

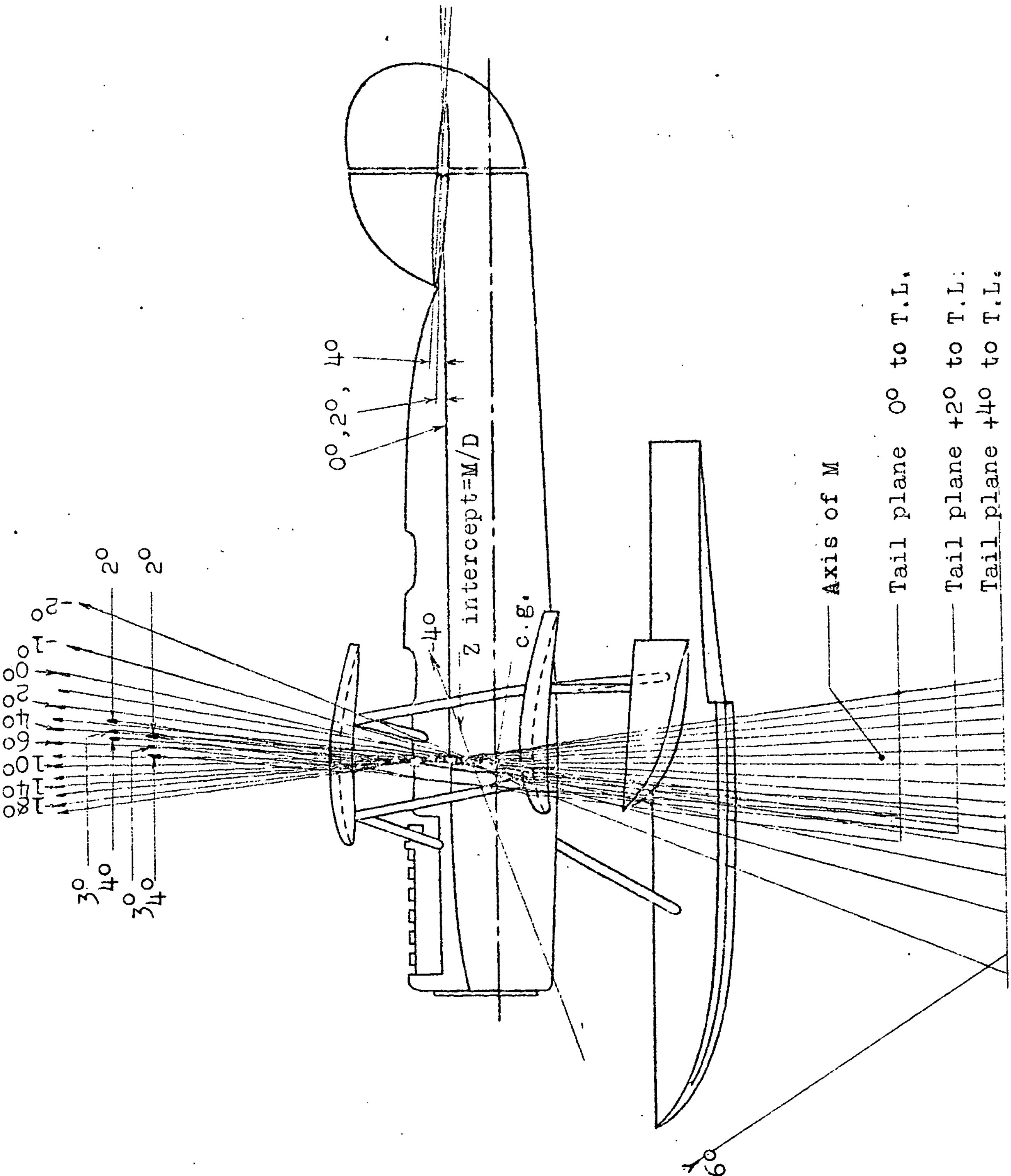

Fig. 4 Working diagram made with vector protractor

Fig.5.

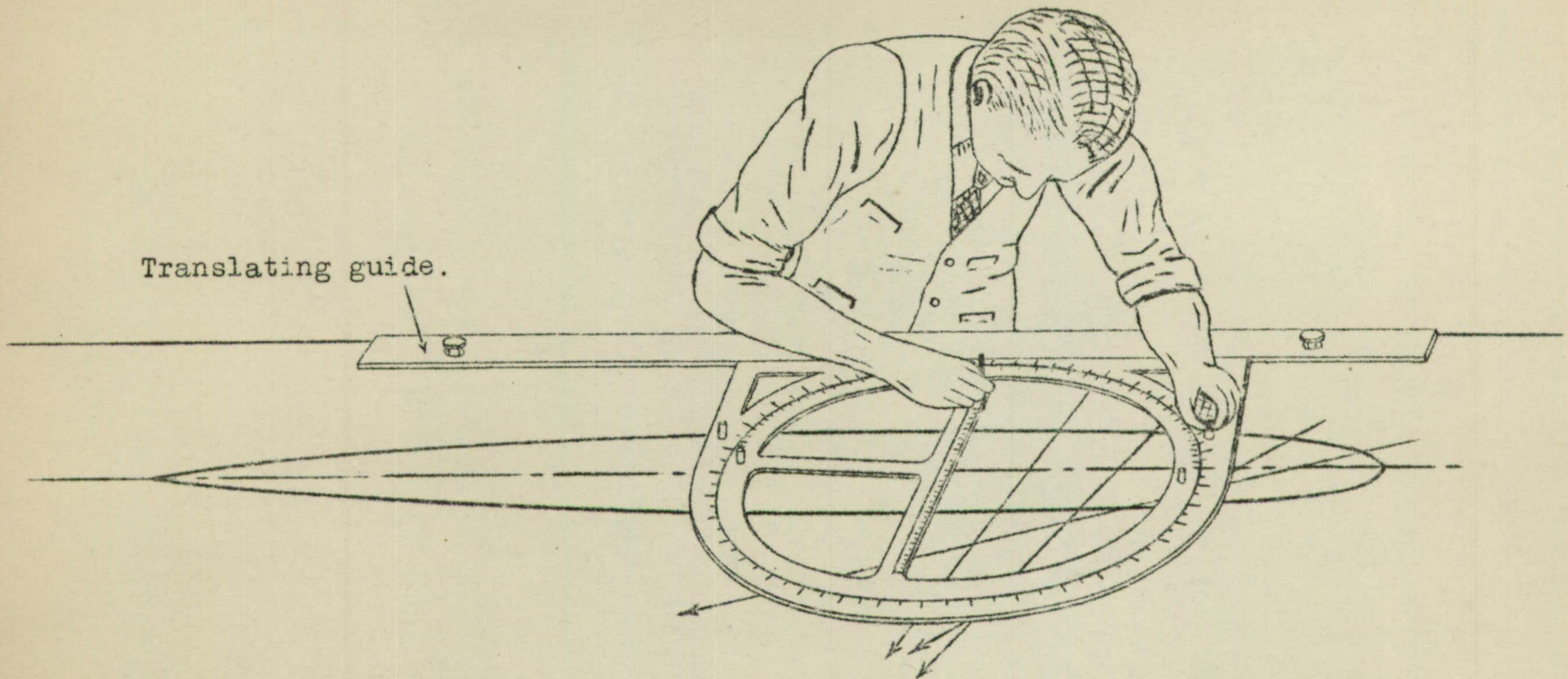

Fig.5. Showing the operation of drawing the line of the wind force for the Shenandoah hull, at various angles of attack.