223

TECHNICAL NOTES

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DETERMINATION OF THE LIFT AND DRAG CHARACTERISTICS OF AN AIRPLANE IN FLIGHT.

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Flight tests are now in progress at the Langley Memorial Aeronautical Laboratory on a Sperry Messenger airplane to determine its lift and drag characteristics when rigged with different sets of wings. At the same time wind tunnel tests are being made on a one-tenth scale model so that comparisons to determine the scale effect will be possible. The ultimate aim of course is accurate performance prediction from wind tunnel tests. The flight tests are accomplished by the so-called "glide method" and since glides have been used for some time to obtain the lift and drag of an airplane, nothing new as to the basic method can be presented. However, some new facts have been brought out by recent experience which seem to be of enough importance and general interest to justify this note.

The principle on which glide tests are based, is that: if the angle of flight path of an airplane, gliding at a constant velocity and under its own weight, is known, the weight can be resolved into components at right angles and parallel to this path, the lift and drag respectively. However, in order to obtain results upon which fair comparisons may be based, the effect of the propeller must be eliminated or accounted for, and this is one of the most difficult problems connected with this type of flight testing.

Fundamental Relations

In order that this article may be read with a clear idea of the fundamental principles on which the tests are based, a brief review of the forces acting on an airplane in the various conditions of steady flight is given.

Fig. 1 shows the diagram for glide with no propeller thrust. The angle of flight path γ, at any one indicated airspeed* has a value constant for any given airplane and consequently values of this glide angle at increments of airspeed may be considered as definite characteristics of that airplane (See Fig. 2). W is a force equal to the total weight and necessarily acts in a vertical direction. L and D are components of W perpendicular and parallel to the flight path, respectively, L being the lift which must be furnished by the whole plane, and D the drag of the whole plane. β is the angle of the thrust axis to the flight path and β plus the angle of incidence, as rigged, is the angle of attack which at any one indicated airspeed is necessary to produce a lift required, L.

Fig. 3 shows the diagram for glide when the propeller is

* The term "indicated airspeed" merits an explanation. An airspeed meter of the Pitot type really measures dynamic pressure, $\frac{1}{2} \rho V^2$. The instrument is calibrated, however, to convert $\frac{1}{2} \rho V^2$ to velocity in miles per hour using ρ for standard air. Therefore, indicated airspeed is simply the result of solving for V in the expression $\frac{1}{2} \rho V^2$ using standard ρ.

producing a small thrust. The thrust T acts along the thrust axis at an angle β with the flight path, so that $T \cos\beta$ is the effective component parallel to the path of flight. Since this thrust is not sufficient to balance the drag D, but has the effect of diminishing the apparent drag as determined by the weight component parallel to the flight path, it follows that: $W \sin\gamma = D - T \cos\beta$. Therefore, to glide at a given indicated airspeed at an angle other than that which the plane will assume, a thrust must be produced. The total lift, $W \cos\gamma$, is made up of two quantities, L the wing lift and $T \sin\beta$ the lift component of thrust. The quantity $T \sin\beta$ is generally small and is often neglected.

In level flight, as shown in Fig. 4, the thrust component parallel to the path of flight balances the drag D. As γ is zero, $W \sin\gamma$ disappears and $W \cos\gamma$ equals W. The value $W \cos\gamma$ is made up of L and $T \sin\beta$ as before.

In climbing flight, Fig. 5, the flight path thrust component must balance the drag added to the value $W \sin\gamma$, the component of weight parallel to the flight path. $W \cos\gamma$ is again equal to $(L + T \sin\beta)$.

Another interesting point deserves mention, i.e., the relation between the angle of attack and the indicated airspeed for different conditions of steady flight. Flight tests have shown that there is not a great variation in this relation except at large angles of climb or glide. If a constant angle of attack is assumed, a change in the flight path angle can only be obtained by a change of thrust. To illustrate this condition, Fig. 9 has been plotted, assuming a constant angle of attack and adding increments of thrust to change the flight path angle. As will be noted, the change in the lift required is not great except when large angles of glide or climb are encountered. Since the lift required changes only slightly, it follows that the change in airspeed is also small and consequently for any one angle of attack the airspeed required to maintain steady flight is practically constant over the greater portion of the range of possible flight path angles. Another fact shown by Fig. 9, is that the small change in lift required is such that for any one angle of attack the maximum resultant air force occurs when the thrust axis is horizontal.

The above discussion applies to steady flight only, and it must be remembered that changes in loading occur due to accelerations encountered in maneuvers and in changing from one flight condition to another, and due to fuel consumption.

Glide Test Procedure

From the foregoing discussion of the principles involved, it follows that the measurements necessary for determining lift and drag characteristics from glides are:

1. Weight of the airplane.
2. The angle of flight path.

3. Angle of wing chord to horizontal (for angle of attack determination).

4. Dynamic pressure ($\frac{1}{2} \rho V^2$).

5. Pressure and temperature at the altitude encountered (used in determining true airspeed for propeller thrust computations).

6. R.P.M. of propeller (for computation of thrust).

Several methods of making glides and also many ways of determining the flight path angle are possible. Most of these have been tried and from the experience gained it is concluded that the best results are obtained with the propeller operating at zero thrust or zero torque and the flight path angle measured as described below.

The weight is determined before the flight and an allowance can be made for its change during the flight by apportioning the weight of gasoline consumed. This correction is generally small unless the flight is unusually long. The remaining determinations are made during the glides.

The angle of the flight path is measured by means of a trailing bomb suspended about 25 feet below the airplane, (The details of this instrument are described in Appendix 2). The readings of dynamic pressure for computations are taken from a Pitot-static tube on the trailing bomb, thus eliminating any error caused by interference.

An oil-damped, recording pendulum-inclinometer in the airplane gives the angle of the wing chord to the horizontal. The instrument is simply a pendulum on which a mirror is mounted, the reflected light beam recording the deflection on a photographic film. The angle of attack can then be obtained by subtracting the angle of the wing chord from the flight path angle.

Barometric pressure is obtained from a recording altimeter and the air temperature and propeller R.P.M. are observed by the pilot. On tests where an observer is carried, a Veeder counter and stop watch may be used for the R.P.M. reading.

In order to eliminate the effect of the propeller it is necessary to know the propeller characteristics. These are determined from wind tunnel tests of a model propeller. From these data a table is prepared for the pilot, giving the necessary combination of airspeed and R.P.M. to maintain zero thrust or torque as the case may be. It is generally assumed in preparing the above-mentioned table that standard conditions will be encountered unless an altitude above 5000 feet is to be used. The pilot brings the airplane into a glide as close as possible to the required R.P.M. and airspeed by the use of the service instruments. After the records are made the temperature and pressure as obtained from a thermometer and a recording altimeter give the data necessary to reduce the bomb recorded dynamic pressure to true airspeed. Using this value of airspeed and the actual R.P.M., the magnitude of small positive or negative thrust, caused by actual values not satisfying the condition desired, may be computed from the model propeller data. This value of thrust, which may be either positive or negative, is used to correct the value (D - T)* found as the component of weight parallel to the flight path, the correction being generally small.

The lift is taken as a direct component of the weight, $W \cos \gamma$. The value of $T \sin \beta$ is entirely negligible for any thrust correction which is likely to occur, so all of $W \cos \gamma$ is credited to the supporting surfaces as the error in $\cos \gamma$ due to a fictitious angle of glide caused by a small amount of thrust would also be small enough to be neglected for any reasonable thrust correction. These two errors are considered as contributing a part of the general experimental error which must be partly eliminated by the repetition of tests.

The lift and drag in pounds having been found, the coefficients can be computed for unit wing area and dynamic pressure. Glides at about 5-mile increments of airspeed give points covering the polar curve (Fig. 6). Angle of attack data make it possible to plot curves of lift and drag coefficients against angle of attack (Figs. 7 and 8).

Since the flight path angle recorded by the trailing bomb is always that of the direction of the relative wind, air disturbances of a steady character do not affect the accuracy of glide test results. This statement is not true of "bumpy" air, when air currents encountered are not steady, and such conditions as cannot be eliminated must be taken as part of the general experi-

*(D - T) is used in this case instead of ($D-t \cos\beta$) as the difference is so slight as to be negligible. (See Fig. 3.)

mental error. Several flights are always necessary to obtain sufficient points to assure accurate results. Figs. 6, 7 and 8 show the scattering of points which may be expected in final results.

Problem of the Propeller

It was previously mentioned that the elimination or accounting for the propeller is one of the most difficult problems connected with these tests. This is princiapply due to the lack of propeller data which is directly applicable to full-scale tests. In order to have the value, $W \sin\gamma$ (Figs. 1 and 3), represent the true drag of the airplane in glide tests and not the difference between the drag and thrust, the effect of the propeller must be eliminated or accounted for. The thrust or torque of a given propeller, at a given dynamic pressure, is dependent on the ratio of its forward velocity to the velocity of its blade due to rotation and results of tests on model propellers are made with that ratio as a basis. The ratio is written as V/ND where V is the forward velocity, N the revolutions of the propeller per unit of time, and D the propeller diameter. Therefore, if a value of V/ND is selected at which the thrust or torque coefficient is zero, various R.P.M. can be computed which will be appropriate for keeping this ratio constant at airspeeds at which it is desired to make glides. If the V/ND used does not really produce the desired condition due to the fact that the characteristics of the propeller are changed under flight conditions, then the results obtained must be considered as the combined characteristics of the airplane and propeller at the V/ND at which the propeller is operated.

Most of the propeller data available are taken from model tests made with no obstructions in the slipstream. Any sizable obstruction, especially if poorly streamlined, would change the characteristics of the propeller (Reference 1). The effects of obstructions such as a fuselage of irregular shape, radial engine cylinders, etc., would be such that the zero thrust or torque condition would not be realized in flight at the V/ND as given by model data.

As stated previously, it has been considered advisable to keep the propeller in operation during glide tests. The zero thrust method would be the proper one to determine the characteristics of the airplane itself. In practice, however, it is very difficult because propeller data obtained from tests in an unobstructed slipstream are not sufficiently accurate. An auxiliary propeller test with proper obstructions would have to be made, requiring an elaborate set-up for driving the propeller and measuring the desired forces. At the present time glide tests are interesting mainly for comparative purposes, to find the actual relation of wind tunnel to flight results. For tests of this kind the zero torque method is much better because the propeller problem may be solved by allowing a propeller to spin freely on the model, simulating the condition of zero torque. Comparison between wind tunnel and flight is then based on the airplane and propeller as a unit, with propellers operating at the same V/ND.

It has been suggested that the distortion of the propeller blades when in operation might change the effective angle of attack to such an amount that a fair comparison between the propeller on the model and the full scale could never be made. The amount of deflection would evidently be dependent upon the type of the propeller, thickness of the blades, material used, etc., so it might very well be said that every propeller is a special case when the question of blade distortion is considered. So far as is known there is no specific information on the actual magnitude of the distortion that might be expected with a given set of conditions, probably because of the extreme difficulty of making accurate measurements which would after all apply to only one propeller. However, in order to determine the effect of a distortion on the measurement of drag in glide tests, some computations of thrust were made, considering the blade sections as airfoils. Values of thrust were computed, first for a given propeller with no distortion, then for the same propeller with an assumed distortion of one degree at the tip decreasing to the normal angle at one foot radius, and finally with one degree twist at the most effective portion of the blade. In all cases the thrust was computed for a condition near zero thrust, the values of airspeed and R.P.M. used being the highest encountered in a set of glide tests with the same propeller. It is felt that the distortions assumed are larger than would actually occur in practice, but even with these the change in thrust as computed amounted to only five per cent of the drag of the airplane as recorded in flight for the first distortion (the most logical) and nine per cent for the second.

Another problem is that of obtaining an accurate model of the propeller in the small size necessary for the wind tunnel model. This is a mechanical problem entirely, but without doubt it will be very necessary to have the greatest accuracy possible in this model.

Although there are still questionable points in the method of comparing model and full scale by operating propellers at the same V/ND, it seems the most practical yet considered for the purpose of effectively accounting for the propeller.

APPENDIX I.

Other Methods

To complete the discussion, two other methods are outlined which have not been developed because of their seemingly undesirable features.

Glides with Stopped Propeller.- The possibility of entirely eliminating the propeller by stopping it during glide tests has been discussed. To use the stopped propeller in connection with present methods makes it still more impractical than it seemed without further complications. To stop an engine in the air, take a glide and reel up a bomb before landing is certainly not a practical nor a speedy method of getting results. A clutch on the propeller offers still more mechanical complications, such as running the engine without balance, besides the unreliability of the clutch itself. A method of testing which requires an airplane to be rebuilt for the purpose is again not practical. Besides, whether running or not the propeller is present and if not stopped in the same position each time will not offer the same resistance.

Altitude Time Methods.- Recording change in altitude, time and velocity during a glide and solving for the flight path angle with the leg and hypotenuse of the right triangle thus obtained, was one of the earlier methods used in glide tests. This method for quite obvious reasons does not work out well in practice. There is considerable lag in altimeters and even a statoscope is not accurate enough for this work. Small errors in airspeed measurement and altitude all add to the error in angle. Two more sources of error are added than would be the case with a direct measurement of angle.

APPENDIX II.

Bomb Inclinometer.

This instrument, as previously mentioned, has been used in glide tests for a direct measurement of the flight path angle. By direct measurement is meant the determination of the angle of flight path relative to the horizontal by the angle which the aerodynamic axis of a streamline body makes with the horizontal when suspended beneath the airplane far enough to be free from the air disturbances set up around the airplane. More simply, the instrument measures angle of flight path by aligning itself with the relative wind. Tail surfaces are attached to the streamline body for more certain alignment and in outside appearance the instrument resembles a bomb, whence it derives its name. A mercury U-tube is carried within the bomb shape. Two metal tubes, the lower ends connected to the U-tube, are inclosed in the cable by which the bomb is suspended and are attached to a pressure capsule of the regular N.A.C.A. recording type (Reference 2). This capsule records changes in pressure created by change in volume when the bomb containing the U-tube assumes different positions. A calibration in degrees from the horizontal relative to the aerodynamic axis of the bomb gives necessary data for obtaining angle of path from records taken in flight.

Two more tubes in the cable serve the Pitot-static head of the bomb and connect to another pressure capsule in the airplane for measurement of dynamic pressure.

The troubles with this instrument have been mostly due to the pneumatic system. The long length of metal tubing in the cable is hard to keep in operation as tubes are often cracked or broken when the cable is reeled up. A new type of flight path angle recorder is now in the process of development which will have the recording mechanism within the bomb shape itself, the wires for supplying the current to the mechanism forming part of the supporting cable. An oil-damped pendulum will be substituted in place of the U-tube for measurement of angle.

A direct measurement of angle of flight path is considered more accurate than any method which depends on both the angle of the longitudinal axis of the airplane and the angle of attack. Angle of attack, if measured by a vane or yaw meter head on the airplane, is hard to obtain accurately because of interference around the wings. The bomb eliminates the necessity of depending on two measurements for a value so important to the accuracy of results.

Records obtained from the bomb are of an oscillating character due to the pendulum action of the instrument. It is assumed that the mean of the oscillation is the correct value. With good air conditions the oscillations are very regular and not of great amplitude.

The dynamic pressure and the flight path angle as measured by the bomb are the most important recorded values upon which the final results of glide tests depend. It is advisable in conducting tests to make calibrations of this instrument very frequently and to check its operation carefully before each flight. For accurate results too much care in this respect is impossible.

References

1. E. P. Lesley and B. M. Woods : The Effect of Slipstream Obstructions on Air Propellers. N.A.C.A. Technical Report No. 177 - 1924.

2. F. H. Norton : N.A.C.A. Recording Airspeed Meter. N.A.C.A. Technical Note No. 64 - 1921.

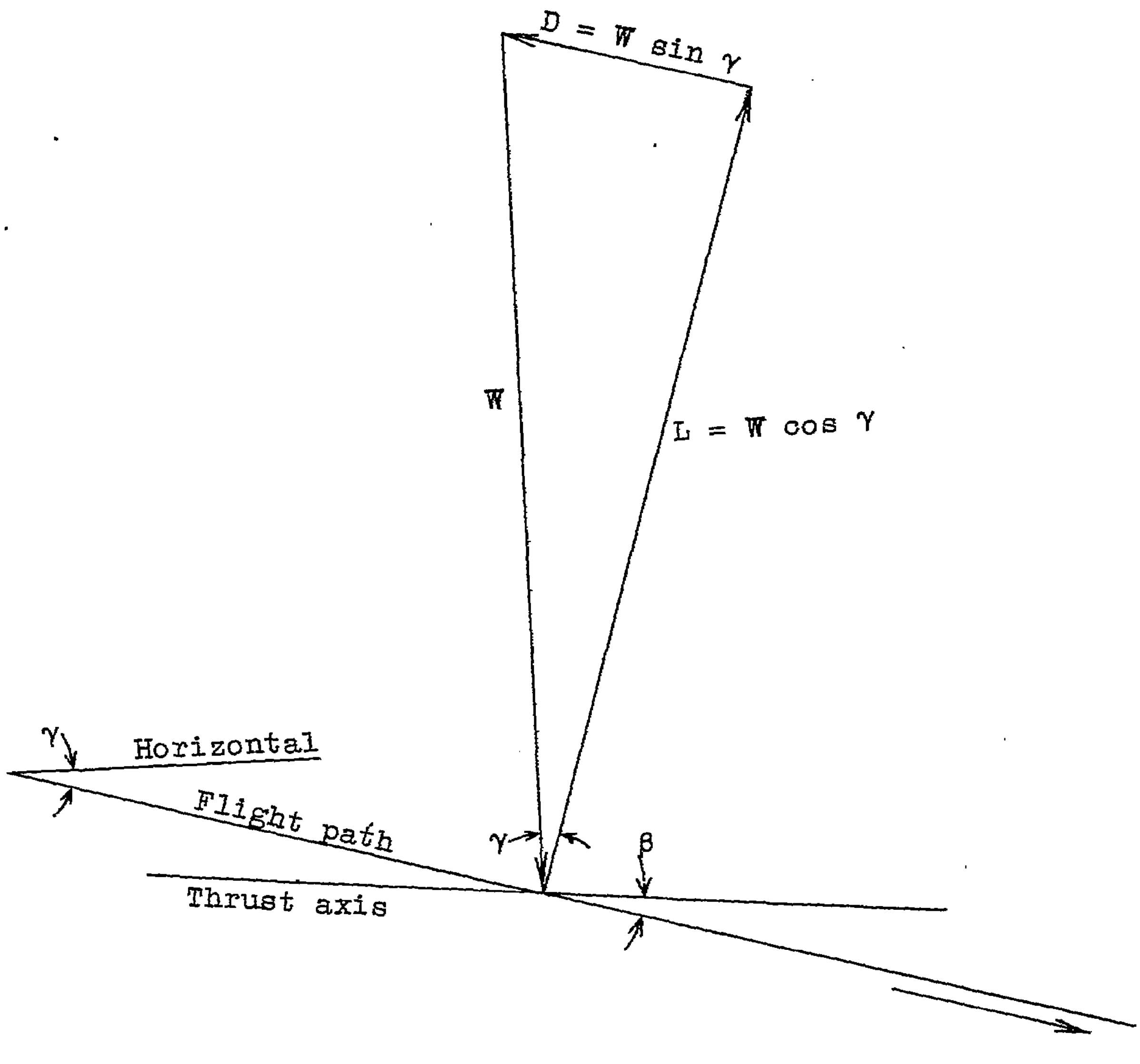

Fig.1 Glide, zero thrust.

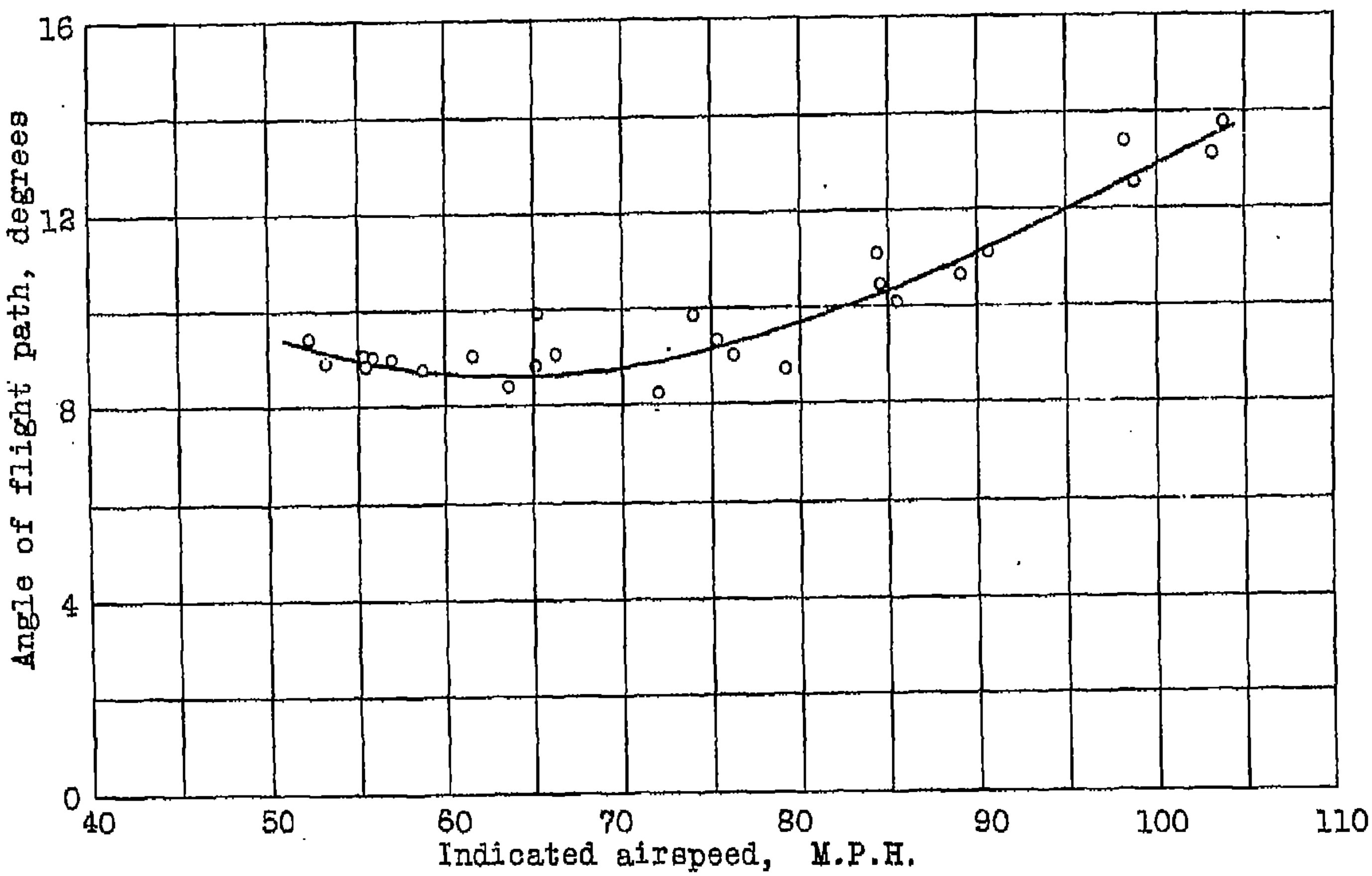

Fig.2 Results of a set of glides showing relation of angle of flight path and indicated airspeed. Values as recorded, and not corrected for small positive or negative values of thrust.

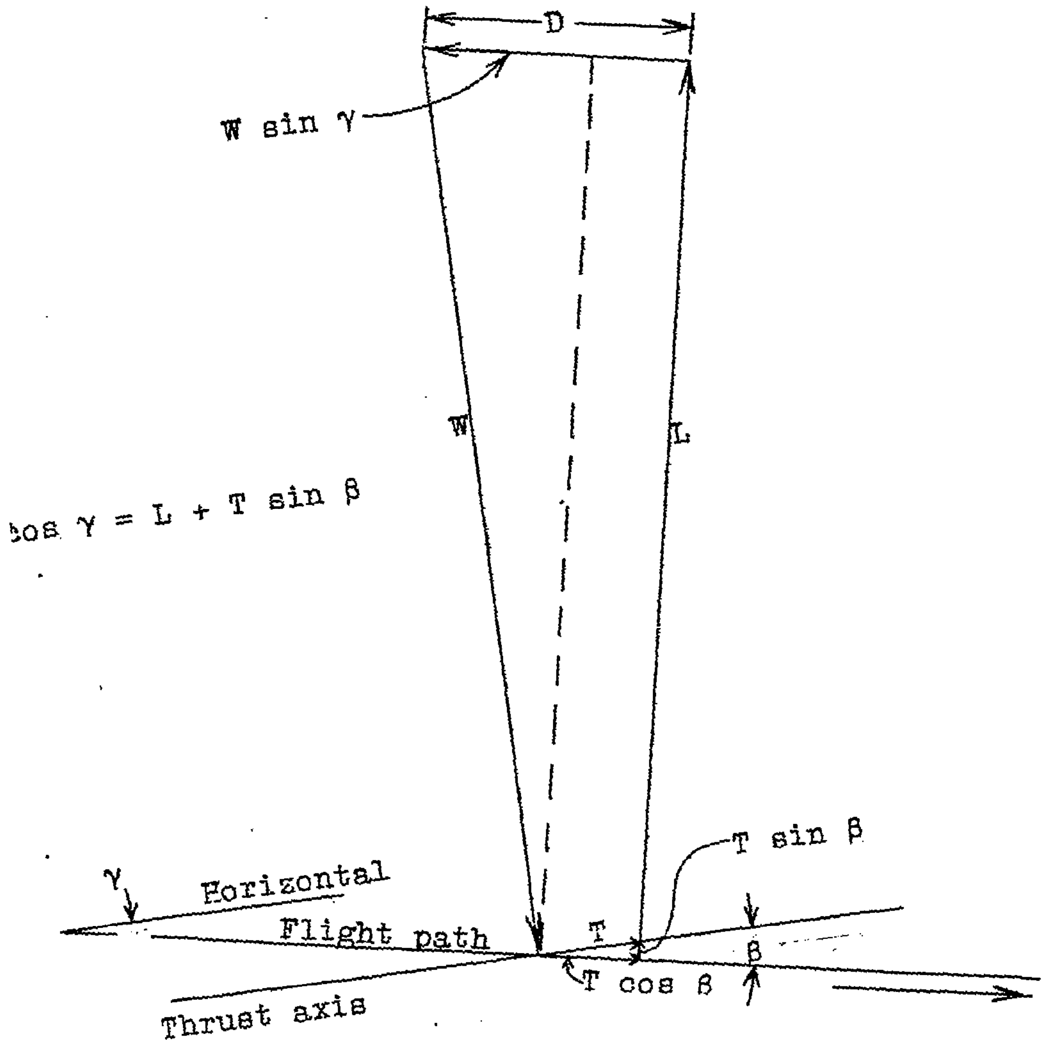

Fig.3 Glide, positive thrust.

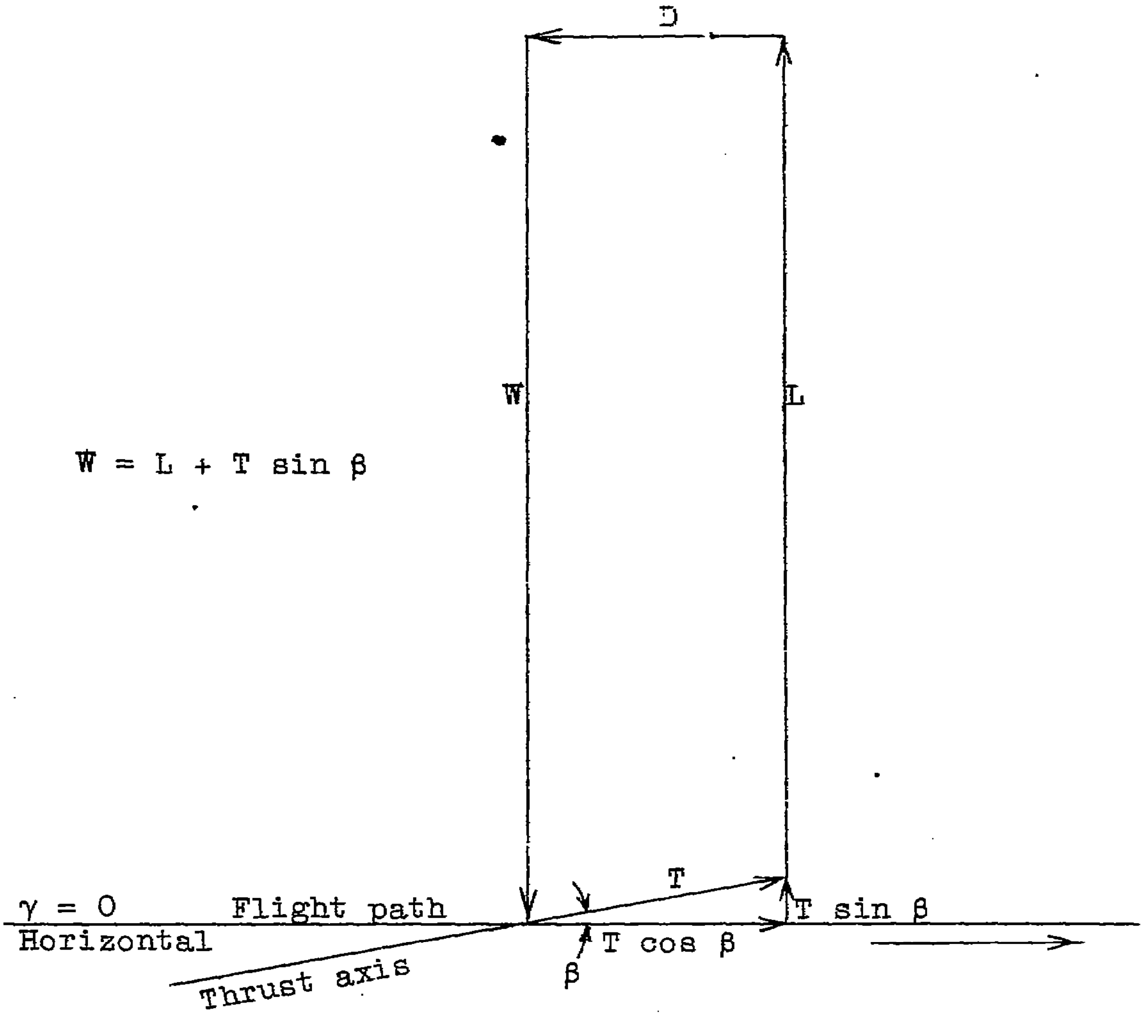

Fig.4 Level flight.

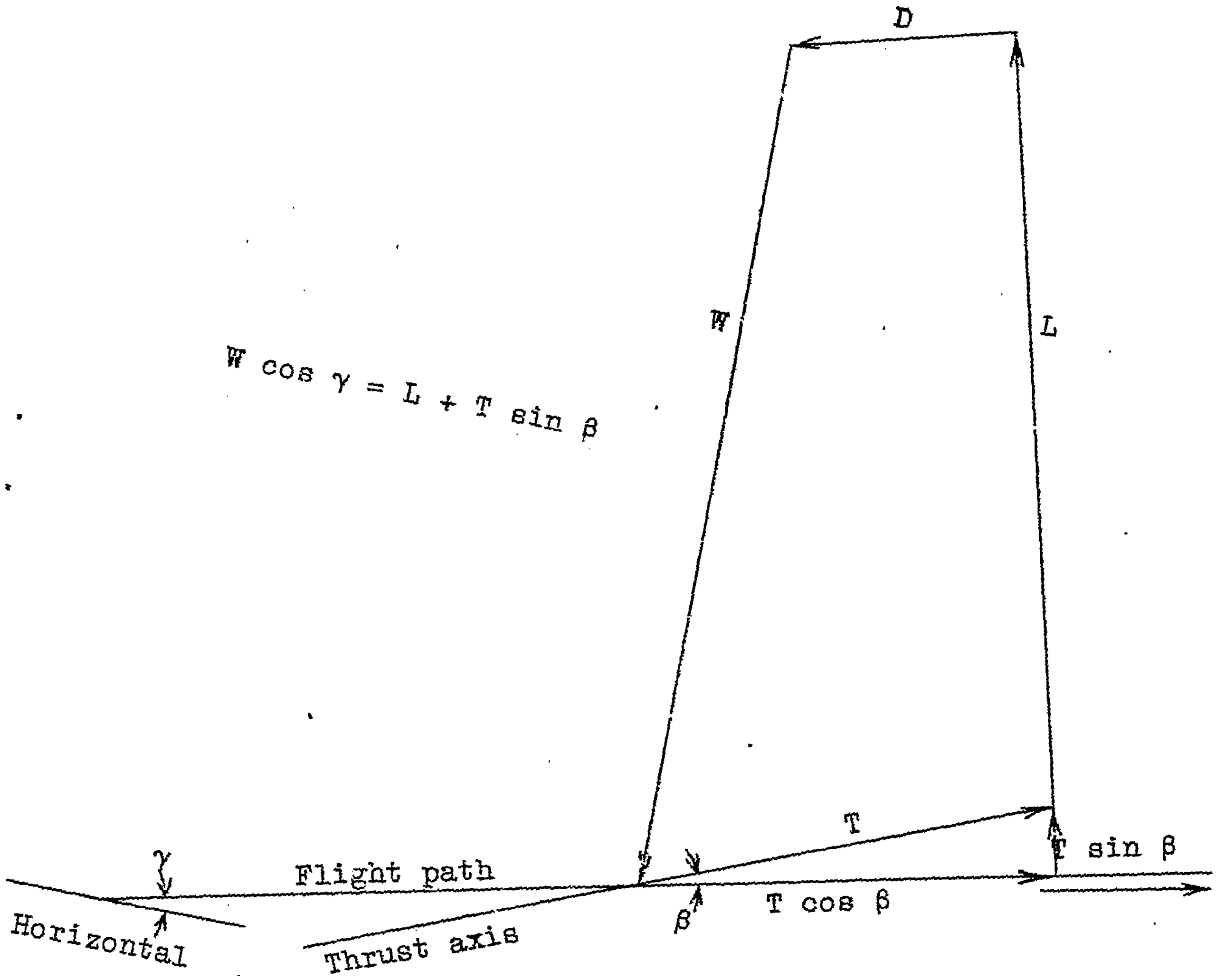
D
W
L
W cos γ = L + T sin β
T
γ
Flight path
T sin β
Horizontal
Thrust axis
β
T cos β

Fig.5 Climb

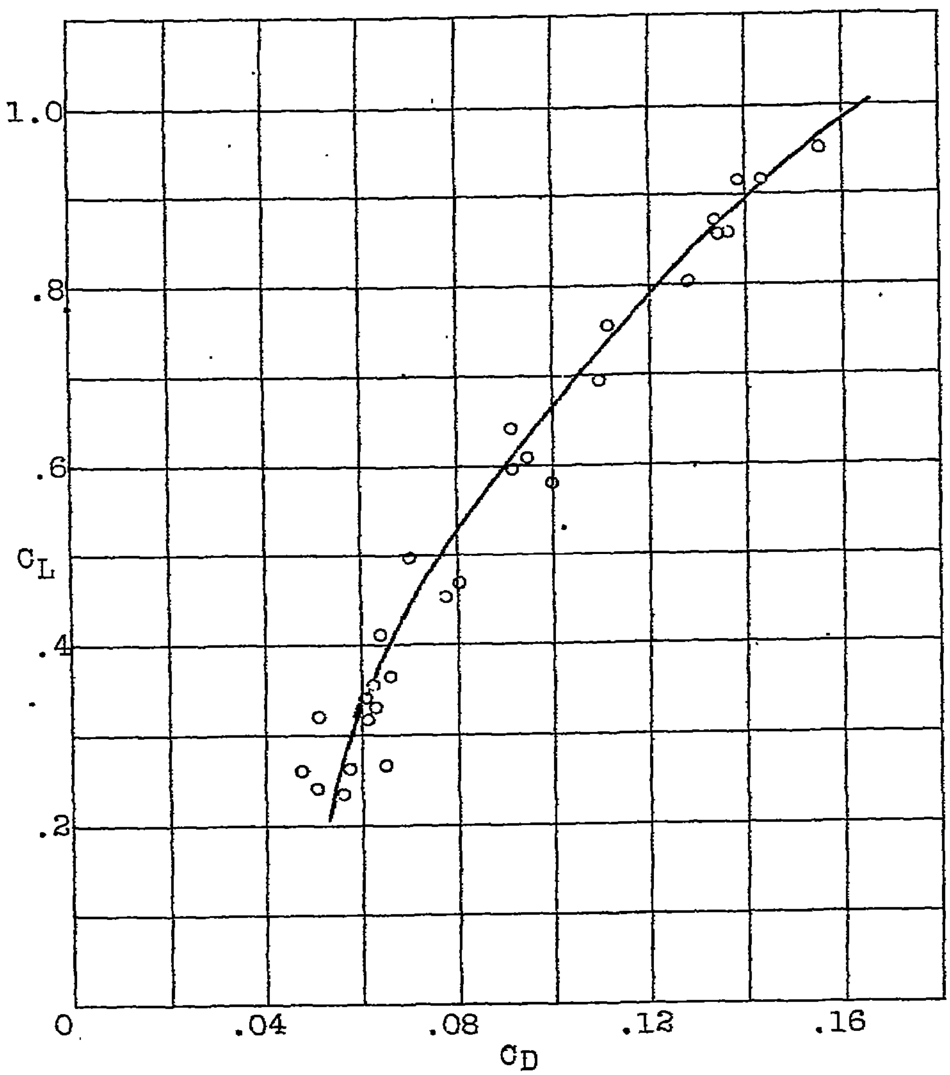

Fig.6 Glide test results.
Polar curve, C_L vs C_D.

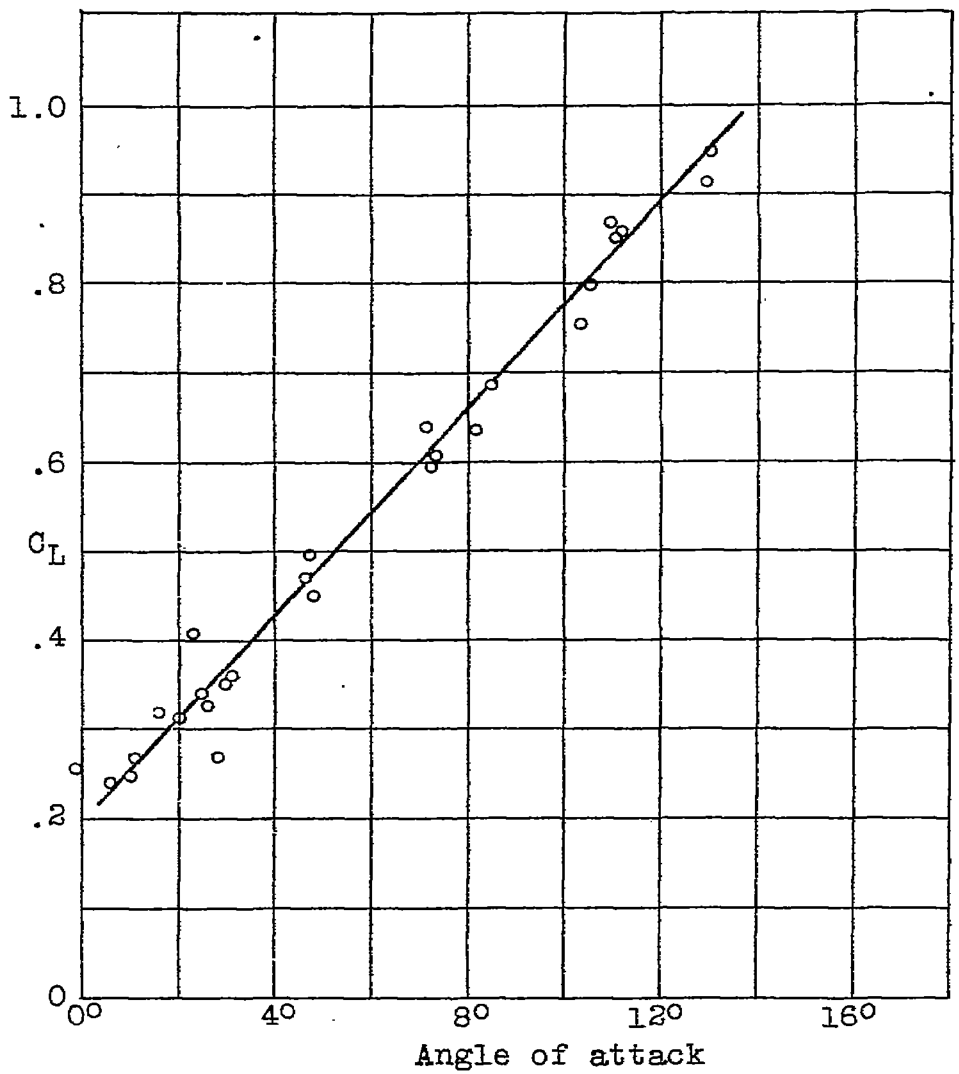

Fig.7 Glide test results.
Lift coefficient(C_L) vs angle of attack.

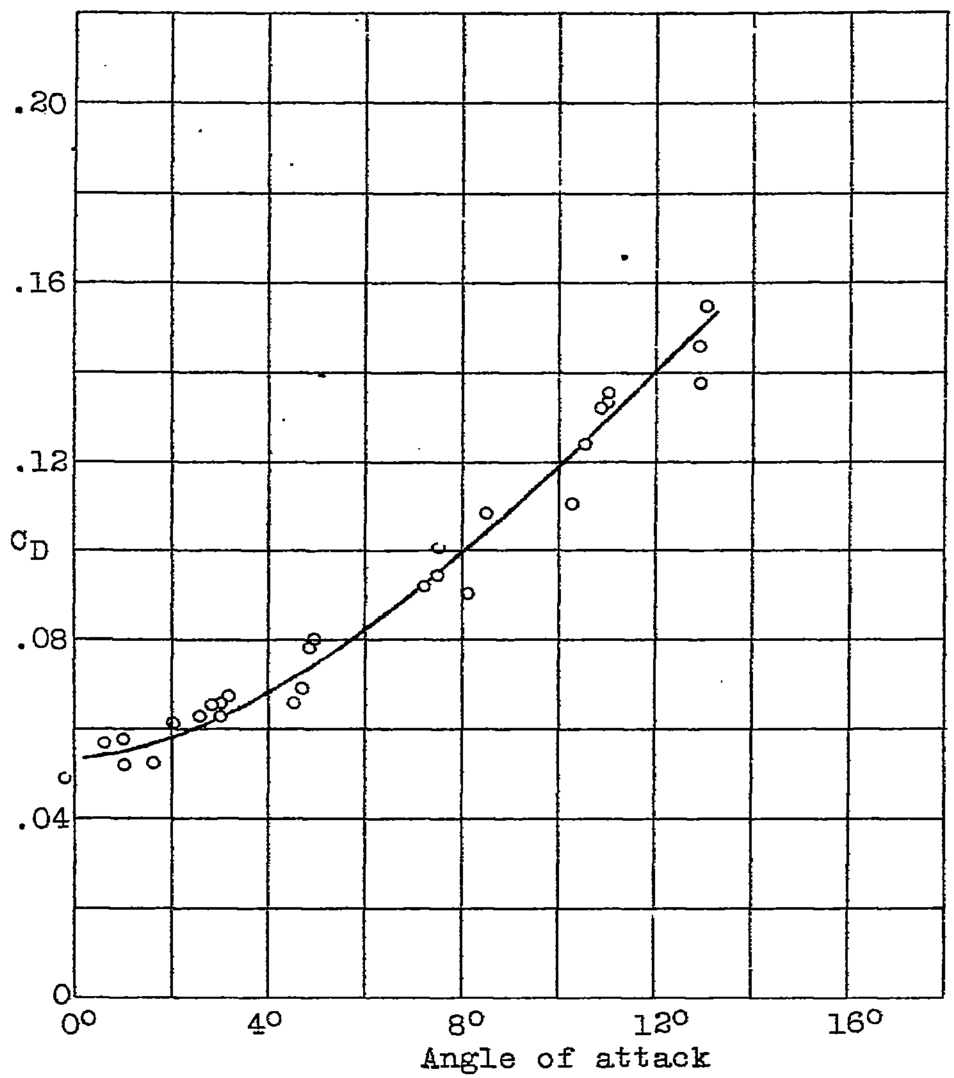

Fig.8 Glide test results.
Drag coefficient(C_D) vs angle of attack.

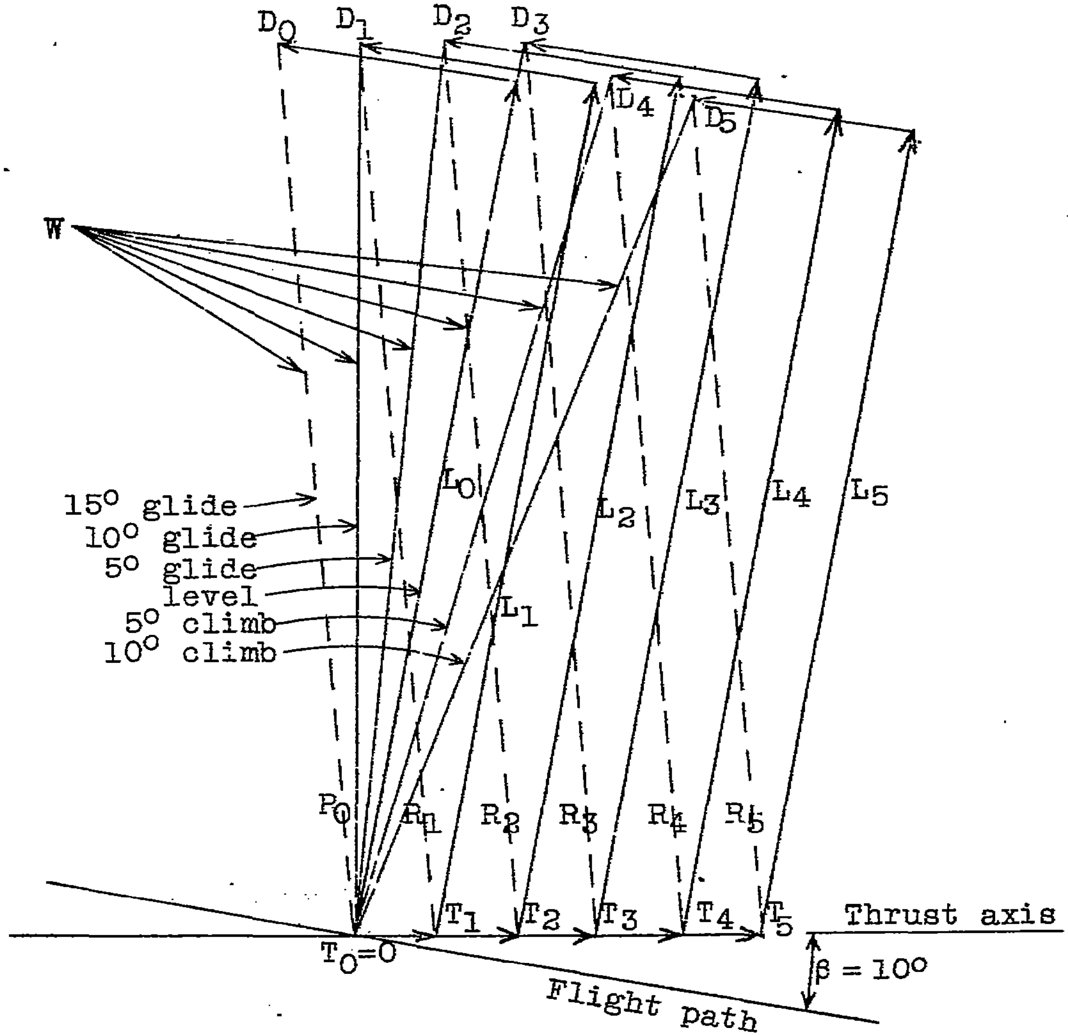

Fig.9 With a constant angle of attack and varying thrust and flight path angles, L_0, L_1, L_2, etc., represent the lift required of the suporting surfaces. Starting with zero thrust in glide sufficient increments of thrust(T) have been added to obtain 5° increments of flight path angle.

The resultant air reaction, R, is a maximum when the weight, W, is perpendicular to the thrust axis, i.e., when the thrust axis is horizontal. Since the triangles, R_0 D_0 L_0, R_1 D_1 L_1, etc., are similar, L is greatest also when the thrust axis is horizontal.