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GROUND INFLUENCE ON AEROFOILS.

By

Arthur E. Raymond,
Massachusetts Institute of Technology.

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Introduction.

The work leading up to the preparation of this report was done as a thesis by the author while a student in the Aeronautical Engineering course at the Massachusetts Institute of Technology. He wishes to acknowledge the assistance in preparing models, conducting tests, and preparing the report for publication, of Mr. Carl Selig, mechanic of the Department of Physics, Mr. Boris V. Korvin Kroukovsky, and Professor E. P. Warner, of the Department of Physics.

The question of ground influence on airplanes has recently attracted some attention in view of the claims made by certain designers that the landing speed of their airplanes is much decreased by an increase in lift coefficient due to the proximity of the ground in landing. As an illustration of this, in the description of the Pischhoff Avionette given in "Aviation" for January 25, 1921, the statement is made that "the proximity of the lower wing to the ground, eight inches, causes the air im-

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prisoned between the wing and the ground to act as a cushion." (The chord of the lower wing of this airplane is 2 ft. 4 in.) It has also been suggested that the difficulty experienced in landing some airplanes with high-lift wings, and notably those models with flap gears, may be due to such an increase in lift coefficient when approaching the ground, causing the airplane to stay off the ground while travelling nearly parallel to it for an abnormal length of time. Several investigations, discussed in detail later, have previously been undertaken on this point.* There seems to be room for another particularly to try out the relative merits of two possible methods of making ground influence tests.

The method of testing which first suggests itself is to set up a flat plate in the tunnel to represent the ground. This was one of the methods employed but the results obtained by it are not entirely satisfactory. Its fault lies in the fact that it is stationary with respect to the aerofoil, not to the wind. It represents the case in practice where the airplane lands in a wind of as great a velocity as its own air speed. Such a condition is fortunately rare and it is doubtful if the flow of air across the landing field at such a time would approximate the flow around a flat plate in the wind tunnel.

A method giving results of more practical value was found in the reflection method. Considering the ground plane as a mir-
* "Ground Effect on Wings," by A. A. Merrill, The Ace, December, 1920; "Ground Influence on Wings," by the Aerodynamics Staff, Report #173; "Wind Tunnel," Navy Yard, Washington, D. C.

ror in which the aerofoil to be tested is reflected in a duplicate aerofoil placed in the position of its image, two wings are placed symmetrically in the tunnel, with the ground plane considered as the plane of symmetry half way between them. Forces are read on one only and whenever the angle of attack of one is altered the angle of the other is changed correspondingly. The ground plane in this case being imaginary, no error is introduced on account of skin friction, as in the flat plate method. The reflection method was found to give two slightly different types of flow at high lift angles, due to disturbance of the plane of symmetrical air flow by vortices, but it is believed that the results show it to give a closer approximation to ground plane influence than does a flat plate.

All tests were made in the 4 ft. tunnel at the Massachusetts Institute of Technology. Wind velocity through the tunnel was in all but two tests 30 m.p.h. In an effort to obtain satisfactory readings on one of the wings at an angle of discontinuity the velocity was increased in these two tests to 40 and 45 m.p.h. The effort was successful but overheated the motor driving the tunnel propeller, and it was not attempted again.

The dimensions of the three models used were 3 in. by 18 in. The models were:

1. Martin No. 2. A thick section wing fitted with flap gear. The duplicate wings used were very accurately made and agree with the specified ordinates to within 2%.

2. R.A.F.15 Special. A double-cambered moderately thin wing. The models used were old ones, both quite warped, but were placed in the tunnel warped in the same direction and were very nearly the same distance apart at all points along their span.

3. U.S.A.27. These models were very inaccurately made and are not true U.S.A.27 aerofoils, but served well enough for the purpose in hand.

Flat plate method. A piece of three-ply birch $3/8$ in. thick, 4 ft. high, 3 ft. wide, was used. The leading edge was chamfered on the side way from the model. Small wooden strips were attached to the top and bottom and screwed to the ceiling and floor of the tunnel, maintaining the plywood flat and at the proper distance from the aerofoil.

Reflection method. The aerofoil to be tested was mounted on the spindle of the balance in the usual way and the reflecting wing placed on a spindle mounted with a graduated head, on an auxiliary wooden fairing having a brass floor plate. After each reading the wind in the tunnel was shut down while the reflecting wing was shifted to its new angle of incidence. In all comparative tests the single wing was tested immediately before the reflecting wing was put in place.

For tests made at a fixed angle of incidence, with the wings at a varying distance apart, the reflecting wing, its spindle, and graduated head were mounted on a brass rail running

from the center fairing to a second fairing placed near the tunnel wall. This brass rail was graduated for distances between spindle centers of from 1.75 to 16.00 inches. It was found that the apparatus holding the reflecting wing caused no measurable influence upon the other wing.

In running a test at a fixed distance it was found best to keep the distance between spindles or from spindle to plywood constant. The wings being lined up at 0° before each test, the distance was measured from chord to chord at that angle and not from spindle to spindle. The position of the spindle (center of rotation) for each aerofoil is given below and a chart is appended for determining the distance between trailing edge and ground in each case.

Wing	Center of Rotation.	
	Back of L.E.	Above Chord
Martin No. 2	1"	0.25"
R.A.F. 15 Special	1"	0.00"
U.S.A. 27	1"	0.20"

In plotting results, absolute coefficients are used throughout.

Reflection method. Considering first the tests made with the ground at $1/2$ chord: The most marked effect is an increase in L/D of from 35% to 40% at angles ranging from -4° to maximum lift. This is caused by an increase in lift and a decrease in drag. The increase in lift is greatest at small angles, weaken-

ing perceptibly as the burble angle is approached. The decrease in drag, on the other hand, is most marked at high angles, the combined effect being an increase in L/D of substantially a constant percentage.

Maximum lift is increased little, if any, at $1/2$ chord ground distance, but there is a tendency to shift it to a smaller angle.

The Martin wing (flap neutral) at 30 m.p.h. showed an increase in maximum lift at $1/2$ chord, but at 40 and 45 m.p.h. this did not occur. While making tests at 14° and 16° at varying distance two types of flow were observed, which account for this on the supposition that the ground plane of symmetry is easily broken up at high angles and speeds by the intermingling of vortices from the two reflecting wings. If this be true, the type of flow which gives an increased lift is the one for which the vortices do not intermingle, and therefore corresponds to the ground influence felt by a full size airplane.

Turning to the tests made at varying ground distances as given in Fig. 3, a noticeable fact is the speed with which the ground influence increases as the wing comes within 1.2 chord of the ground. The effect on lift is very slight at 2 chords but that on drag is still considerable. The curves approach asymptotically the single wing values as would be expected with the exception of the 16° lift curve, which for distances greater than $1/2$ chord lies below this value. The single wing lift was

checked carefully after the test and is correct.

The drag curve for this same test is also interesting. The sharp upward bend as the ground distance becomes less than half a chord is probably due to stoppage of the air flow, for the trailing edge of the wing at this angle and these distances are very close to the ground.

The diminution of effect on lift and increase of effect on drag with increasing angle for the U.S.A.27 aerofoil is shown very nicely in Fig. 6.

Flat plate method. This method only differs in its results from the reflection method at angles approaching maximum lift for the Martin and the U.S.A.27 and somewhat higher angles for the R.A.F.15 Special. Above these angles the lift drops off abruptly and it is evident that the trailing edge has entered the region of slower moving air surrounding the flat plate. It will be noted that the redundant type of air flow found in the reflection method at high angles introduces less inaccuracy than is found here.

In "The Ace" for December, 1920, an account is given of a test by Mr. A. A. Merrill, of the California Institute of Technology, of ground influence on a biplane model at the single angle of incidence of 13° . In an aeronautical report, No. 173, of the Construction Department, Navy Yard, Washington, D. C., dated February, 1921, are charts of a test made on an R.A.F.6 aerofoil with the ground at various distances. In both of these tests,

the flat plate method was employed. The results are in consonance with the work done with a flat plate in the present tests. In the tests on the R.A.F.6 a decrease in lift at high angles was found. This report did not come to hand until the present tests were completed.*

Ground effect is not entirely beneficial. It decreases the landing speed and cushions the landing shock somewhat, but does so at the expense of an increased length of preliminary skimming over the ground. By decreasing the drag and increasing the lift it lengthens the distance necessary for the airplane to travel before losing enough speed to land.

On the other hand, its influence is helpful in taking off, especially in the case of flying boats with their low-lying wings. It points to the fact that the closer the wings are to the ground the easier it is to pick up speed. It promises economy for low-skimming flight over smooth water, provided such flight be practicable.

In the conventional tractor airplane, the height of the wings above the ground is determined largely by propeller clearance, but a small low-speed airplane like the Pischoff and large low-speed commercial airplanes with engines between wings can utilize ground influence to good advantage.

* In Fig. 5 three curves from the W.H.Y. tests are reproduced for comparison.

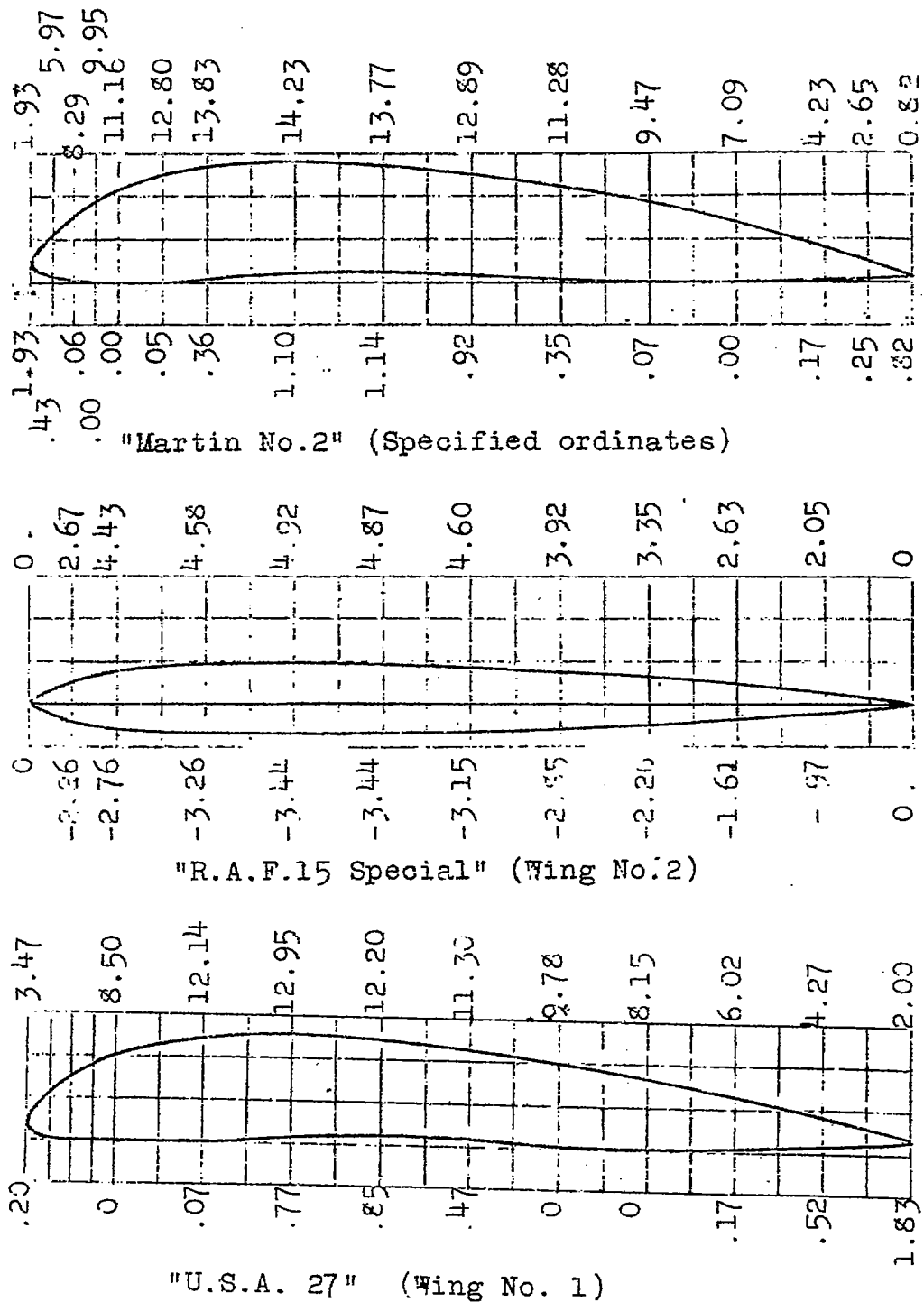


Fig. 1. Aerofoil tested for ground effect.

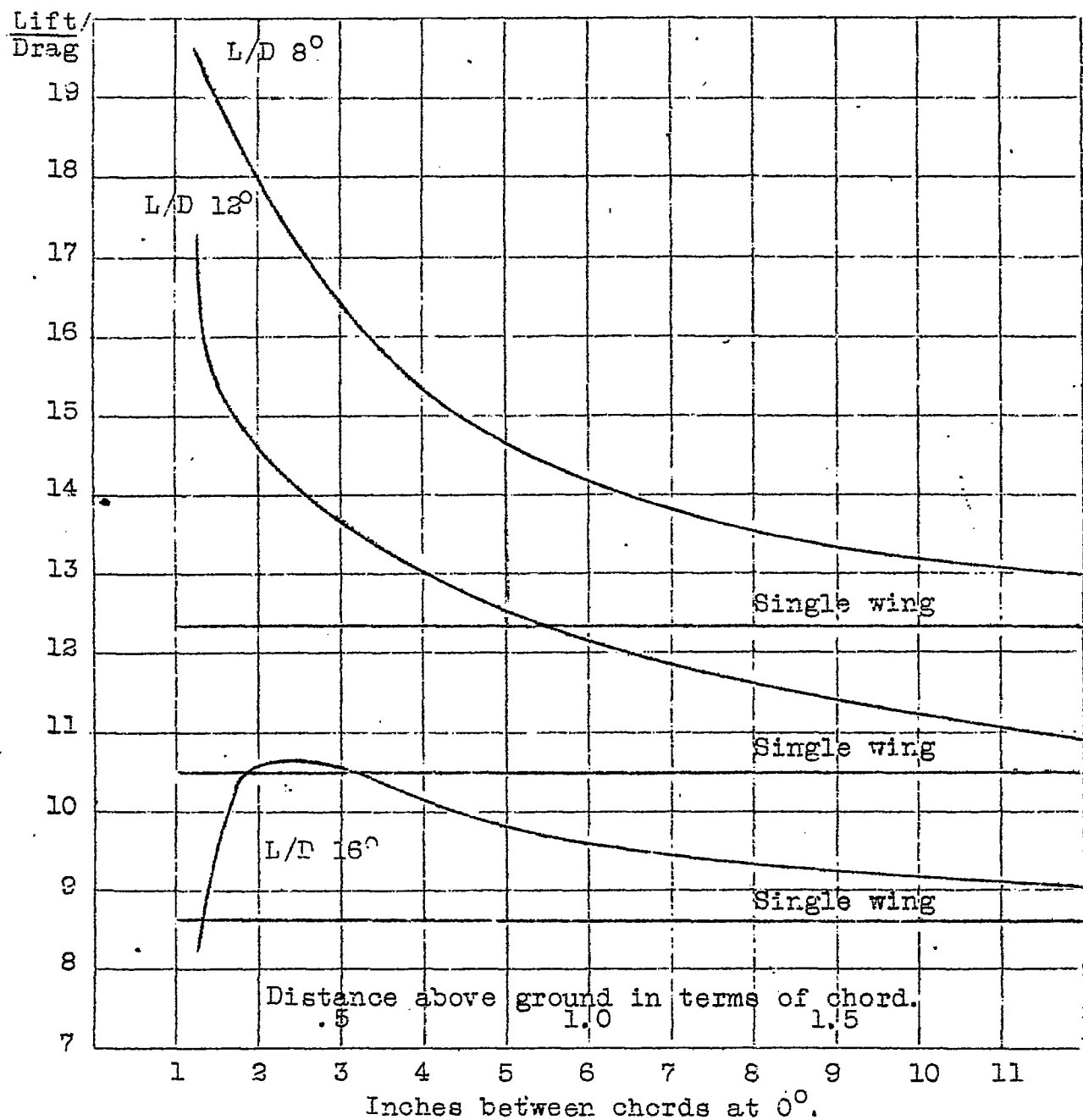


Fig. 2. - Martin wing. Ground at various distances. Reflection method. Wind velocity 30 m.p.h.

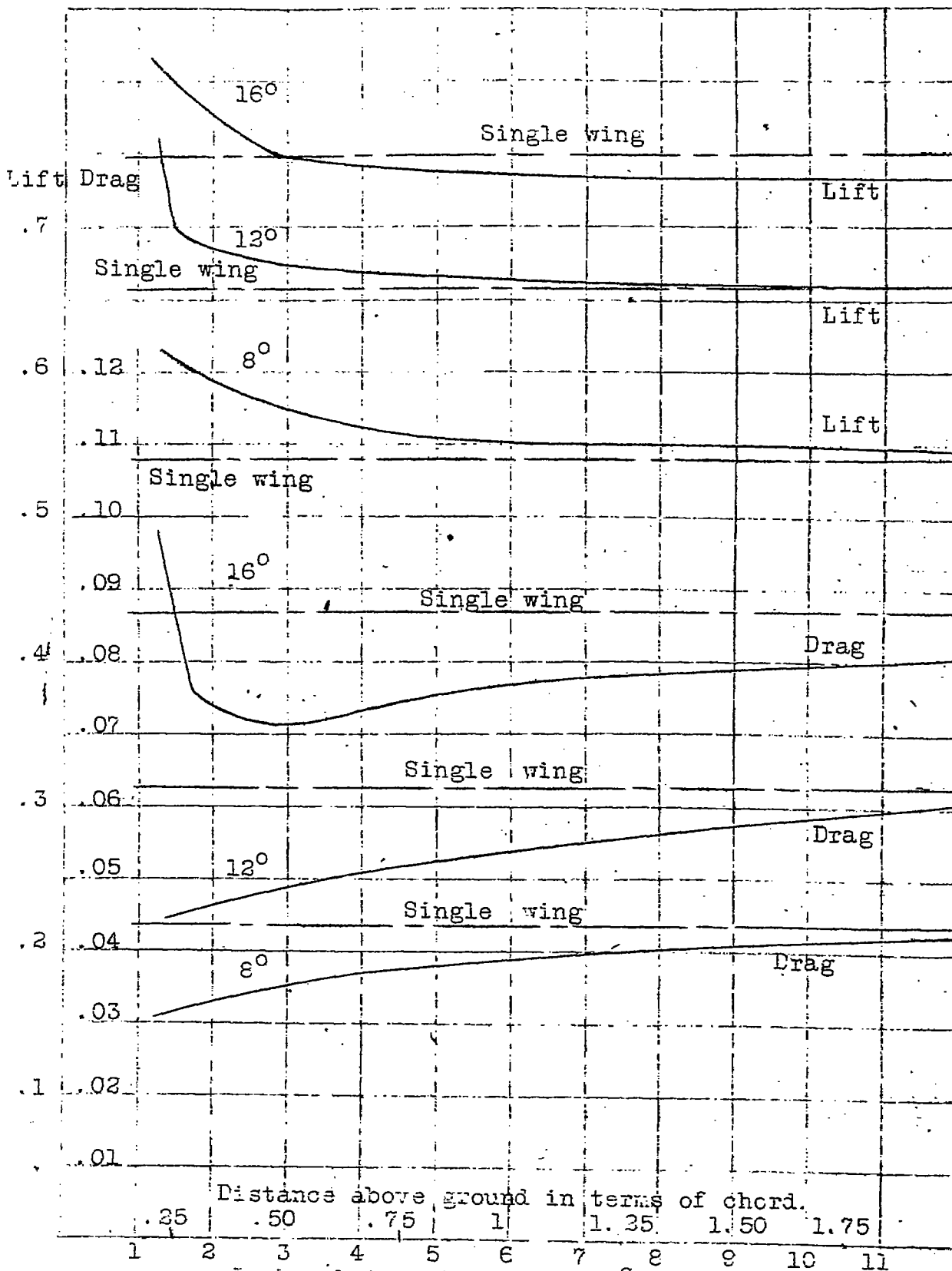


Fig. 3. Martin wing. Ground at varying distance. Reflection Method. Flaps neutral. Readings on Wing. Wind velocity 30 m. p. h.

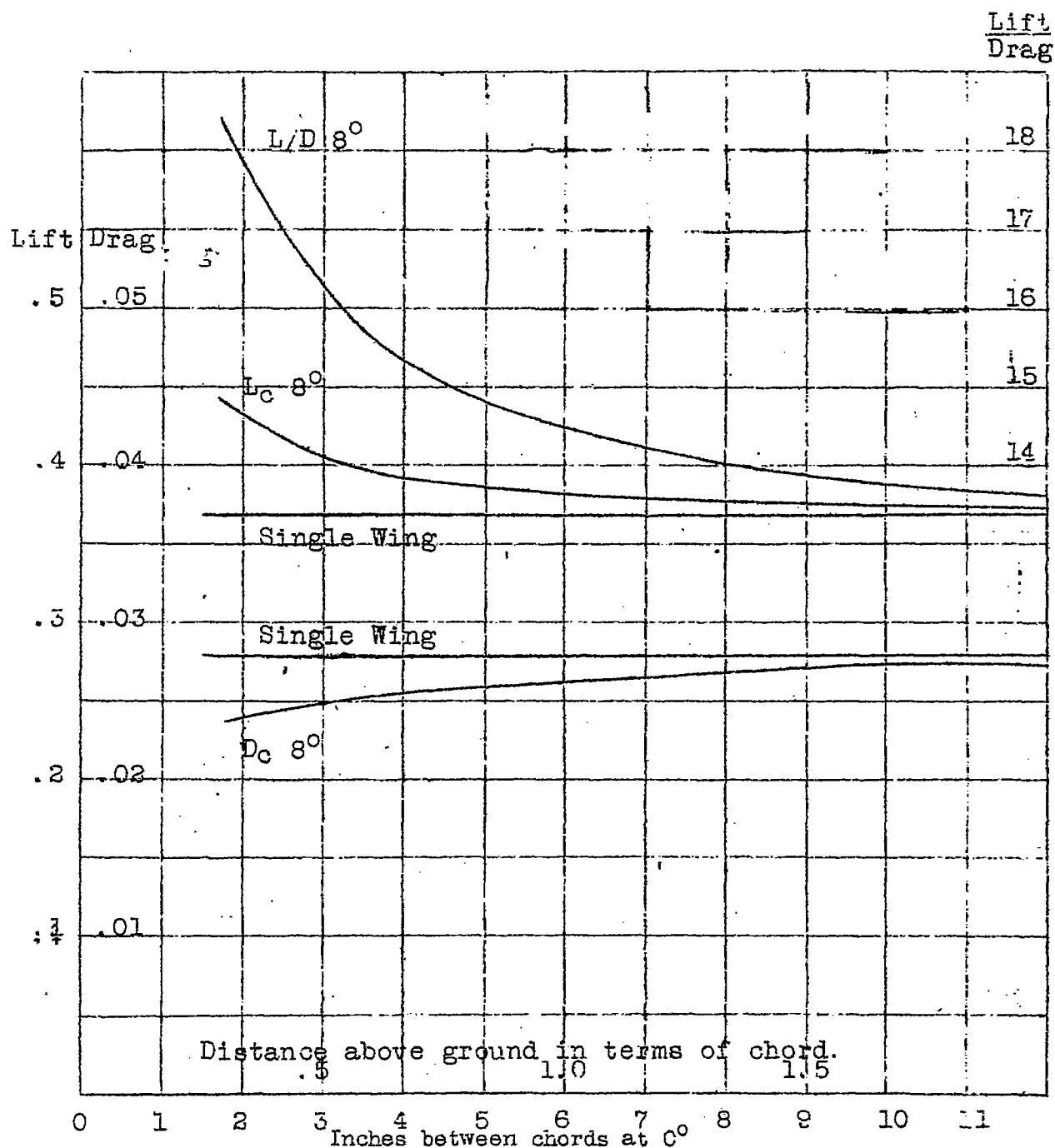


Fig. 4. - R.A.F.15 Special ground at various distances. Reflection method. Wind velocity 30 m.p.h. Reading on Wing 2.

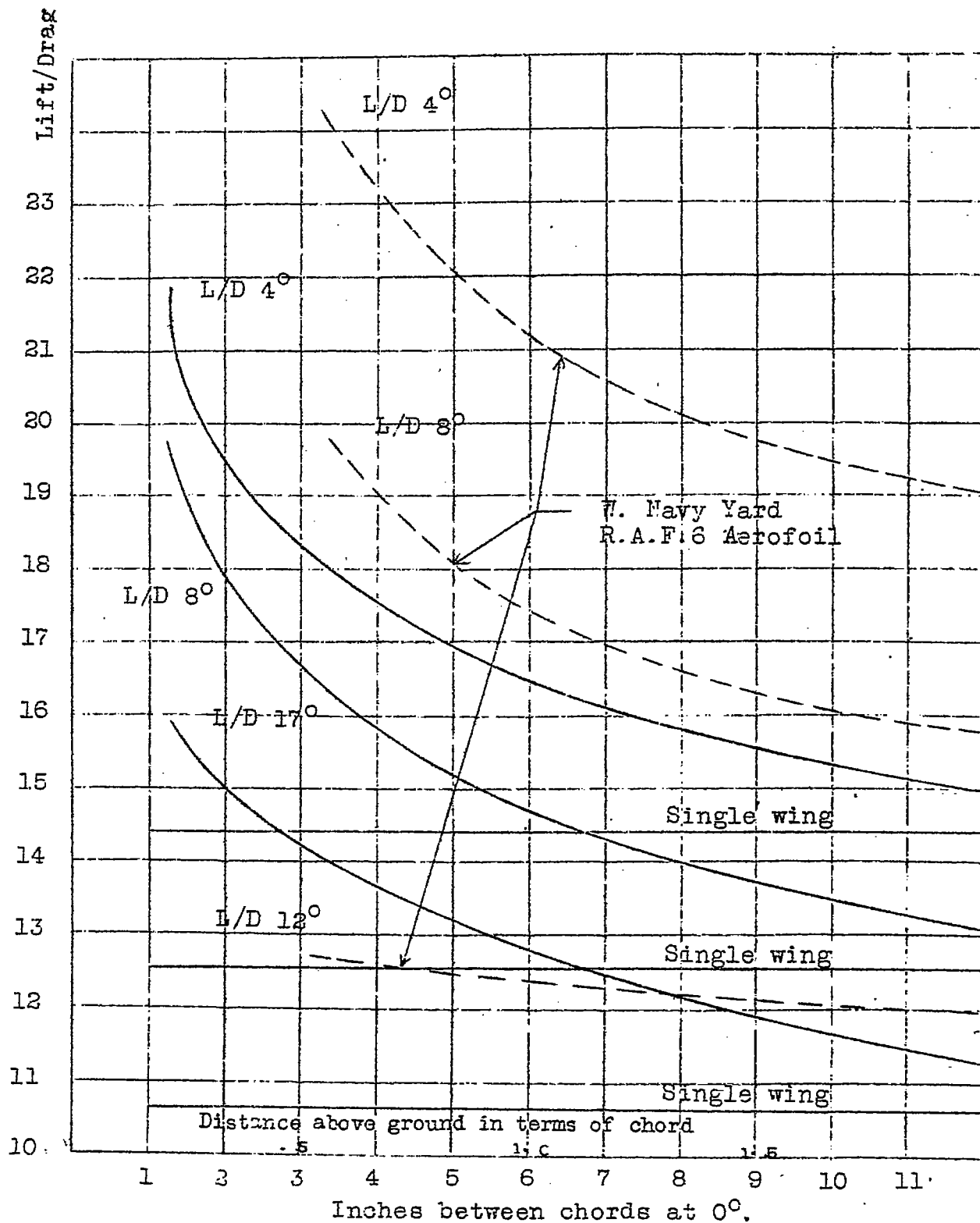
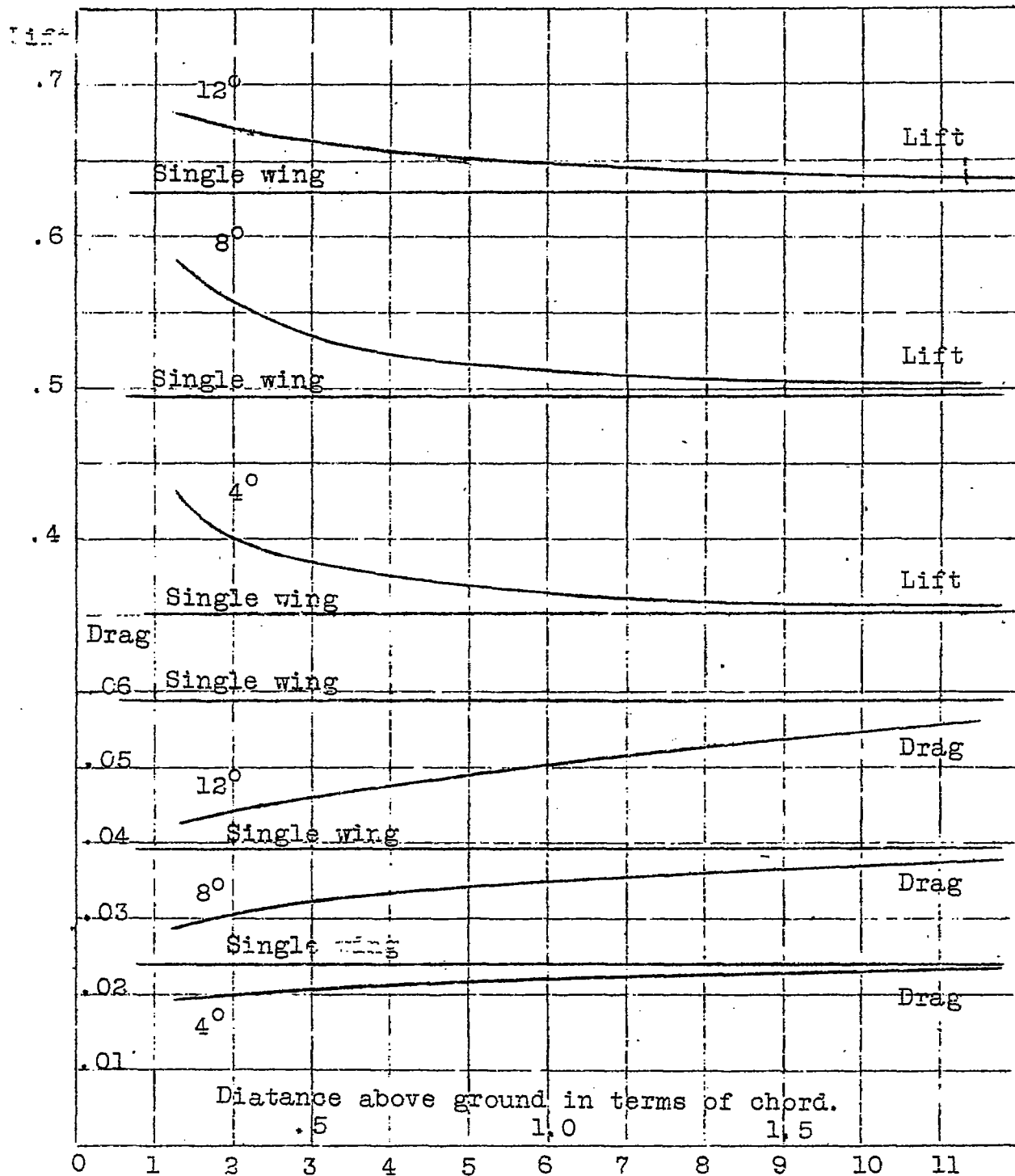


Fig. 5. U.S.A. 37. Ground at various distances.
 Reflection Method.
 Wind velocity at 30 m/p/h.



Inches between chords at 0°.
 Fig. 6. U.S.A. 27. Ground at varying distance (Reflection Method)
 Readings on Wing 1. Wind velocity 30 m.p.h.

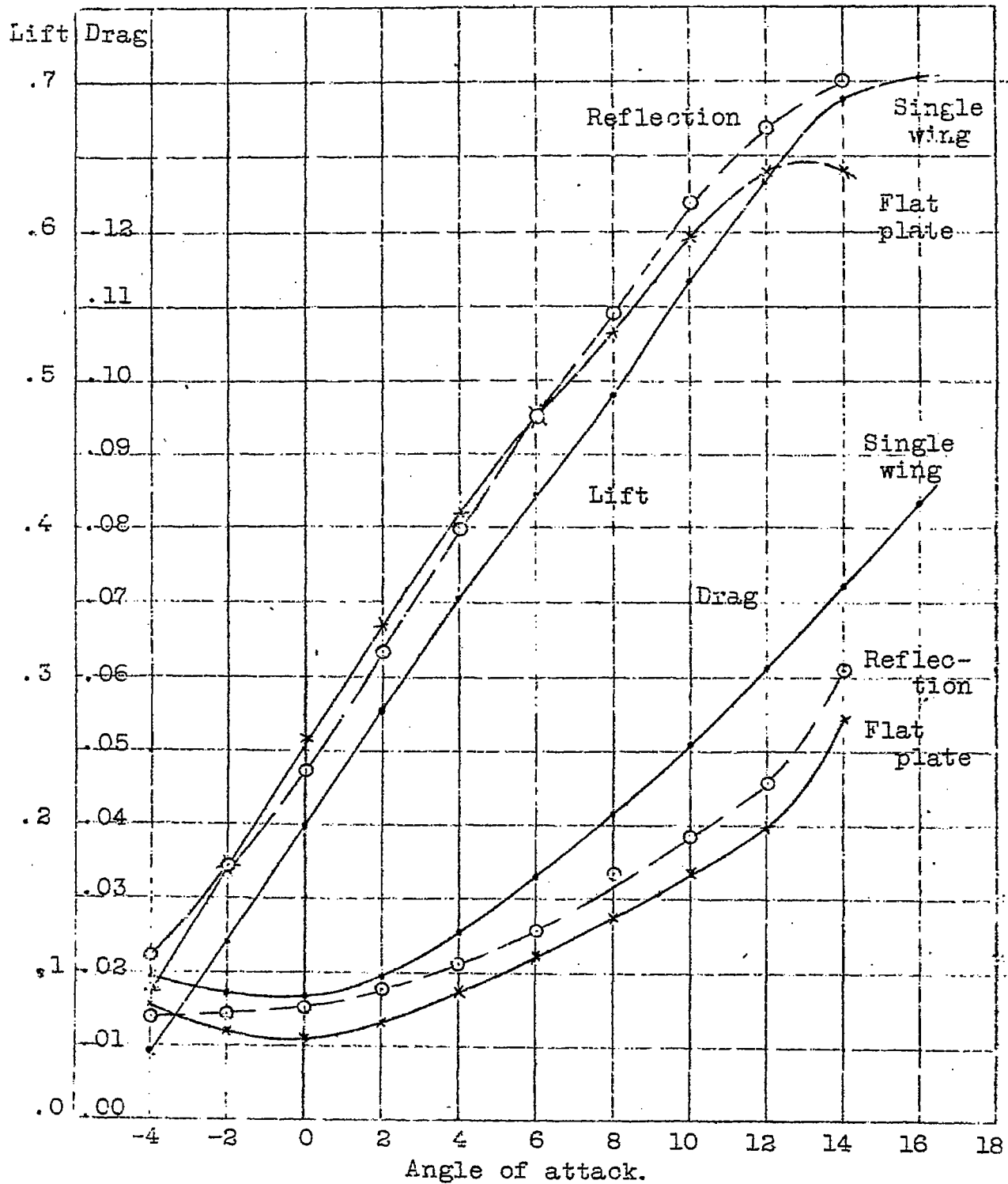


Fig. 7.- U.S.A. 27. Ground at 1/3 chord. Wind velocity 30 m.p.h.
Reading on Wing 1.

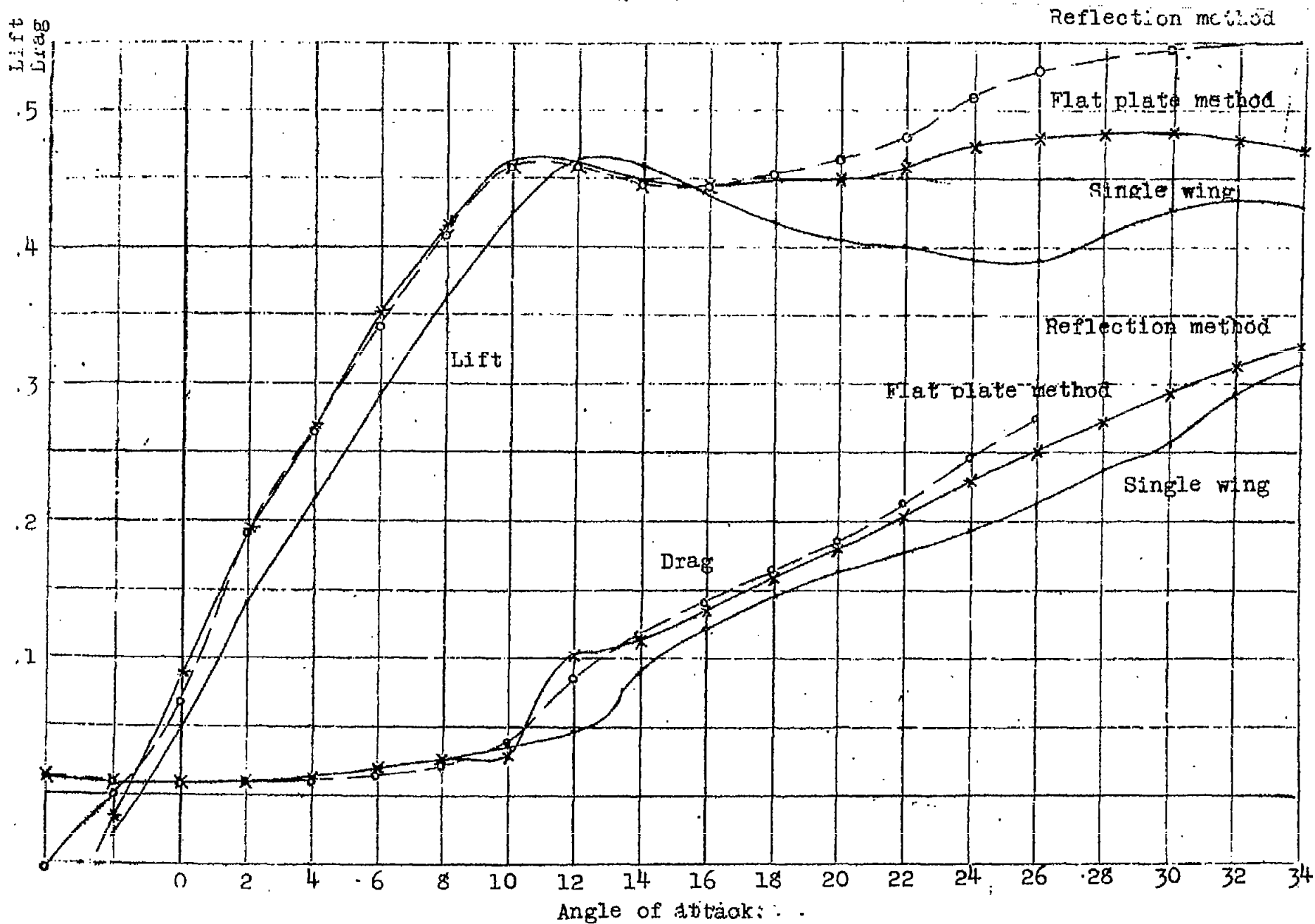


Fig.8. R.A.F.15 Special. Ground at 1/2 chord. | Wind velocity: 30 m.p.h.
Readings on wing 2.