R. & M. No. 2375
(9043)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Flight Tests on "King Cobra" FZ.440 to investigate the Practical Requirements for the Achievement of Low Profile Drag Coefficients on a "Low Drag" Aerofoil

By

F. SMITH, M.A. and D. J. HIGTON

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1950
FOUR SHILLINGS NET

Flight Tests on "King Cobra" FZ.440 to investigate the Practical Requirements for the Achievement of Low Profile Drag Coefficients on a "Low Drag" Aerofoil

By

F. SMITH, M.A. and D. J. HIGTON

COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
MINISTRY OF SUPPLY

Reports and Memoranda No. 2375

August, 1945*

Summary.—This report describes measurements of profile drag made on the wing of the King Cobra aircraft, which has a low-drag profile of N.A.C.A. design. The profile drag was high with the original surface finish and although it was improved when the surface was polished the profile drag was still much too high for a low-drag aerofoil.

By reduction of the surface waviness to ± one thousandth of an inch low drag coefficients of the order of 0·0028 were obtained.

The report describes the technique used to reduce the waviness and also the effect of flies, dust, water, high Mach number and normal acceleration upon the low drag characteristics of the wing.

1. *Introduction*.—In the past few years a considerable effort has been put into the examination of the theoretical requirements for the maintenance of laminar flow much further aft on an aerofoil than has hitherto been thought possible. The major requirement has been found to be the maintenance over the surface of a steadily rising velocity gradient. On this basis series of aerofoils have been designed, both in this country and the U.S.A., maintaining a rising velocity gradient back as far as 60 per cent. of the aerofoil chord. Wind-tunnel tests have demonstrated that these aerofoils are suitable for the maintenance of laminar flow back to 60–70 per cent.

The theoretical work, however, assumes that the aerofoil can be manufactured to the required profile. But, in practice, certain inaccuracies such as joints, rivet heads and waviness due to manufacturing limitations and section distortion under load are bound to occur. Such inaccuracies cause variations in the velocity gradient which may be sufficiently large to produce permanent transition from laminar to turbulent flow further forward than the optimum position.

Several types of aircraft incorporating wings of "low-drag" design have been produced in the U.S.A., but it has been found that standard manufacturing limits are not sufficiently close for the maintenance of laminar flow in flight.

---

* R.A.E. Report No. Aero. 2078 received 13th October, 1945.

The object of the present tests was to investigate the criteria for laminar flow and to examine the practicability of meeting the necessary requirements. Measurements of the profile drag of a test section were made with the wing surface as received, with the roughness reduced to the smallest practicable limit, by using the U.S. specification finish and with both the waviness and roughness greatly reduced by the method described in this report. " Low-drag " was achieved and maintained for some thirty flights in the latter condition. The effect of rain, dust, flies and polish upon the low-drag qualities of the final surface finish was investigated. The tests were extended to examine the effect of Mach number up to $M = 0 \cdot 7$ and of normal acceleration.

The measurements of drag were correlated with the transition point by a series of tests in which the transition was fixed by surface ridges.

2. *Description of Aircraft.*—The aircraft used for these tests was the King Cobra (P.63) FZ440. This aircraft is a single-engined low-wing monoplane with tricycle undercarriage (Figs. 1 and 2); the engine is placed behind the pilot as in the Airacobra. The wing profile is NACA 662x–116 at the root and 662x–216 at the tip. Further details are given in Table 1. The section chosen for the experimental work was on the port wing 137 in. from the aircraft centre line (Fig. 4). The choice of section was rather limited by external fittings on the wings. In fact, the test section was handicapped by the wing fuel tank access panel and by the aileron (Fig. 2). The aileron is however, pressure-sealed and, in some tests, the gap was also sealed between the aileron and the shroud (Fig. 6) to confirm that the results were not affected by airflow into or out of the aileron gap.

3. *Methods of Test.*—3.1. *Measurement of Profile Drag.*—The profile drag of the test section was measured by a pitot comb 10·4 per cent. chord aft of the wing trailing edge (Fig. 3). A single centrally placed static tube was used. The total head loss in the wake was obtained by connecting the pitot tubes of the comb to airspeed indicators mounted in an automatic observer. The aircraft A.S.I. and altimeter and a desynn recording the aileron position were also included in the automatic observer. The usual " top-hat " curves were obtained and the results were analysed by the method described in Ref. 1.

3.2. *Flight Test Data.*—Almost all the tests were made in level flight at 10,000 ft. altitude. The exceptions were (*a*) high Mach number tests which were made at 25,000 ft. in a shallow dive and (*b*) tests to investigate the effect of doubling the lift/weight ratio for which the aircraft was flown at 10,000 ft. with a steady bank of 60 deg. An aircraft limitation of 350 m.p.h. A.S.I. gave $C_L = 0 \cdot 1$ as the smallest lift coefficient which could be obtained in level flight. The pilot was given a desynn indicator to show the port aileron position and he was instructed to fly with this aileron neutral during the actual recording of results. The aileron linkage and tabs were adjusted in preliminary flights so that at high speed with the port aileron neutral the aircraft did not roll and also no stick force was required to hold the aileron in this position. At slow speeds in this condition putting the port aileron neutral gave rise to a very slow roll; this was negligible in effect.

3.3. *Improvement of Surface Finish.*—The reduction of roughness on the test section was obtained by rubbing the surface with damp carborundum paper, fine grade (400A), held on a soft pad. This technique is similar to that recommended by N.A.C.A. for low-drag aerofoils. Careful rubbing removed small excrescences on the surface and also the well known " orange peel " effect obtained when a surface is spray painted. The paper tended to clog easily and it was necessary to renew it frequently to avoid scratching the surface. If the paper is used very wet, as in the reduction of waviness technique, the tendency to clog is much reduced but the finished surface appears matt. By rubbing with damp paper a smooth highly polished surface is obtained, in fact, the subsequent use of polish (Sinec Nos. 2 and 3) made little difference in the appearance of the surface and gave only a small reduction of profile drag. The polish did however give good protection against water and is recommended from that point of view.

3.4. *Measurement of Surface Waviness.*—An Ames dial which could be read to one-fifth of one-thousandth of an inch was used for the investigation of surface waviness. The dial was mounted centrally on a metal base supported on points 2 in. apart (Fig. 7). The deflection of the gauge was thus a measure of curvature over a 2-in. base. This technique has been criticised for two reasons. Firstly, the gauge does not give true local curvature on a wavy surface, and secondly, if used on regular waves of 1-in. pitch the instrument would give no reading of curvature. Although it is true that the curvature shown by the instrument is not the true one, it is at least representative of the curvature, and a reduction in the instrument reading will in general correspond to a reduction in curvature. The second criticism is not important in the present tests since the waviness of the King Cobra surface was irregular (see the traverses of Figs. 8 to 14). For surfaces on which the waves are regular, due perhaps to the method of manufacture, the base length should be adjusted to give the maximum variation of reading when being traversed across the surface.

In addition, any gauge of this type used on a bumpy surface will show apparent waves of wavelength equal to gauge length corresponding to each bump. Thus the gauge readings taken on a surface with occasional indiscriminate bumps will appear to show a succession of waves. This is the case in the present tests (Fig. 8 to 14). The apparent waves of 2-in. wavelength are not true waves but represent occasional bumps on the surface.

Using this instrument, static traverses parallel to the flight direction were made on the test section. It was not possible to measure deflections in flight during these tests, but an instrument is being developed for this work. It is appreciated that the surface waviness in flight is the important factor, but, for these tests, it has been assumed that a reduction of waviness under static conditions will represent a reduction of waviness in flight.

Five spanwise position for these traverses over the wing were used on both top and bottom surfaces, namely the test section and sections 4½-in. and 8½-in. inboard and outboard of the test section. From the examinations of the results of these traverses in standard positions it was possible to deduce the areas of the surface which needed to be filled.

3.5. *Reduction of waviness.*—After initial tests on surface polish indicated that low drag could not be obtained by simple reduction of roughness, it was decided to try to reduce the waviness. An examination of the surface waviness (Fig. 8.) indicated theoretical critical speeds of the worst bulges to be about 160 to 200 m.p.h. A.S.I. (Ref. 2). Since the tests were being made up to 350 m.p.h. A.S.I. theory indicated that our efforts to obtain low drag were being defeated by the waviness of the surface, particularly over the first 40 per cent. of the chord where the boundary layer is most sensitive to surface waves.

The test portion of the wing extending 18 in. either side of the test section was first cleaned down to the metal surface, and the standard traverses were made (Figs. 9, 13), showing that the waviness had been unaffected by the paint and filler put on during manufacture. These had probably been sprayed on evenly and then rubbed down in the manner described in section 3.3. As we found during the present tests this technique has little or no effect on the waviness and will result in a smooth but wavy surface.

The test portion of the wing was given two coats of primer paint and then paint type filler was sprayed on. A coat of filler was sprayed on evenly and then local areas shown by the traverses to be low were filled with further coats, the number depending on the depth of the local hollow. It was found that at least twenty-four hours should elapse between spraying of large areas, and after the final coat the surface should be left for three days before any work is carried out on it (Figs. 10–12, 14).

To facilitate the reduction of waviness three sets of wooden rubbing blocks with curvatures on one surface corresponding to the surface curvatures were used (Fig. 5). Strips of carborundum paper (grade 280C) were held over these curved surfaces, and the blocks were rubbed chord wise in the manner sandpaper blocks are used. Each block was used over the area in which the mean surface curvature most nearly matched that of the block. The paper and surface were kept thoroughly wet during the rubbing.

The process of spraying filler and rubbing down with the curved blocks was repeated three times on the top surface and twice on the bottom surface (Figs. 10–12, 14) at which stage the reduction in waviness was thought to be sufficient to prevent any effect in the transition point.

The large fluctuations at the spar on the unpainted surface (Figs. 9, 13) were caused by the bad joint in the surface skin at the spar, the chordwise cross-section being in the form of an inverted V at the joint. This defect was improved by filling the surface for about 6 in. on either side of the joint until a smooth continuous surface was formed. This resulted in a slight modification to the main section profile which is represented in Fig. 12 by a long wave of some 10 to 12 in. wave length covering the spar joint in the final surface finish. This wave has, however, such a large wave length that it should preferably be regarded as a small modification to the section profile.

3.6. *Effect of Flies and other Insects*.—The flight tests were made during fine weather in March–April, 1945, and as the days became warmer it was found increasingly difficult to avoid the tests being spoilt by flies and other insects picked up during flights. On landing, these flies were found to be with very few exceptions on the first 10 per cent. of the section and never aft of 30 per cent. chord. It was found that by flying before about 11 a.m. (9 a.m. G.M.T.) that contamination of the surface by flies could generally be avoided. With warmer weather this zero hour became earlier still, and eventually it was impossible to fly the aircraft with any reasonable hope of keeping the surface clean.

The following method was therefore devised to enable the tests to be continued. A large sheet of paper was placed over the leading edge of the specially treated part of the wing, being about 3-ft. wide and extending from 30 per cent. chord on the top surface round the leading edge to 30 per cent. chord on the bottom surface. The paper was kept in position by adhesive tape along the sides; a string loop was made around the paper along the leading edge, the free end being led to the cockpit.

After take-off and climb to about 5,000 ft. the pilot pulled the string thus tearing the paper along the leading edge. The two halves on top and bottom surface were then blown off by the air stream, leaving the surface clean and free from flies.

This technique was used successfully in the latter part of the present series of tests, and is recommended for tests of this type.

3.7. *Use of Tapes to fix Transition Point*.—To relate the drag results obtained in flight to their corresponding transition points, drag measurements were made with surface ridges at fixed percentages of the chord. These ridges consisted of strips of adhesive tape, rectangular cross-section 0·0036-in. thick and $\frac{3}{4}$-in. wide, used in one, two or three layers of one strip and two strip widths. The drag results showed whether transition had been caused by a particular ridge, and thus gave the drag corresponding to fixing the transition at a known position.

4. *Results of the Tests*.—4.1. *Reduction of Waviness*.—Traverses taken with the waviness gauge are given in Figs. 8–12 for the top surface of the test portion of the wing at successive stages of the improvement. It will be seen that there is a steady reduction in the maximum fluctuations over the surface and a marked improvement at the spar about 30 in. aft of the leading edge.

Apart from the spar the general improvement in waviness particularly of the front half of the wing is represented by a reduction of the fluctuations from ± two thousandths of an inch on the unpainted surface to ± one thousandth of an inch on the final surface.

The initial and final traverses for the bottom surface are given in Figs. 13, 14. Here again the main improvement is at the spar. The reduction in waviness on the bottom surface is in general not so good as that on the top surface for the following reasons: firstly, the bottom surface was initially better than the top; secondly, the bottom surface is much more difficult to rub down than the top surface by the simple technique used in this work; thirdly, the bottom surface is operating in general under more favourable conditions than the top surface, and a slightly larger tolerance was considered to be permissible.

4.2. *Profile Drag*.—The profile drag was obtained from the pitot-static comb by the method described in Ref. 1. The results in the form of section profile-drag coefficient against aircraft lift coefficient are given in Figs. 15 to 21.

With the original surface a steady high drag coefficient of $0 \cdot 0075$ to $0 \cdot 0080$ was recorded (Fig. 15) but on removal of the small local surface defects such as grit embedded in the paint, a drag coefficient of $0 \cdot 005$ to $0 \cdot 006$ was obtained in the neighbourhood of $C_L = 0 \cdot 2$ (Fig. 15). At higher and lower lift coefficients the drag rose rapidly to $0 \cdot 0075$ at $C_L = 0 \cdot 1$ and $C_L = 0 \cdot 5$.

The characteristic drag-coefficient curve for this section should show a low drag range from roughly $-0 \cdot 05$ to $+0 \cdot 35$ C_L rising rapidly outside this range to $0 \cdot 006$–$0 \cdot 008$ (depending on Reynolds number). The main differences between this and the curve in Fig. 15 are the rise in drag between $0 \cdot 1$ and $0 \cdot 2$ C_L and the large minimum drag obtained in the King Cobra tests.

The test surface was next smoothed down to the standards recommended by the N.A.C.A. for low-drag wings; the results are shown in Fig. 16. It will be seen that there is no improvement of the drag minimum or the rise in drag at low lift coefficients. It thus appeared that smoothness alone was not the limiting criterion in the achievement of low drag in flight.

Examination of the surface waviness indicated that on theoretical grounds[2] the local bulges were sufficiently large to cause earlier transition at speeds greater than 200 m.p.h. A.S.I. As a result the surface waviness was next reduced by the technique described in section 3.

The profile drag was measured in this condition and the results are shown in Fig. 17. The characteristic shape of the drag-lift curve was obtained, and drag coefficients of $0 \cdot 0028$ at $C_L = 0 \cdot 1$ were recorded. Application of polish (Table 3) to the surface made very little difference in appearance and only a small improvement in drag (Fig. 18). A value of drag coefficient of $0 \cdot 00245$ was, however, recorded in this condition.

Fig. 19 shows the results of several flights made after an interval of four weeks and fifteen hours flying. No deterioration of drag is noticeable.

4.3. *Effect of Mach Number on Profile Drag*.—A few tests were made at 25,000 ft. to investigate the effect of Mach number on profile drag. The higher indicated speeds were obtained in shallow dives. Fig. 20 shows these results at 25,000 ft. compared with a typical curve obtained at 10,000 ft. The drag curve is in general unchanged except at the lowest lift coefficients (about $0 \cdot 1$). Here there is a noticeable rise in profile drag at a Mach number of $0 \cdot 70$ as compared with that at $M = 0 \cdot 52$ (10,000 ft.). It is not clear why the drag rises at $M = 0 \cdot 70$, but it may be due to either an unfavourable modification in the pressure distribution causing the transition point to move forward, or a breakaway of the boundary layer on the back part of the wing behind the maximum suction point giving a rise in form drag, or distortion of the surface at high Mach number. The matter is of some importance, since such a drag rise would be undesirable on a high-speed transport designed to fly for long periods a little below the critical Mach number.

4.4. *Effect of Normal Acceleration on Profile Drag*.—The King Cobra wing is built to fighter specifications and has been designed to break at a lift/weight of about 10. The distortion in level flight is thus only that corresponding to 1/10 of the breaking stress. Civil transports or bombers are however, designed to break at lift/weight ratios of 4 to 5; their distortion in level flight is thus 1/5 of the maximum. The tests on the King Cobra are therefore likely to show optimistic results. In order to investigate the effect of doubling the lift/weight ratio the drag was measured at 10,000 ft. in 60-deg. banked turns. The maximum lift coefficient that could be obtained was $0 \cdot 2$, but the aero-elastic distortion was, of course, that corresponding to speeds up to 350 m.p.h. A.S.I. The results, although of necessity rather scattered, showed that the effect was negligible, and it is concluded that, had the design load of the King Cobra been doubled, the effect on the present results would have been negligible.

4.5. *Effect of Flies on the Profile Drag.*—The difficulty of avoiding flies and other insects and the method adopted have been discussed in section 3.6. Several flights were made however, on which flies were picked up on the wing during and after take-off. It was impossible for the pilot to see whether the test section was affected and so occasionally results were obtained in this condition. These results were analysed and are given in Fig. 21 for the surface which would otherwise have shown low drag characteristics. The low drag of 0·003 has been raised to values ranging from 0·004 to 0·006 depending upon the position and number of flies picked up. In general it can be said that flies upon the surface will raise the drag over the low-drag range by 50 to 100 per cent. If low-drag sections are to be used with any reliability some means must be found to prevent the flies reaching the surface or to remove them from the surface after take-off and climb. The device used in the present tests of protecting the leading edge with paper which could be torn off by the pilot was satisfactory for the smaller section under test but it is not very suitable for complete wings without a great deal of development. The alternative is to arrange to clean the surface after contamination, but from the experience gained on the present tests it is felt that this would be difficult. The flies on hitting the surface disintegrate and are found in the form of small parts of the flies' bodies stuck to the surface with a particularly potent glue. Even on the ground it was found to be quite difficult to remove them, and to do so in flight would present a large problem.

In general it is felt that prevention is better than cure and that the wings should be protected from flies rather than cleaned after contamination.

4.6. *Effect of Dust and Water.*—Before flight tests the test section was dusted off but a certain amount of dust was picked up during taxying and take-off. It was felt, however, that if the surface were wet a considerably larger amount of dust would be picked up during taxying. Tests were made with the surface thoroughly wet before taxying and it was found the drag was unaffected both by dust and water. Examination of the surface after landing showed it to be clean except for a few small white spots presumably due to residue left when the water dried. On one occasion the aircraft was flown through rain before the test measurements were made. Low drag coefficients were recorded again, indicating that water has no effect on the surface.

When the surface had been polished with " Sinec " polish the water did not penetrate the paint, as with the unpolished surface, but rolled off leaving only a few local drops of water and a clean wing. Polish of this type with a wax base is thus recommended mainly as a protection from water, and if it is used, the wings can be washed down with water before take-off in much the same way as a motor car is washed down. It is felt that this represents a cheap and simple way of maintaining aircraft with low-drag wings. It is recommended that the water is filtered before use to prevent residue being deposited on the wing surface.

4.7. *Profile Drag with Fixed Transition.*—The low drag obtained with the best surface finish corresponds according to theoretical drag-transition relations (Fig. 25) to transition at about 0·75 chord. This was felt to be appreciably better than could have been anticipated for this particular section, and so it was decided to make tests in which the transition was fixed by surface ridges, and thus to establish a transition point-drag relationship for the actual test section. Ridges of varying heights and widths were put on the bottom and top surfaces of the test portion of the wing (section 3.7). Tests were made with these ridges at 10 per cent., 30 per cent. and 50 per cent. of the wing chord; the results are shown in Fig. 23. These were analysed in the form of drag rise due to fixing transition (Fig. 24) and plotted against the criterion[2] height of ridge divided by the root of the width of ridge. The results show that in all cases (except the lowest width ridge at 50 per cent. chord) the ridges gave a drag rise almost independent of the height. It was concluded that the ridge had fixed transition, and the centre line of the ridge was taken as the transition point. The section profile drag corresponding to fixed transition is given in Fig. 25 together with the theoretical relation. The lowest drag obtained in flight now appears to correspond to about 65 per cent. chord transition point. This position is more reasonable and, in fact, corresponds to the best that could be expected with maximum suction at 60 per cent. of the chord.

We now have, however, an appreciable discrepancy between the theoretical[3] and measured drag-transition relation. It was suggested that this might be due to a flow of air into the aileron gap. Since the ailerons are pressure-sealed there can be no flow from the bottom to top surface. There is the possibility of a spanwise flow in the aileron gap towards the tip or root, but since the thickness/chord ratio is constant along the span this was unlikely. To examine this possibility a few tests were made in the fixed transition condition with rubber seals actually in the aileron gap on top and bottom surfaces over the test portion of the wing. The results (Fig. 25) showed the effect to be small. The discrepancy between flight tests and the theoretical drag-transition relation is thus unsolved.

A summary of the drag results in the various conditions is given in Fig. 22 together with the measured and theoretical drag-transition relations. Using the flight transition values it will be seen that the results of this series of tests reducing waviness and roughness has been to move the transition point from the leading edge to 60–65 per cent. chord over the C_L range $0 \cdot 1$ to $0 \cdot 22$. The low drag has not been kept up to the theoretical value of $C_L = 0 \cdot 35$ but this is probably due to the appreciable waviness and surface inaccuracies still left which would tend to reduce the critical lift coefficient.

4.8. *Maintenance of the Surface.*—It is of general interest to know how satisfactorily the special finish used in these tests is and how difficult it was to maintain during the tests. No trouble was experienced with cracking of the surface filler and there appeared to be no tendency to dry out or lose its flexibility. At the time of writing this report the surface is six months old and is still satisfactory.

Only one slight difficulty was experienced and that was at the skin joint on the main spar. The gap between the two skins was five to ten thousandths of an inch and was filled with filler. During flight, owing to small variations in the gap under load, there was a tendency for the filler to squeeze out of the gap, and it was necessary to rub down the slight ridge so formed every few flights. This difficulty could have been avoided if the skin had been chamfered on the under side before assembly, thus forming a dove-tail joint for the filler.

Apart from rubbing down this ridge occasionally, nothing was done to the surface throughout the tests.

5. *Conclusions.*—The main conclusion of this report is that low-drag coefficients can be achieved and maintained in flight on a low-drag wing under load up to a Reynolds number of 18×10^6. To obtain low-drag coefficients of the order of $0 \cdot 0028$ it was necessary to reduce the surface waviness over the front portion of the surface to $\pm$ 1 thousandth of an inch; a larger tolerance can be allowed further back on the wing. Roughness has to be reduced to reasonable standards such as the N.A.C.A. recommendations for low-drag wings.

Water can be used to wash down wings before take-off without any detrimental effects. Rain during flight has no subsequent effect on the low-drag qualities of an aerofoil.

Polishing the surface with wax polishes reduces the drag only slightly but facilitates washing down the surface and is recommended for this purpose. Polish would only need to be applied at infrequent intervals, e.g. during inspection.

Over the period of the tests the filler used to produce a satisfactory surface gave no trouble and would probably be suitable for production aircraft. Accurate manufacture of the metal surface to $\pm$ 1 thousandth of an inch would give equally satisfactory results and would obviously be the better way of obtaining an accurate and more lasting surface.

Any metal skin joints requiring subsequent filling should be chamfered during manufacture to give a dove-tail joint for the filler.

The surface must be kept free from surface irregularities such as inspection doors, access panels, etc., as far as possible and protection against damage from boots and shoes during servicing and from stones thrown up by wheels must be provided.

Tests at a Mach number of 0·70 indicated a rise in drag as compared with the drag at $M = 0{\cdot}52$. This may be due to a variety of causes, but it is of some importance for aircraft designed to cruise at high Mach numbers.

The tests made with increased lift/weight ratio indicated that the increased surface distortion in the condition did not affect the drag coefficient.

The most important result is the effect flies and other insects have upon the drag. The drag rise when the surface is contaminated is 50 to 100 per cent. of the basic low drag coefficient. It is clear that the surface must be protected from flies either by cleaning the surface after contamination or by covering the surface near the leading edge with some form of protective cover which can be jettisoned after climbing above the maximum height at which flies are normally encountered (about 5,000 ft. in this country).

Tests with surface ridges chosen to fix transition indicated that the transition with the test finish was at 60–65 per cent. chord. The drag-transition relation, however, differs appreciably from the theoretical relation for low drag aerofoils.

To summarise, the results of these tests show that low-drag coefficients can be achieved and maintained on an aircraft of low-drag design without exceptional difficulty, and it is felt that production of the wing structure to the requisite limits is quite practicable.

REFERENCES

No.	*Author*	*Title, etc.*
1	Thompson	A Simple Method of Computing C_D from Wake Traverses at High Speeds. R.A.E. Report No. Aero. 2005. A.R.C. 8462. December, 1944. (Unpublished.)
2	Fage	The Smallest Size of a Spanwise Surface Corrugation which affects Boundary Layer Transition on an Aerofoil. R. & M. 2120. January, 1943.
3	Winterbottom and Squire	Note on Further Wing Profile Drag Calculations. R.A.E. Report No. B.A.1634. A.R.C. 4871. October, 1940. (Unpublished.)

TABLE 1

Aircraft Data

Aircraft wing area	248 sq. ft.
Aircraft weight (all-up)	8,000 lb.
Aircraft C.G. position	27·5 per cent. A.M.C.
Aerofoil section (root)	N.A.C.A. 662x–116
Aerofoil section (tip)	N.A.C.A. 662x–216
Distance of section from aircraft centre-line	137 in.
Test section chord length	74·37 in.
Maximum thickness/chord ratio	15·91 per cent.
Position of maximum thickness	45·3 per cent. chord
Distance of comb behind trailing edge	7·70 in.

TABLE 2

Ordinates of test section

Per cent. chord	y/c upper	y/c *lower*	y/c total
2½	2·29	2·26	4·55
5	3·23	3·05	6·28
7½	4·05	3·61	7·66
10	4·71	4·17	8·88
15	5·87	4·96	10·83
20	6·74	5·64	12·38
30	8·02	6·54	14·56
40	8·74	7·01	15·75
50	8·80	7·04	15·84
60	8·24	6·69	14·93
70	6·69	5·34	12·03
80	4·30	3·51	7·81
90	1·85	1·51	3·36
95	0·78	0·54	1·32
100	—	—	—

Max. thickness 15·91 per cent. at 45·3 per cent chord.

TABLE 3

Reference to materials used when improving roughness and waviness

Material	*Reference*
Primer	Type " UP " Ref. No. 33B/208
Filler	" Belco " Ref. No. KAF 4362
Cellulose	D.T.D. 83A Ref. No. 33B/468
Carborundum paper ..	" Hydro-Durexsil " Grades 280C and 400A
Polish	" Sinec " Nos. 2 and 3

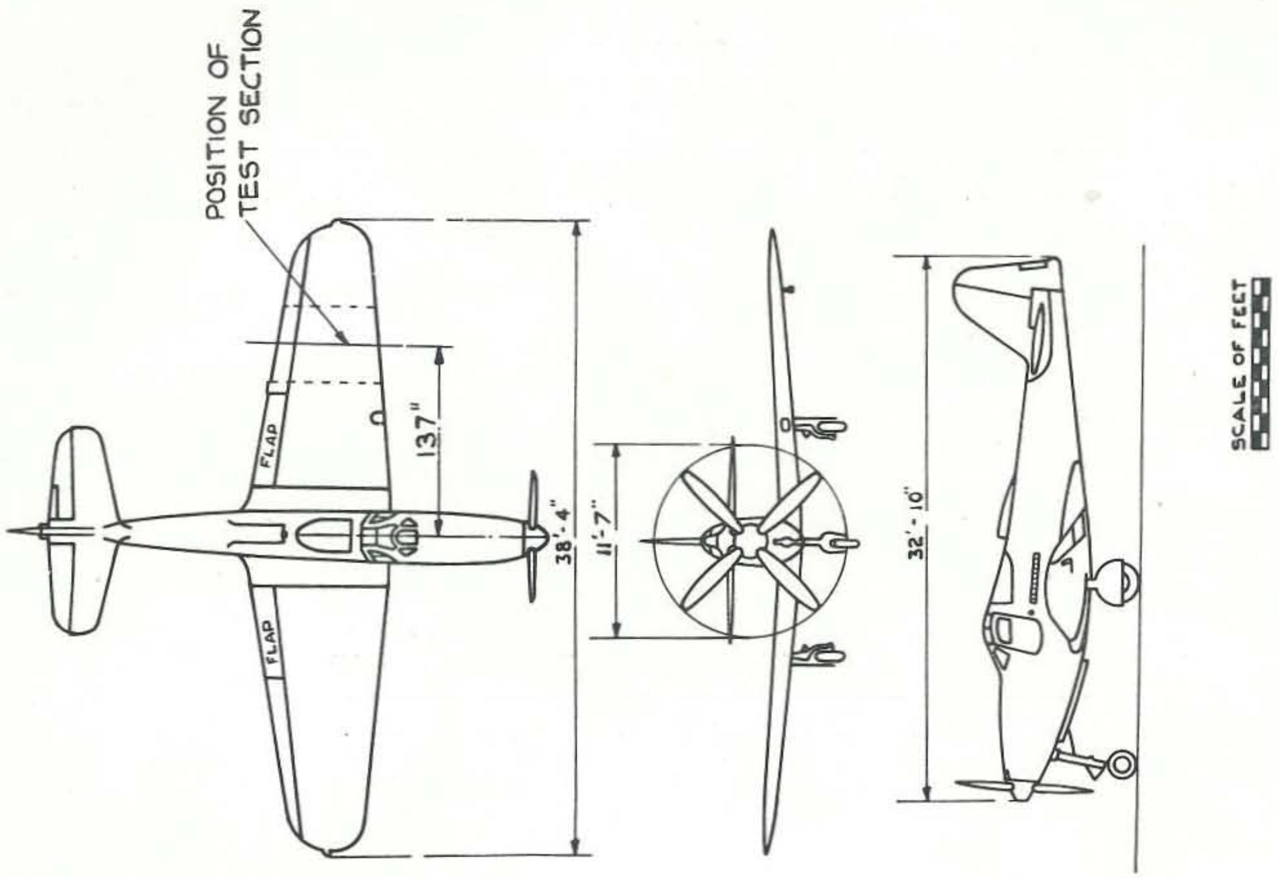


Fig. 1. General Arrangement of King Cobra FZ 440.

Fig. 2. King Cobra FZ 440.

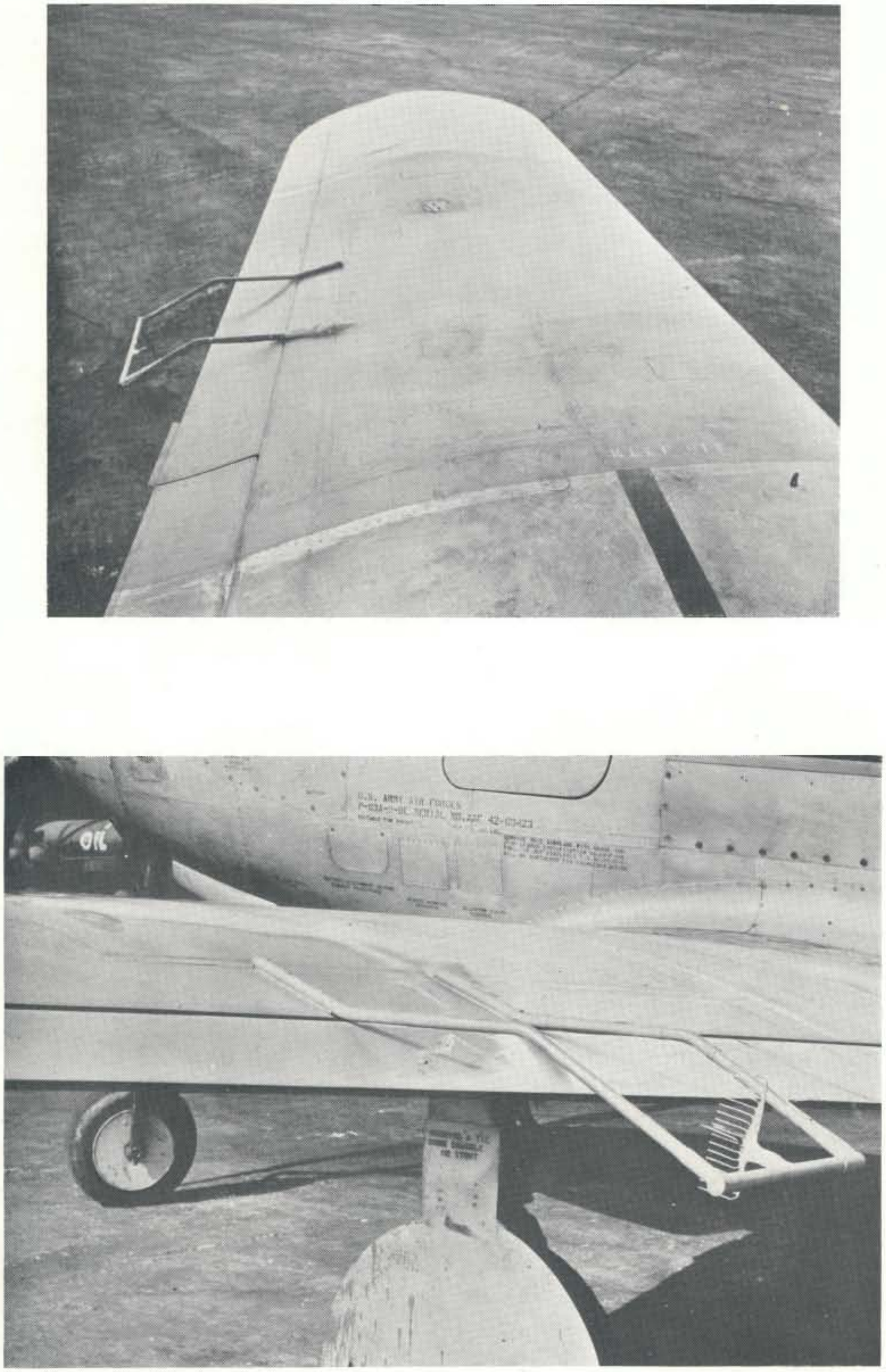
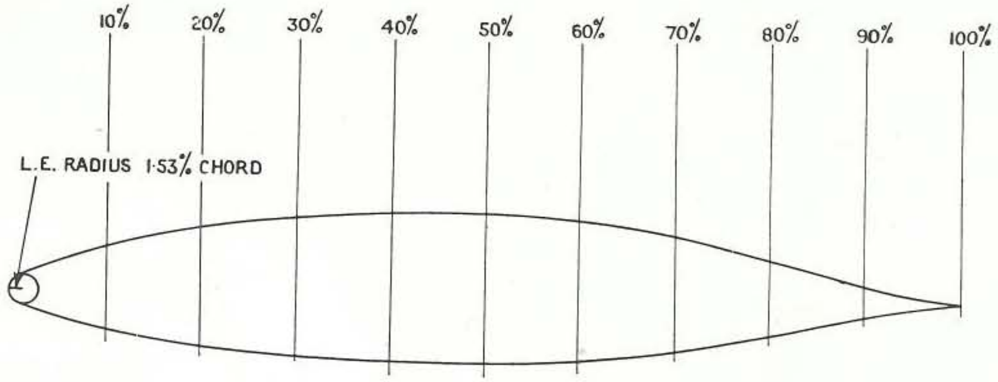


FIG. 3. Photographs of Test Section and Comb.



FOR ORDINATES SEE TABLE 2

MAXIMUM THICKNESS = 15·91% CHORD

POSITION OF MAXIMUM THICKNESS = 45·3%

FIG. 4. Profile of Test Section.

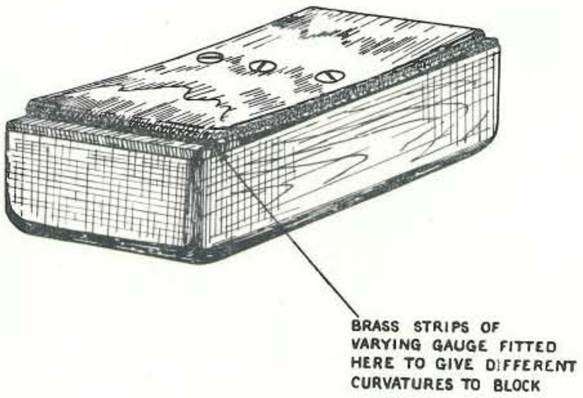


FIG. 5. Sketch of Curved Block used for Rubbing Down Wing Surface.

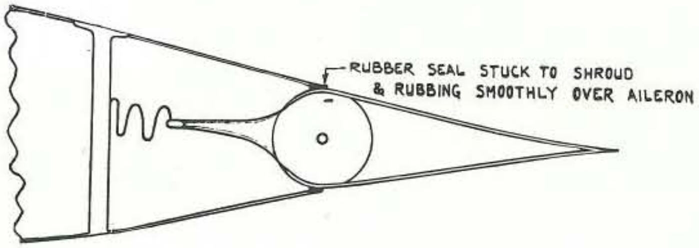


FIG. 6. Diagrammatic Sketch Showing Method of Sealing Aileron Gap.

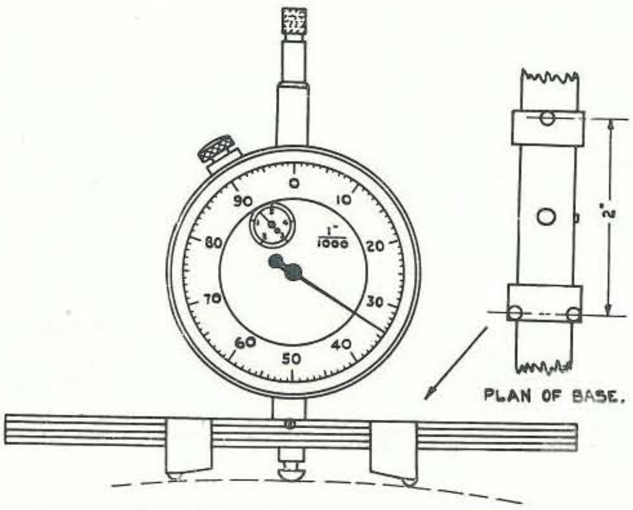


FIG. 7. Surface Waviness Gauge

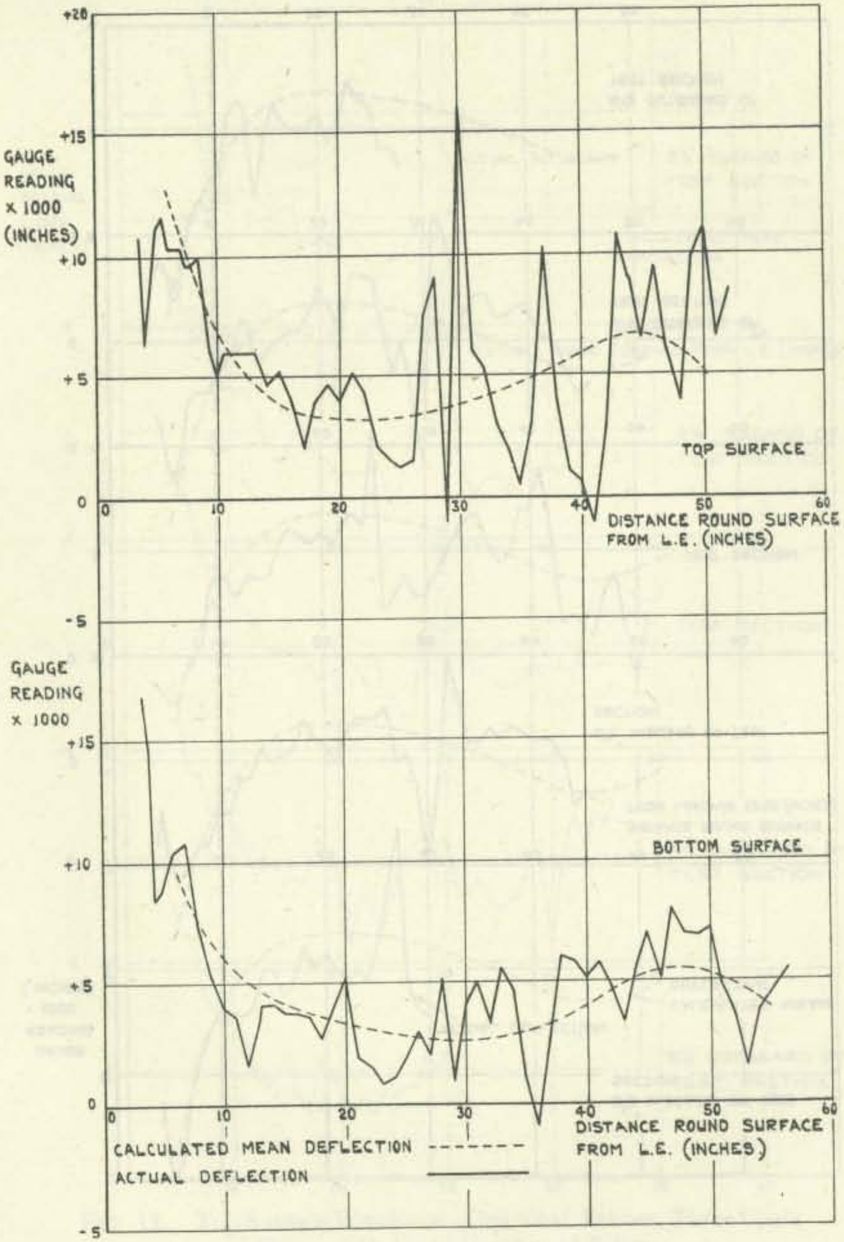


FIG. 8. Surface Waviness as Received at R.A.E. (Both surfaces).

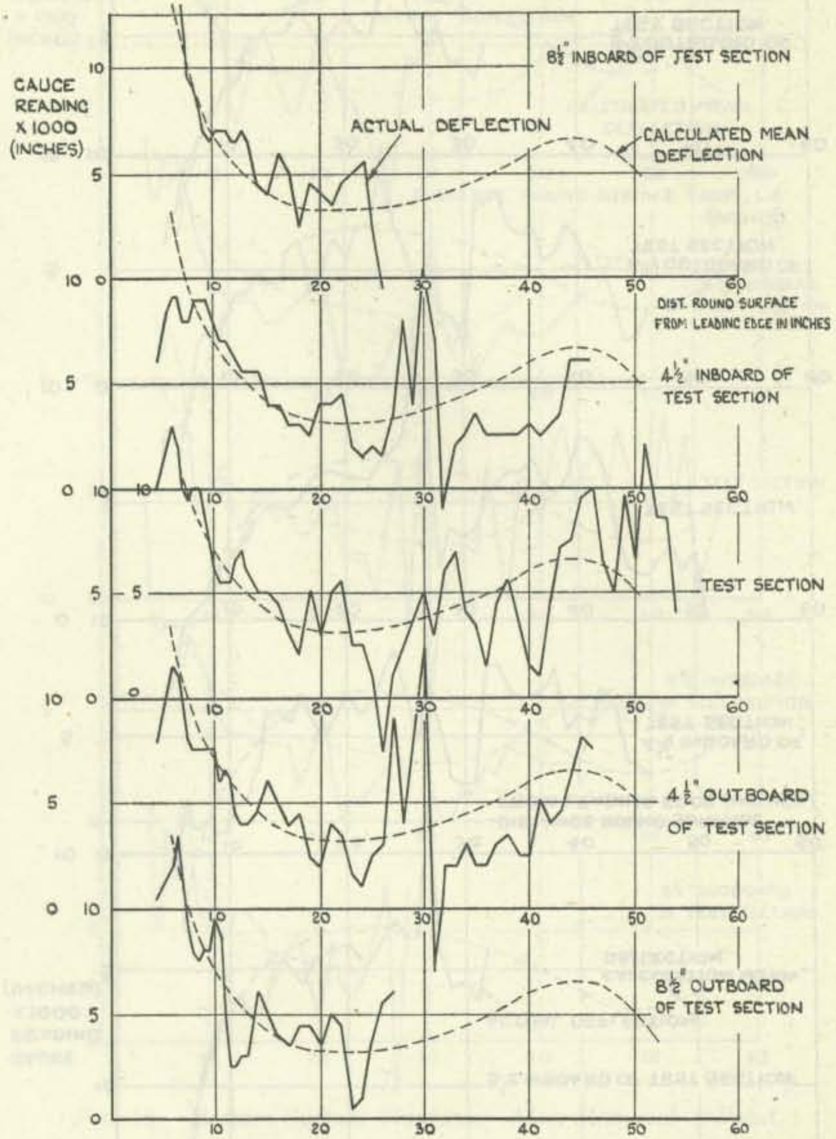


FIG. 9. Top Surface Waviness—After Removal of Paint.

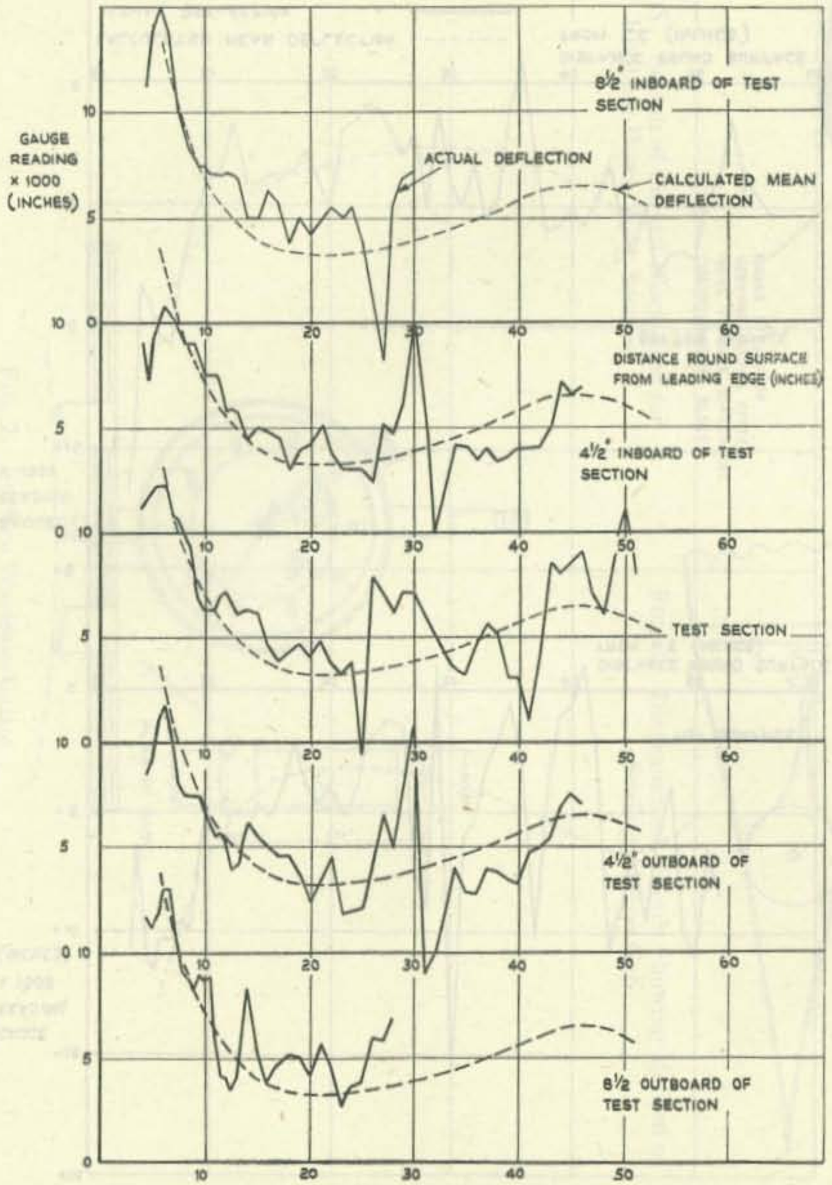


FIG. 10. Top Surface Waviness—One Coat of Primer, One Coat of Filler, with Local Patches of Filler.

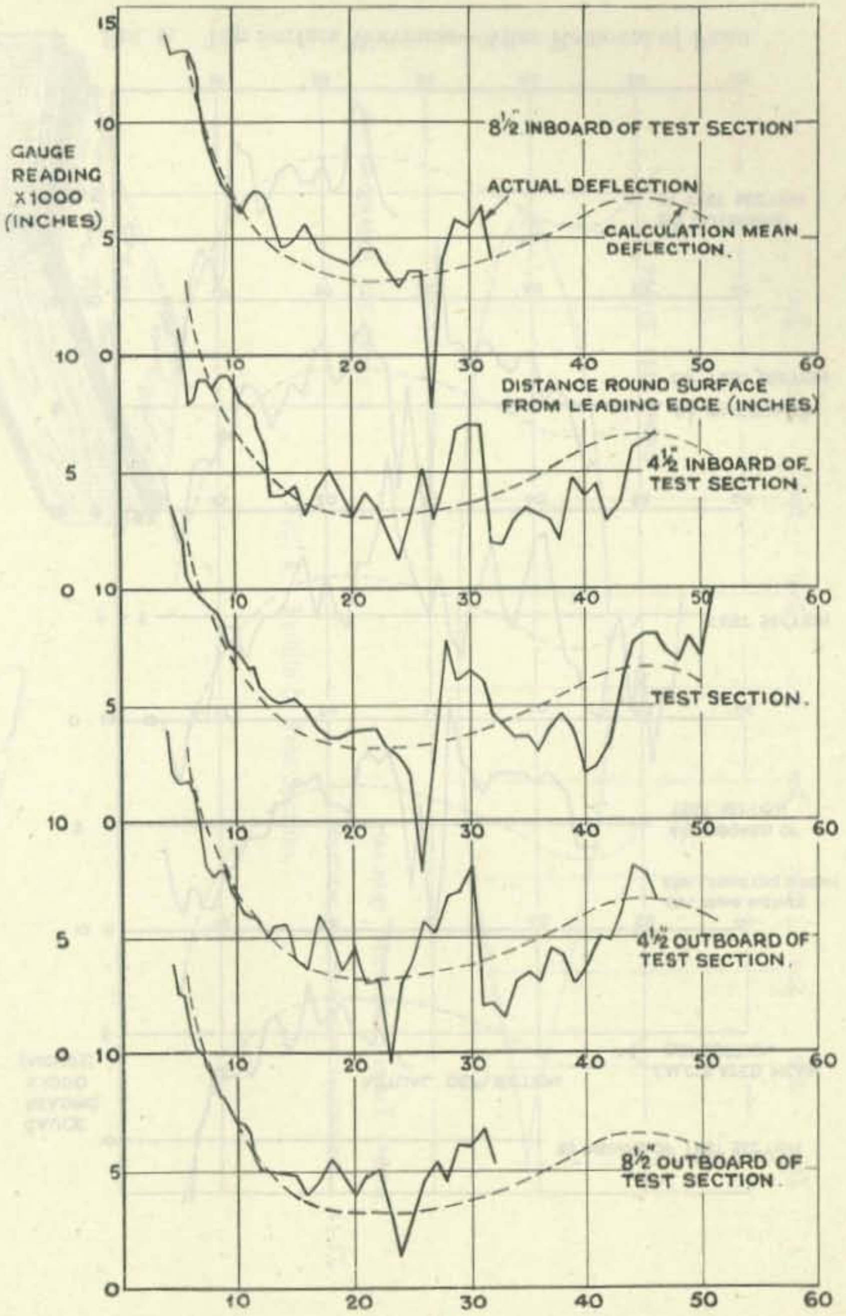


FIG. 11. Top Surface Waviness—One Coat Primer, Two Coats Filler, with Local Patches of Filler.

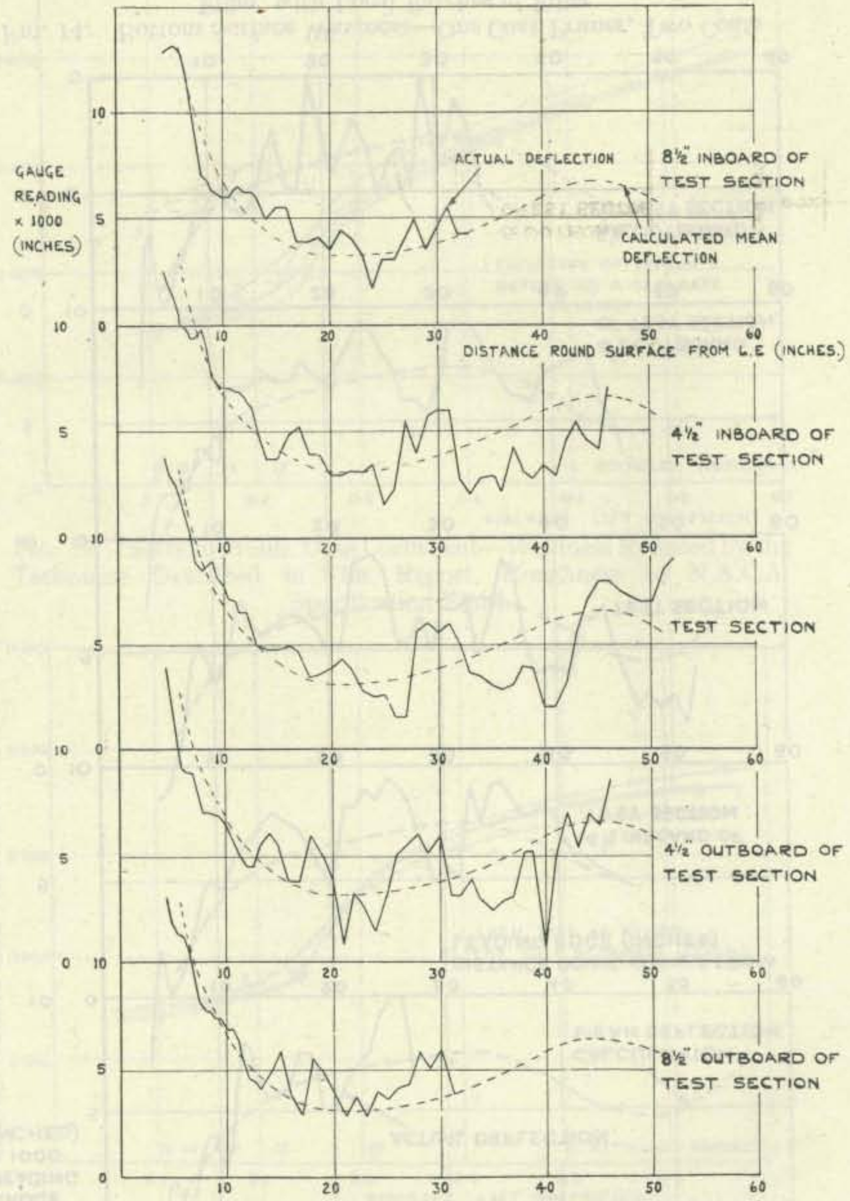


FIG. 12. Top Surface Waviness—One Coat Primer, Three Coats of Filler, with Local Patches of Filler.
(Waviness of final surface with which low drag was obtained.)

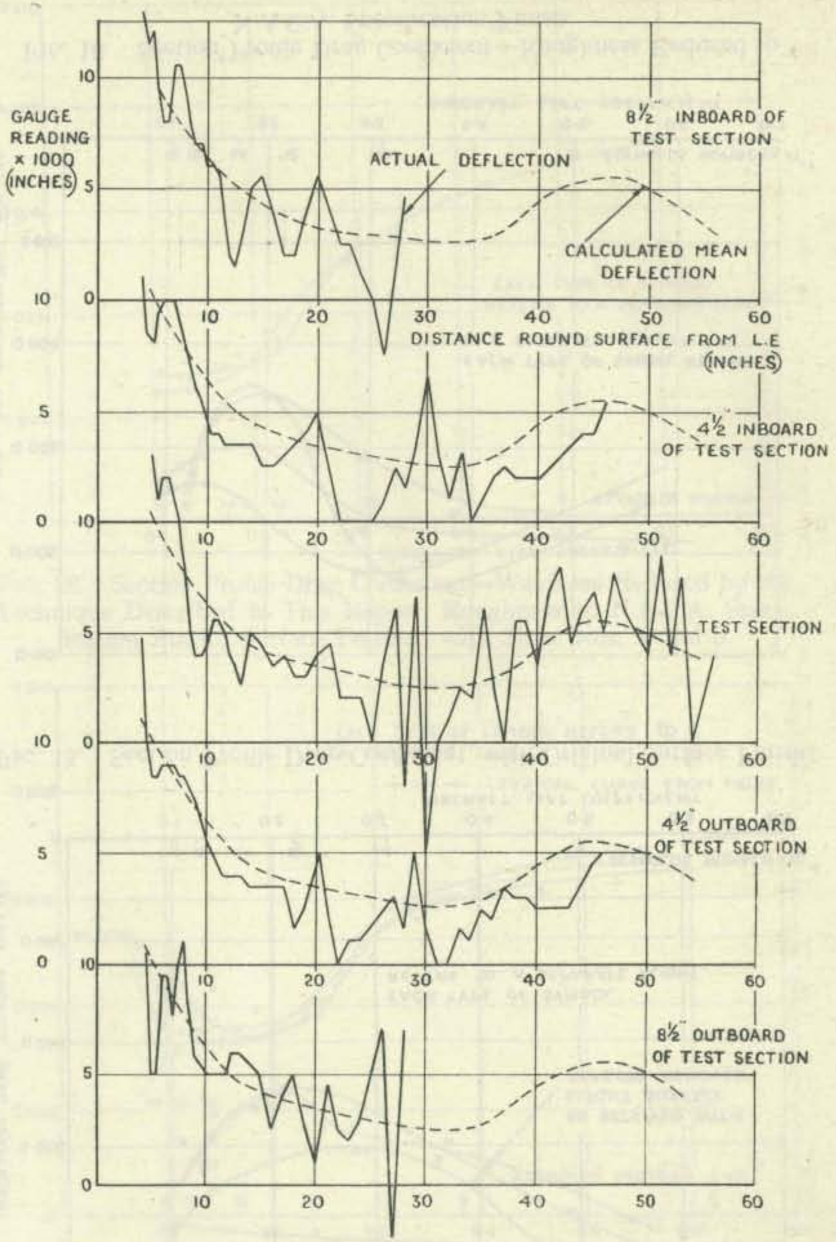


FIG. 13. Bottom Surface Waviness—After Removal of Paint.

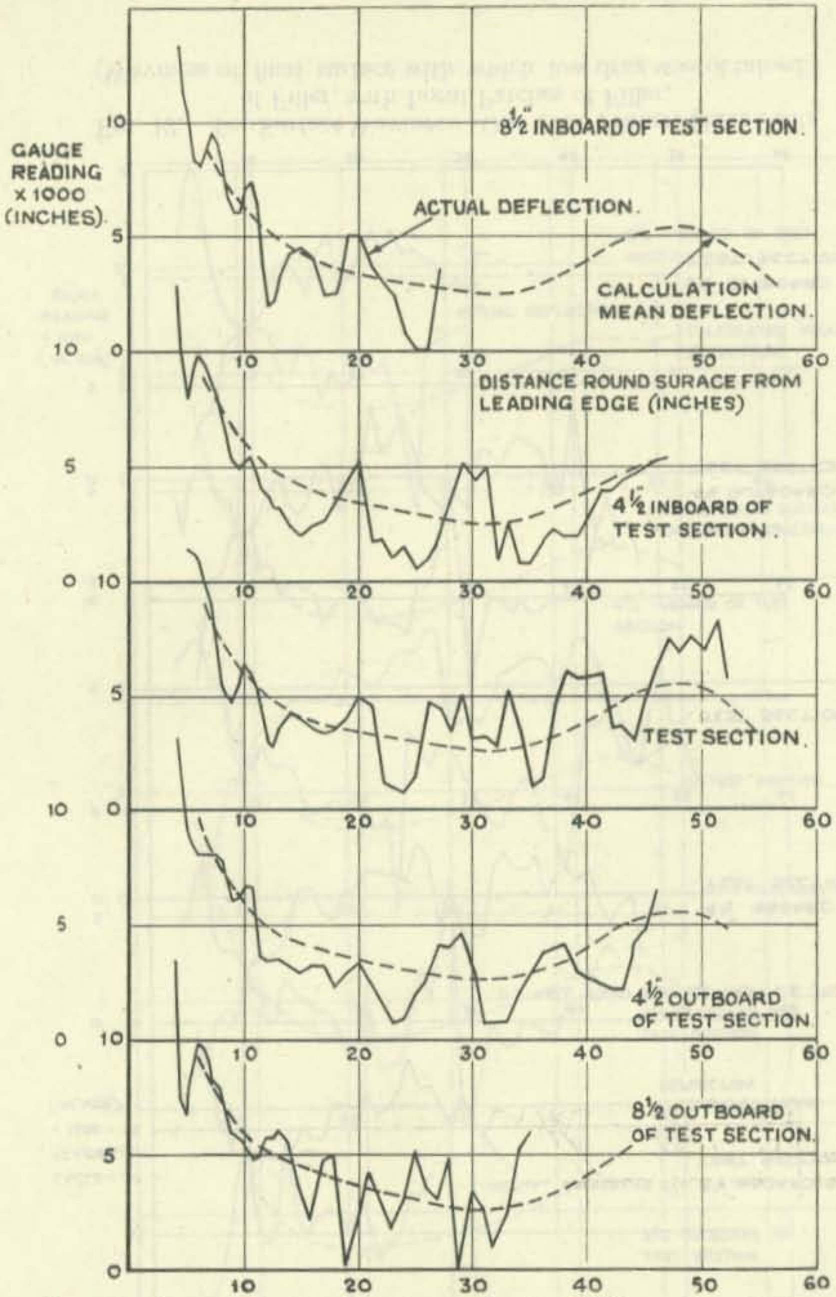


FIG. 14. Bottom Surface Waviness—One Coat Primer, Two Coats Filler, with Local Patches of Filler.
(Waviness of final surface with which low drag was obtained.)

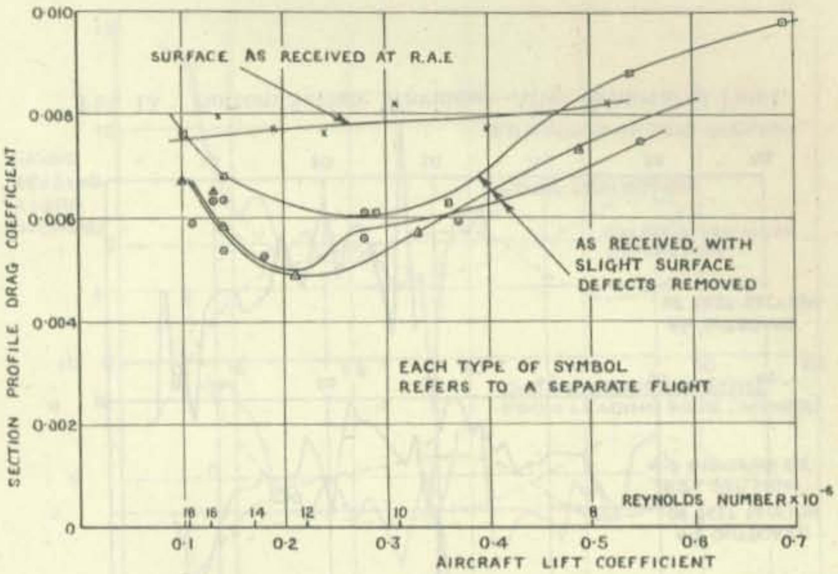


FIG. 15. Section Profile Drag Coefficient, with Original Surface Finish.

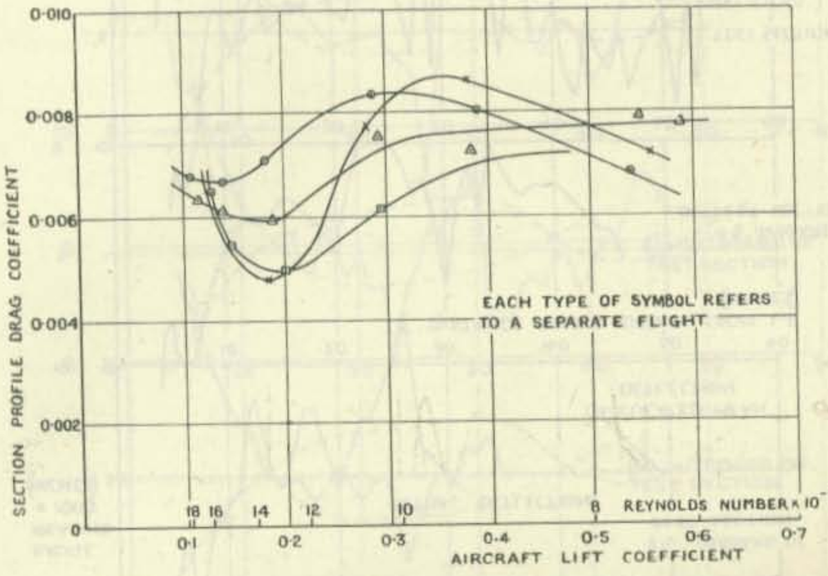


FIG. 16. Section Profile Drag Coefficient—Roughness Reduced to N.A.C.A. Specification Finish.

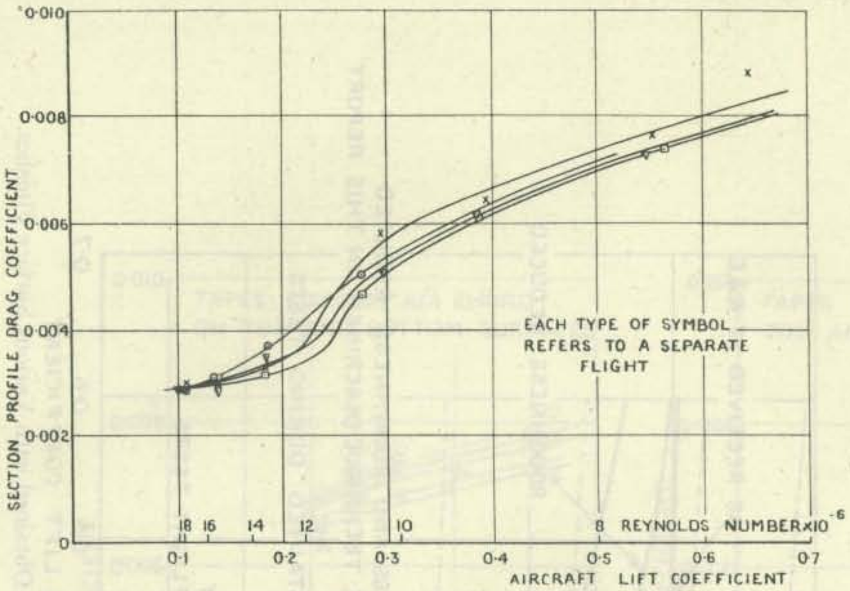


FIG. 17. Section Profile Drag Coefficient—Waviness Reduced by the Technique Described in This Report, Roughness to N.A.C.A. Specification Finish.

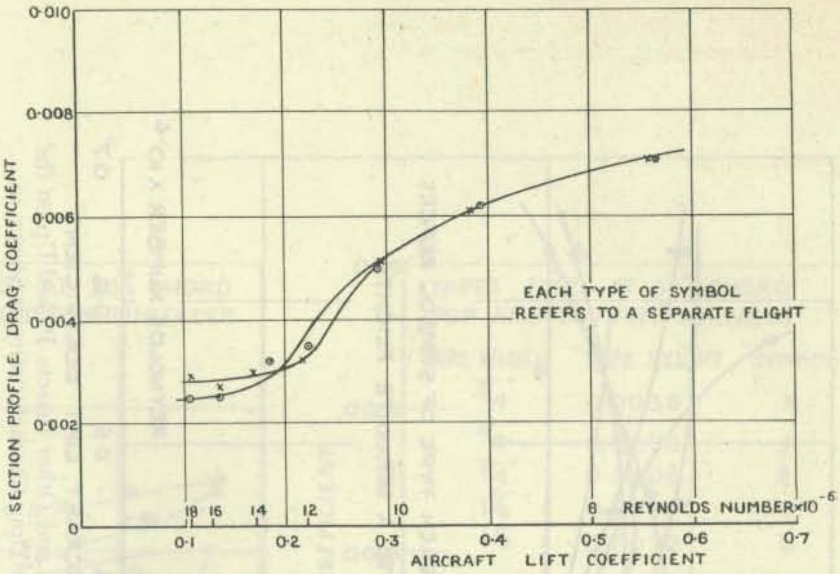


FIG. 18. Section Profile Drag Coefficient—Waviness Reduced by the Technique Described in This Report, Roughness to N.A.C.A. Specification Finish, Surface Polished with Sinec Nos. 2 and 3.

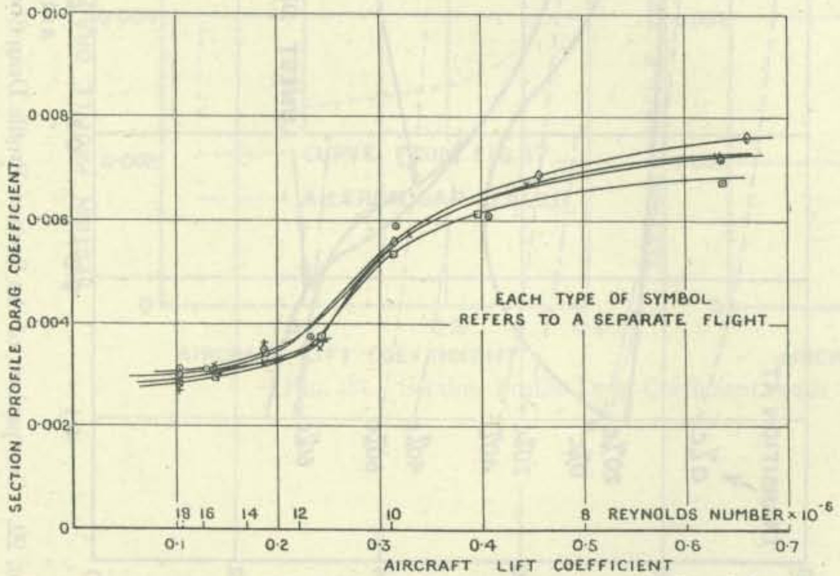


Fig. 19. Section Profile Drag Coefficient—Waviness Reduced by the Technique Described in This Report, Roughness to N.A.C.A. Specification Finish, Surface Polished with Sinec Nos. 2 and 3. Repeat of Tests Shown in Fig. 18 after an Interval of Four Weeks and Fifteen Hours Flying.

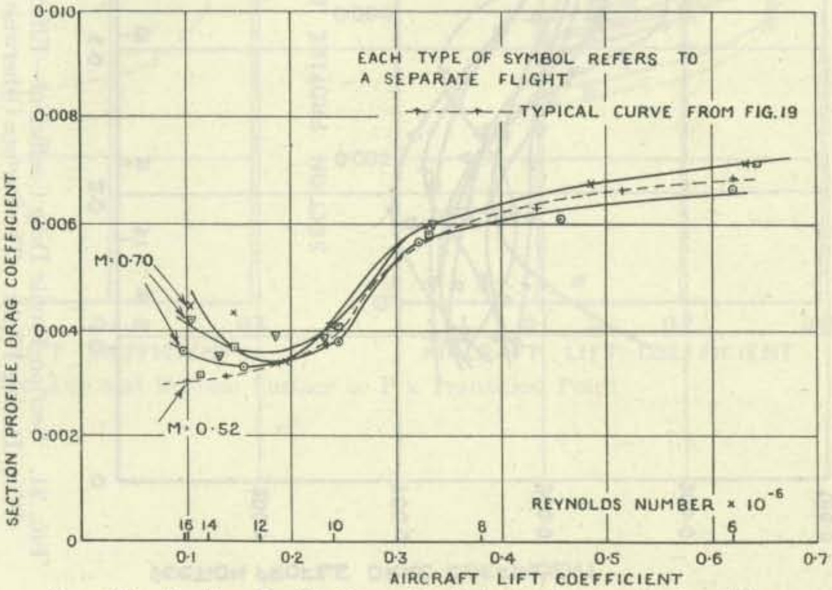


FIG. 20. Section Profile Drag Coefficient—Surface in Condition Described in Fig. 19. Tests at 25,000 ft. to Investigate Effect of Mach Number.

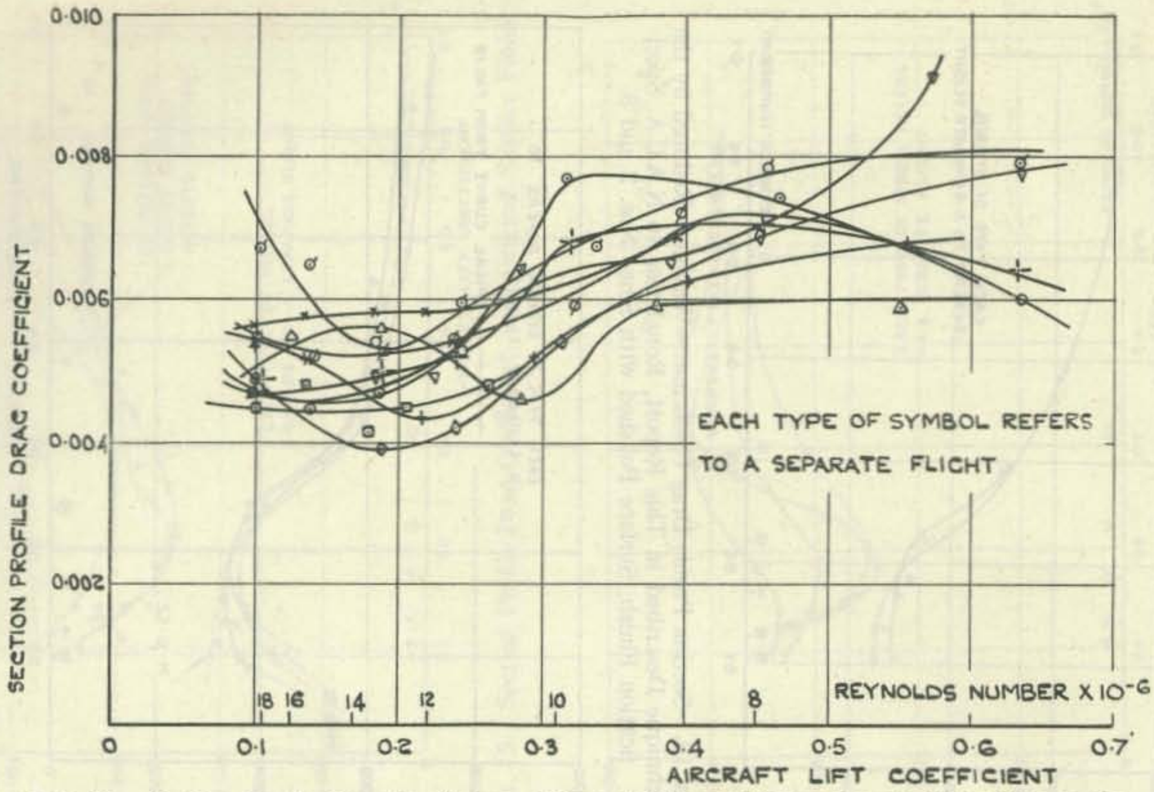


FIG. 21. Section Profile Drag Coefficient—Effect of Flies and Other Insects Picked Up on the Wing During Flight. The Surface Otherwise Had Low Drag Characteristics as Shown in Figs. 17, 18 and 19.

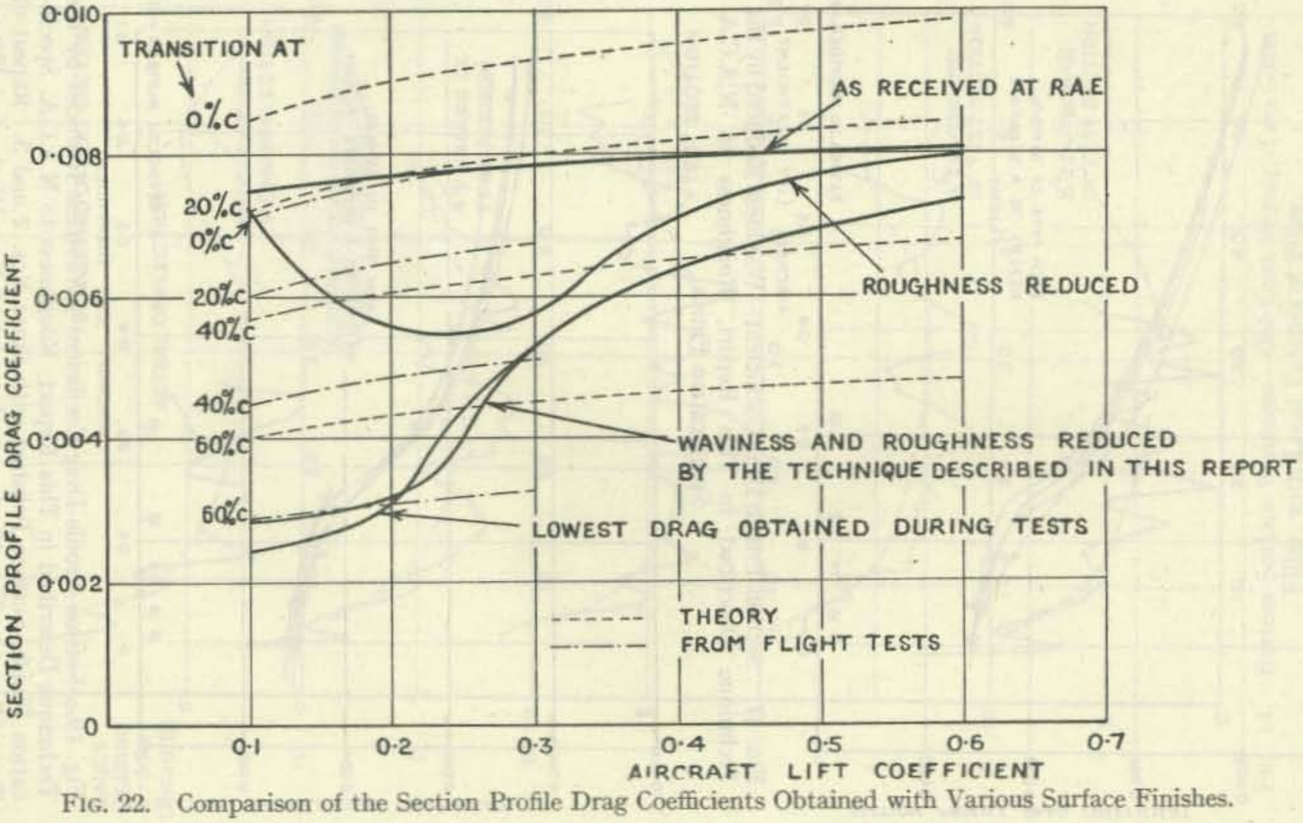


FIG. 22. Comparison of the Section Profile Drag Coefficients Obtained with Various Surface Finishes.

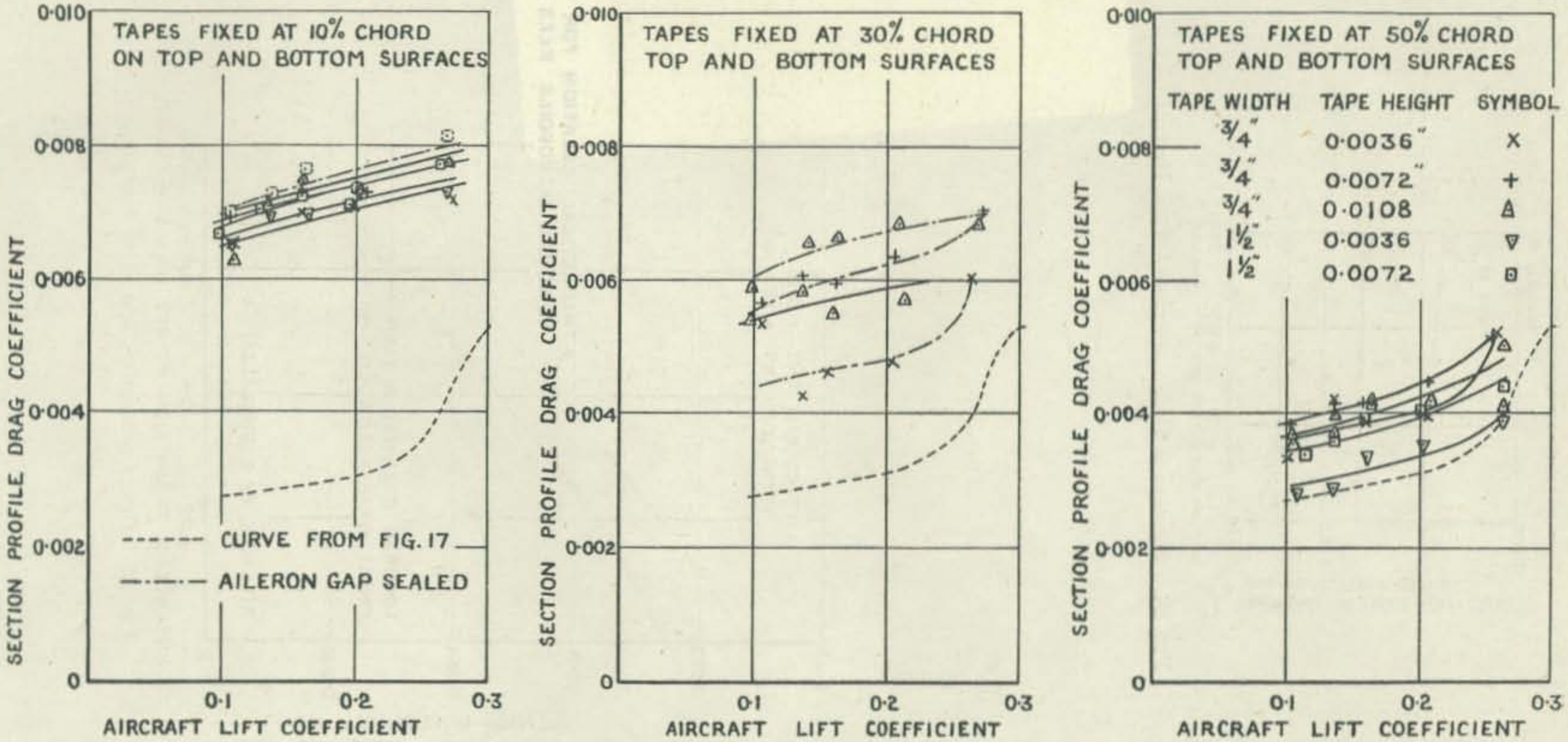


FIG. 23. Section Profile Drag Coefficient, with Tapes on Top and Bottom Surface to Fix Transition Point.

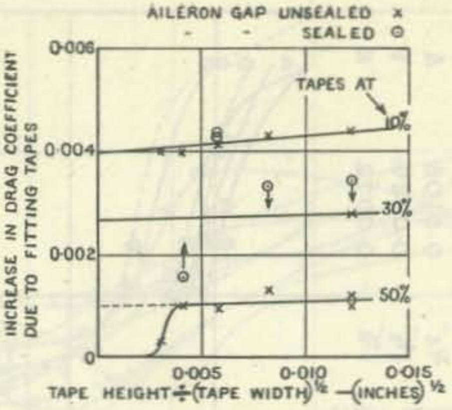


FIG. 24. Increase in Drag Coefficient—Tape Height.

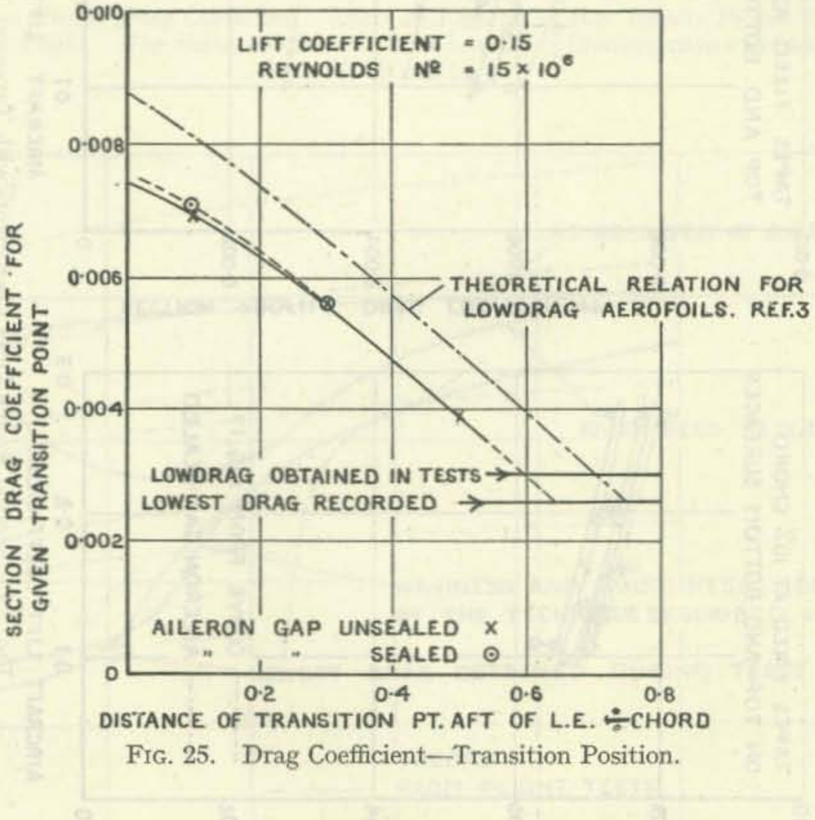


FIG. 25. Drag Coefficient—Transition Position.

(88922) Wt. 13/806 K5 3/50 Hw.

PRINTED IN GREAT BRITAIN