[redacted]

(2264)
A.R.C. Technical Report,

1

ARC-R/M-1708
ARC-TR-1936

18 ARC
19 TR-2264

AD A951598

AIR MINISTRY

AERONAUTICAL RESEARCH COMMITTEE
REPORTS AND MEMORANDA

Effect of Surface Roughness on Characteristics of Aerofoils N.A.C.A. 0012 and R.A.F. 34

By

R. JONES, D.Sc., and D. H. WILLIAMS, B.Sc.

13 Feb 36

Crown Copyright Reserved

LONDON: HIS MAJESTY'S STATIONERY OFFICE
~~Price 8s. 0d. net~~

DTIC FILE COPY

008450

AERODYNAMIC SYMBOLS.

1. GENERAL

m	Mass
t	Time
V	Resultant linear velocity
Ω	Resultant angular velocity
ρ	Density, σ relative density
ν	Kinematic coefficient of viscosity
R	Reynolds number, $R = lV/\nu$ (where l is a suitable linear dimension)

Normal temperature and pressure for aeronautical work are 15°C and 760 mm.

For air under these conditions $\begin{cases} \rho = 0{\cdot}002378 \text{ slug/cu.ft.} \\ \nu = 1{\cdot}59 \times 10^{-4} \text{ sq.ft/sec.} \end{cases}$

The slug is taken to be 32·2 lb. – mass.

α	Angle of incidence
e	Angle of downwash
S	Area
b	Span
c	Chord
A	Aspect ratio, $A = b^2/S$
L	Lift, with coefficient $C_L = L/\frac{1}{2}\rho V^2 S$
D	Drag, with coefficient $C_D = D/\frac{1}{2}\rho V^2 S$
γ	Gliding angle, $\tan\gamma = D/L$
L	Rolling moment, with coefficient $C_l = L/\frac{1}{2}\rho V^2 bS$
M	Pitching moment, with coefficient $C_m = M/\frac{1}{2}\rho V^2 cS$
N	Yawing moment, with coefficient $C_n = N/\frac{1}{2}\rho V^2 bS$

2. AIRSCREWS.

n	Revolutions per second
D	Diameter
J	V/nD
P	Power
T	Thrust, with coefficient $k_T = T/\rho n^2 D^4$
Q	Torque, with coefficient $k_Q = Q/\rho n^2 D^5$
η	Efficiency, $\eta = TV/P = Jk_T/2\pi k_Q$

The Effect of Surface Roughness on the Characteristics of the Aerofoils N.A.C.A. 0012 and R.A.F. 34

By

R. Jones, D.Sc., and D. H. Williams, B.Sc.,
of the Aerodynamics Department, N.P.L.

Reports and Memoranda No. 1708
13*th February*, 1936

CONTENTS

Summary.
§ 1. Introductory.
§ 2. Aerofoil Sections.
§ 3. Aerofoils and Surfaces.
§ 4. Range of Experiments.
§ 5. Routine Tests on N.A.C.A. 0012.
§ 6. Effect of Surface Roughness on Maximum Lift.
§ 7. Effect of Surface Roughness on Minimum Drag.
§ 8. Profile Drag.
§ 9. Conclusion.
References.
Tables.

DTIC ELECTE JAN 11 1982 D

SUMMARY.—Predictions from work on rough pipes suggested that surface roughness would increase the drag of an aerofoil at high Reynolds numbers. Experiments have been carried out in the Compressed Air Tunnel on the aerofoil N.A.C.A. 0012, (*a*) with the usual finish, (*b*) with the surface chromium plated and (*c*) with the surface coated with carborundum powder to two degrees of roughness; and on the aerofoil R.A.F. 34, (*a*) with the usual finish, (*b*) with the entire surface roughened and (*c*) with only the back-half roughened. The tests were made at Reynolds numbers ranging from $0 \cdot 16 \times 10^6$ to $7 \cdot 2 \times 10^6$ and at angles of incidence up to $28 \cdot 5°$. It was found that surface conditions had a large effect on maximum lift and on minimum drag at high Reynolds numbers.

Maximum Lift.—Maximum lift increases with Reynolds number. The effect of surface roughness on maximum lift is to cause the curve, plotted against Reynolds number, to diverge from that for a smooth aerofoil at a value of R which decreases as the roughness increases. Above that value of R, the maximum lift remains nearly constant. (Fig. 9 for N.A.C.A. 0012, Fig. 10 for R.A.F. 34.) Surface roughness thus decreases the maximum lift, the loss on $C_{L\,max.}$ increasing as the roughness is increased. The two degrees of roughness caused a loss of 15 per cent. and 20 per cent. on maximum lift for N.A.C.A. 0012 at high values of R, and the coarser roughening caused a loss of 26 per cent. on $C_{L\,max.}$ for R.A.F. 34. Roughening only the back-half of R.A.F. 34 caused no loss in maximum lift up to the highest value of R in the experiments.

Minimum Drag.—The minimum drag curve for a roughened aerofoil, plotted against Reynolds number, diverges from that for a smooth aerofoil at about the same value of R as for the maximum lift curves. The point of divergences agrees well with the predicted value. Above this point, the drag increases with increasing roughness. (Fig. 11 for N.A.C.A. 0012, Fig. 12 for R.A.F. 34.) The value of R at which the divergence occurs is higher when only the back-half of an aerofoil is roughened. Uniformly distributed excrescences of 0·0004 in. and of 0·001 in. on an 8 in. aerofoil increase the minimum drag at high Reynolds numbers by some 25 per cent. and 60 per cent. respectively.

Further Developments.—Chromium plating the aerofoil N.A.C.A. 0012 decreased the minimum drag by 5 per cent. and increased the maximum lift by 5 per cent., indicating that further improvements might be obtained with better finish. It is proposed to test an aerofoil with as fine a polish as can be obtained ; and also, for maximum lift, to experiment with different areas of roughness on the upper surface.

---

1. *Introductory.*—The effect of surface roughness on the behaviour of an aerofoil at high Reynolds numbers has been much discussed lately on account of its great importance in the design of high speed aircraft. The work of Nikuradse[1] on the resistance to flow in rough pipes, and the deductions from this work made by Prandtl and Schlichting[2] on the skin friction of rough plates, have suggested that at high Reynolds number a comparatively small degree of roughness may produce an important increase in profile drag. This is borne out in practice in tests made by Schrenk[3] and Ebert[4] on the profile drag of wings in flight.

Measurements have been made in the Compressed Air Tunnel on two aerofoils with the usual finish and with the surface roughened. On an aerofoil of symmetrical section, N.A.C.A. 0012, tests have been completed over a large range of Reynolds number with the usual finished surface, with the surface coated with a paste of carborundum powder and lacquer to two degrees of roughness and with the aerofoil chromium plated in an attempt to improve the surface. An aerofoil of section R.A.F. 34 has been tested with the whole surface roughened in a similar way and with only the back-half roughened, to compare with results previously obtained on this section[5].

It is not pretended that these roughened surfaces represent at all accurately any full scale roughness likely to be realised in practice. The object of the tests was merely to establish the general effect of roughness by Compressed Air Tunnel tests, and to correlate the results in a general way with the predictions from Nikuradse's work on rough pipes.

Roughening the entire surface in these cases has no effect at Reynolds numbers below 1×10^6 and this accounts for the negative results obtained by experimenters on models tested in atmospheric tunnels. At higher values of Reynolds number, surface roughness increases the minimum drag and decreases the maximum lift. The effects are discussed in detail below.

The original aim of the experiments on the aerofoil N.A.C.A. 0012 was to provide data for a direct comparison of results from the two tunnels operating with compressed air, the Variable Density Tunnel at Langley Field and the Compressed Air Tunnel of the National Physical Laboratory. It is known that the turbulence in the two tunnels differs considerably and any discrepancies in the results may be attributed to turbulence. Turbulence is known to have a large effect on maximum lift, so that the best section for comparison would be one which showed a marked change in maximum lift with Reynolds number. The selection was made by the technical staff of the National Advisory Committee for Aeronautics, who chose the section N.A.C.A. 0012. Subsequently the same aerofoil was used for the roughness tests. This aerofoil and the R.A.F. 34 are both very suitable for measurements of minimum drag as they both have very small moments about the quarter chord point at low angles of incidence, an important feature in the determinations of drag in the Compressed Air Tunnel as these are obtained by the subtraction of readings taken about the so-called drag and moment axes. For aerofoils having a large C_{m_0}, these readings are frequently of the same order and the accuracy of minimum drags is small.

A preliminary note of the results of the effects of surface roughness on the aerofoil N.A.C.A. 0012 was circulated to the Aeronautical Research Committee.

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist
A
UNANNOUNCED

2. *Aerofoil sections.*—N.A.C.A. 0012 is a symmetrical section of 12 per cent. thickness, with the maximum ordinate 0·3c aft of the leading edge. The profile is determined by the equation[7]

$$\pm y = 0{\cdot}17814\sqrt{x} - 0{\cdot}07560\,x - 0{\cdot}21096\,x^2 + 0{\cdot}17058\,x^3 - 0{\cdot}06090\,x^4$$

where y is the distance of the surface from the line of symmetry and x is the distance from the leading edge. The dimensions are given in Table 1, in terms of the chord.

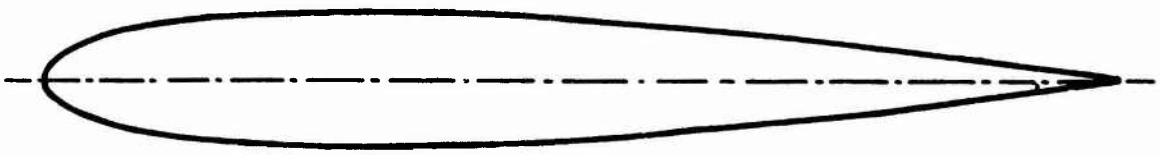


FIG. 1.—N.A.C.A. 0012.

TABLE 1

N.A.C.A. 0012

x	0	0·0125	0·025	0·05	0·075	0·10	0·15	0·20
y	0	0·0189	0·0261	0·0356	0·0420	0·0468	0·0534	0·0574

x	0·30	0·40	0·50	0·60	0·70	0·80	0·90	0·95	1·0
y	0·0600	0·0580	0·0530	0·0456	0·0367	0·0262	0·0145	0·0081	0·0020

R.A.F. 34 is based on a Joukowski section with 0·02c centre line camber and having a reflexed trailing edge[8]. The centre line equation is

$$y = 0{\cdot}02065\,x(1 - x)\,(7 - 8x).$$

The maximum thickness is 12·65 per cent. at a distance 0·3c from the leading edge. This section is designed to have no moment about the quarter chord point. Table 2 gives the profile of the section.

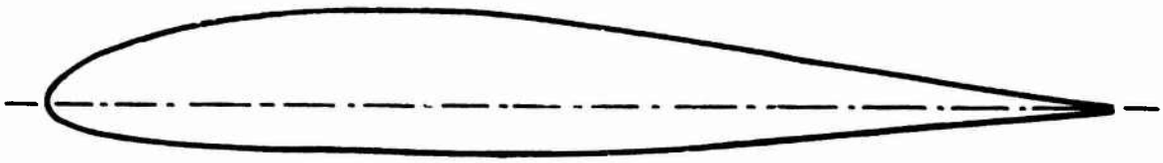


FIG. 2.—R.A.F. 34.

TABLE 2

R.A.F. 34

U = y for upper surface. L = y for lower surface.

x	0	0·0125	0·025	0·05	0·075	0·10	0·15	0·20	0·30
U	0	0·0197	0·0283	0·0411	0·0505	0·0582	0·0698	0·0772	0·0833
L	0	0·0163	0·0214	0·0281	0·0323	0·0353	0·0391	0·0416	0·0433

x	0·40	0·50	0·60	0·70	0·80	0·90	0 95	1·0
U	0·0808	0·0722	0·0588	0·0431	0·0270	0·0126	0·0064	0
L	0·0433	0·0411	0·0369	0·0309	0·0230	0·0134	0·0076	0

3. *Aerofoils and surfaces.*—The two aerofoils were rectangular in plan, of aspect ratio 6, span 4 ft., chord 8 in. Measurements on the aerofoils showed that errors in the manufacture were usually not greater than $\pm$ 0·001 in. The two aerofoils were hand finished for the normal tests, but not polished. Some measurements made in the Engineering Department showed that there were scratches of a maximum depth of 0·0001 in., but that in general the surface irregularities were considerably less than this. The N.A.C.A. 0012 aerofoil was of steel, the R.A.F. 34 of aluminium.

The surfaces were roughened by painting with a paste made by mixing carborundum powder with a suitable lacquer. It is almost impossible to specify the roughness, but the degree of uniformity attained by this process is illustrated in Fig. 3, where microphotographs of the surface are shown for the two roughened conditions of test. The grades of carborundum powder used were FF and FFF, the average size of particles being about 0·001 in. and 0·0004 in. respectively. The particles were

found to adhere perfectly throughout the tests. An attempt was made to improve the hand finished aerofoil by chromium plating the N.A.C.A. 0012 model to a thickness of 0·001 in. This process made a slight improvement, but it is doubtful if the plating did more than round off small scratches, as irregularities could still be seen on the surface after plating.

The aerofoil R.A.F. 34 was roughened with FF carborundum powder (0·001 in.) only. After tests had been made with the entire surface roughened, the lacquer and carborundum was removed from the forward half of the upper and lower surfaces and the aerofoil tested with the back-half roughened.

It is proposed to improve the surface of an aerofoil by hand polishing to as fine a surface as possible and to repeat the tests on this aerofoil.

4. *Range of experiments.*—The hand finished N.A.C.A. 0012 aerofoil was tested over the whole range of Reynolds numbers from $0 \cdot 164 \times 10^6$ to $7 \cdot 20 \times 10^6$, the pressure in the tunnel being varied from 1 to 25 atmospheres and the wind speed from 17 to 80 ft./sec. Lift, drag, pitching moment and centre of pressure coefficients are given in Table 3 for a range of α from $-3°$ to $+28 \cdot 5°$ for low values of R and from 0° to 28·5° for high values of R.

Tests over the full range of angles on N.A.C.A. 0012 roughened with FFF and FF carborundum were only carried out at three Reynolds numbers, with measurements of lift near maximum lift at two additional values of R. The results for these two surface conditions are given in Tables 4 and 5 respectively.

A comprehensive series of tests, similar to that on the hand finished aerofoil, was made on N.A.C.A. 0012 with chromium plated surface, the results of which are given in Table 6. In addition, with this surface condition, measurements were made with the aerofoil inverted in order to determine the corrections due to any slight asymmetry of the model. A small correction on moment was found and this has been applied to all the results on the N.A.C.A. 0012 aerofoil. The correction was $-0 \cdot 0006$ on the calculated values of C_m.

Results on the aerofoil R.A.F. 34, hand finished, are given in Table 7. These are taken from R. & M. 1706[5] with an additional set taken at a high Reynolds number to get further information on the maximum lift.

Tables 8 and 9 give the results obtained for R.A.F. 34 with the back-half roughened with FF carborundum and the entire surface similarly roughened.

The values of pressure, Reynolds numbers and speed for the sets given are tabulated below.

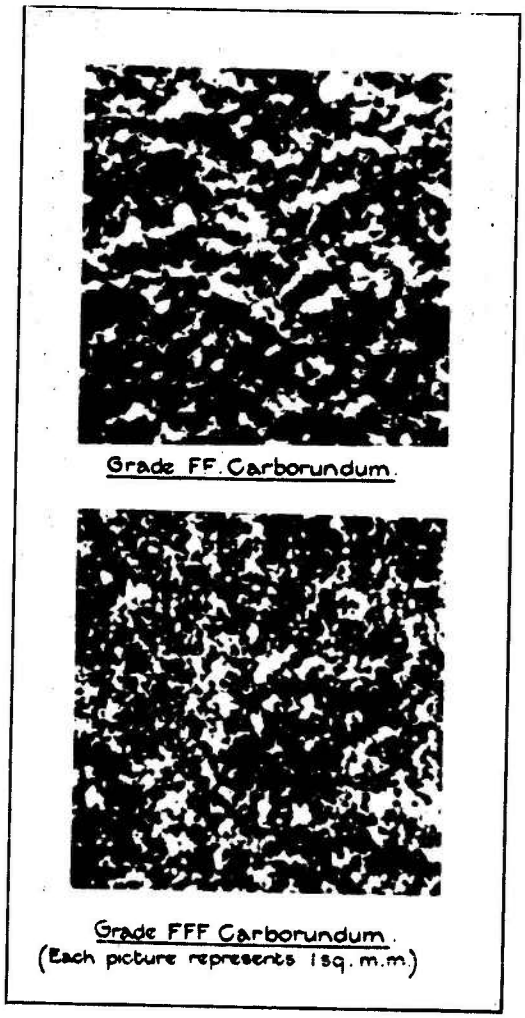

Grade FF. Carborundum.
Grade FFF Carborundum.
(Each picture represents 1 sq. m.m.)

FIG. 3.

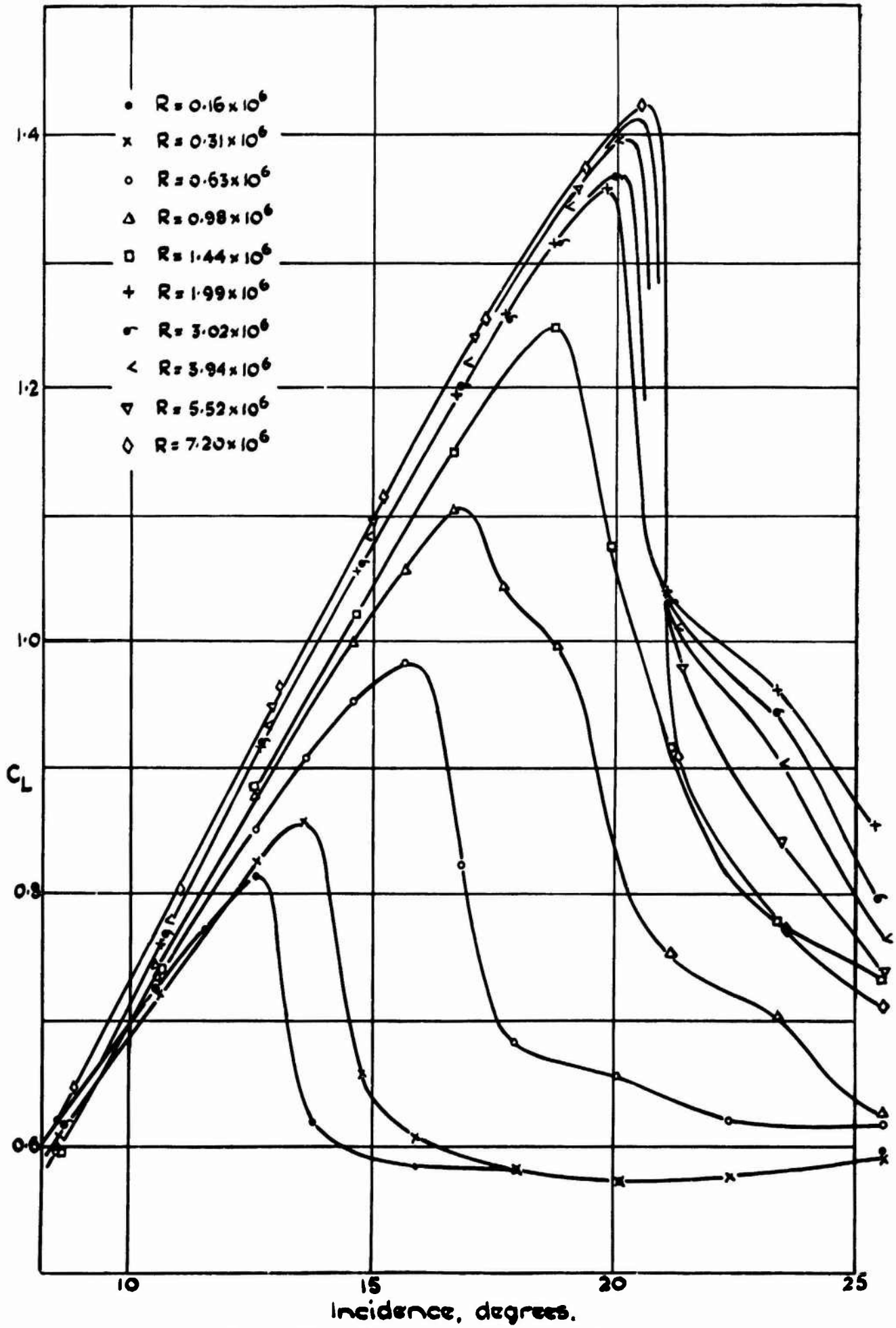


FIG. 4.—Lift on N.A.C.A. 0012 with Increasing Incidence.
Aspect Ratio 6. Chord 8 in.
Hand Finished.

TABLE 3

N.A.C.A. 0012. *Hand finished*

R × 10^{-6} ..	0·164	0·312	0·63	0·98	1·44	1·47	1·99	3·02	3·94	5·52	7·20
P. atmos. ..	1	1	2·1	3·6	4·8	22·9	7·7	11·5	14·4	18·4	24·1
V.f./s.	42·9	75·5	73·7	68·7	77·3	17·1	64·4	68·2	70·7	79·2	79·6

TABLE 4

N.A.C.A. 0012. *Roughened FFF*

R × 10^{-6} ..	0·319	1·06	2·08	3·18	5·67
P. atmos. ..	1	4·0	8·4	11·7	18·2
V.f./s.	74·9	64·1	62·0	67·3	78·4

TABLE 5

N.A.C.A. 0012. *Roughened FF*

R × 10^{-6} ..	0·308	1·03	2·01	3·11	5·52
P. atmos. ..	1	3·9	7·9	11·6	18·3
V.f./s.	76·2	65·4	63·7	67·8	79·2

TABLE 6

N.A.C.A. 0012. *Chromium plated*

R × 10^{-6}	0·313	0·64	0·98	1·39	1·98	2·94	3·94	5·56	7·43
P. atmos. ..	1	2·2	3·7	4·3	7·7	11·2	14·7	18·4	24·6
V.f./s. ..	75·9	71·3	68·0	80·9	64·5	69·4	70·5	78·9	78·1

TABLE 7

R.A.F. 34. *Hand finished*

R × 10^{-6} ..	0·31	1·25	2·56	3·52	4·51	5·47	6·47	2·52	2·52	7·17
P. atmos. ..	1	4·3	8·3	13·2	14·7	18·0	22·5	20·9	13·6	23·8
V.f./s.	75·8	70·9	75·0	69·0	78·7	78·0	73·8	30·6	47·4	76·3

TABLE 8

R.A.F. 34. Back-half roughened FF

$R \times 10^{-6}$	0·312	1·27	2·58	4·99	6·98
P. atmos.	1	4·6	9·7	16·2	23·6
V.f./s.	76·1	69·3	68·0	81·3	77·5

TABLE 9

R.A.F. 34. All roughened FF

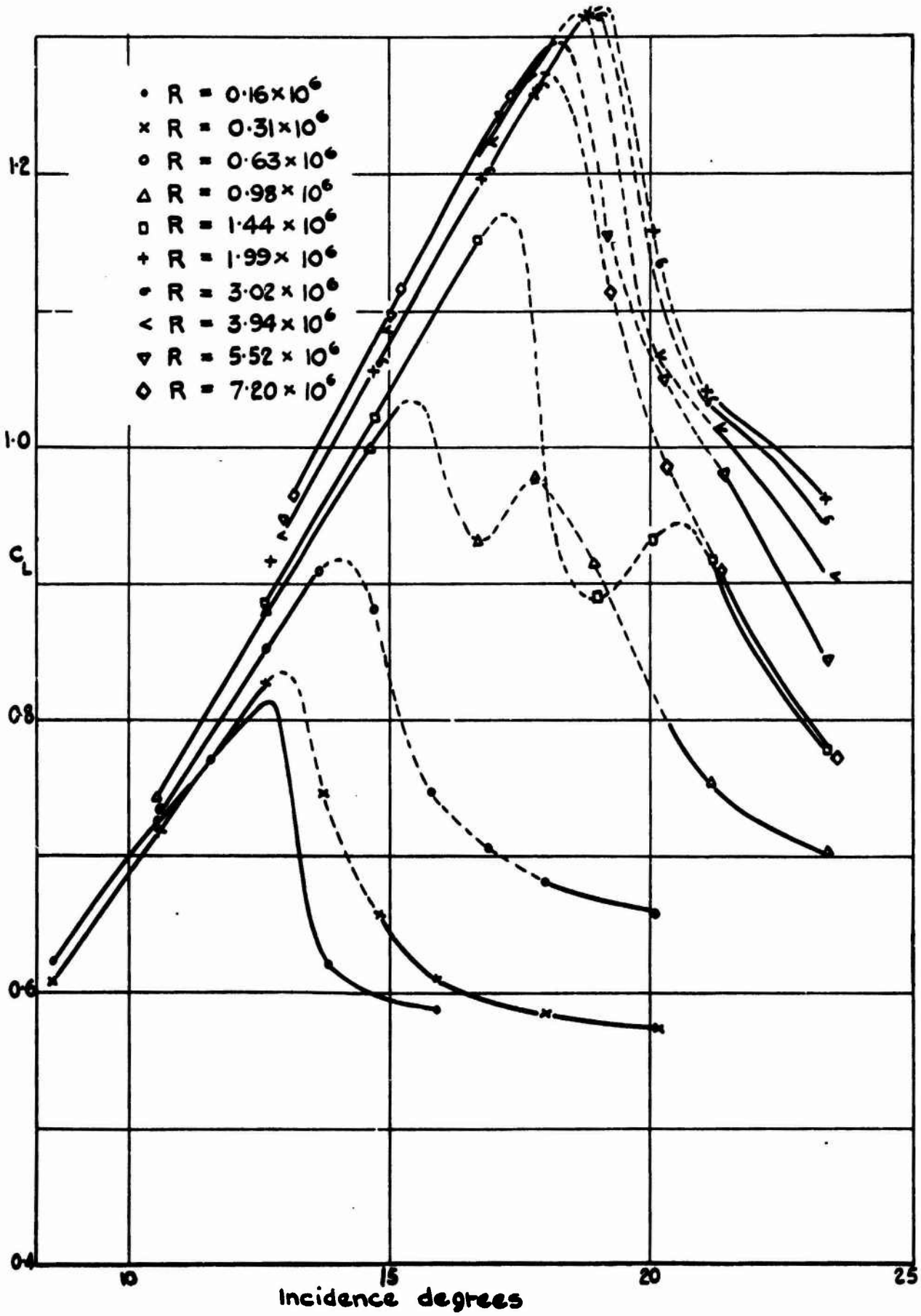
$R \times 10^{-6}$	0·31	1·26	2·62	5·05	7·14
P. atmos.	1	4·5	9·8	16·0	24·4
V.f./s.	75·8	69·7	67·3	82·6	76·0

In addition to these results, a number of observations of $C_{D\,min.}$ were made on these aerofoils with the various surface conditions for a range of pressures and speeds. The results, with details of the appropriate values of R, pressure, V and ϱV^2 are given in Tables 10–13 for N.A.C.A. 0012, and in Tables 14–16 for R.A.F. 34. The results are shown in Figs. 11 and 12 for the two sections.

All the results have been corrected for tunnel interference.

5. *Routine tests on N.A.C.A.* 0012.—The values of the lift coefficient, with increasing incidence, near maximum lift have been plotted in Fig. 4 for the hand finished aerofoil. The maximum lift increases rapidly with Reynolds number from 0·81 at $R = 0{\cdot}164 \times 10^6$ to 1·36 at $R = 2 \times 10^6$ and then slowly to 1·425 at $R = 7{\cdot}2 \times 10^6$. This is well brought out by curve B in Fig. 9 where the maximum lift coefficient is plotted against Reynolds number. There is a large drop in C_L above the stall and the drop becomes more and more abrupt as R increases. The value of C_L just above the stall increases with R to a maximum at $R = 2 \times 10^6$ after which it decreases as R continues to increase.

On a number of aerofoils, as the angle of incidence is decreased from above the stall, the stalled condition persists below the normal stalling angle: this applies particularly to aerofoils having a large drop in lift at the stall. For such aerofoils, there is a region of incidence where either flow can be obtained and where there are alternative readings of lift, drag and moment coefficients; the values obtained depending on whether the particular angle is approached from below or from above the stall. In Fig. 5 the lift coefficient with incidence decreasing has been plotted



The curves are shown broken in the region where the lift differs from that obtainable with increasing incidence.

FIG. 5.—Lift on N.A.C.A. 0012 with Decreasing Incidence.
Aspect Ratio 6, Chord 8 in.

for comparison with Fig. 4. Where the readings differed from those for increasing incidence, the curves have been drawn with broken lines. Alternative values were obtained at all values of R except the lowest, but it was sometimes difficult to find them where they existed. For example, at $R = 5 \cdot 52 \times 10^6$, it is obvious that the maximum value of C_L at $\alpha = 20 \cdot 2°$ was missed as the incidence was increased; the two sets of values were found for the readings about the drag and moment axes. Only the drag is given in the Tables at this point as both lift and drag are necessary for the computation of C_m. Similarly, no reading of C_L for decreasing incidence could be obtained at $\alpha = 18 \cdot 6°$ for $R = 3 \cdot 94 \times 10^6$ or at $\alpha = 15 \cdot 4°$ for $R = 0 \cdot 98 \times 10^6$, though duplicate readings were found about the other axes in these cases also. About $R = 1 \times 10^6$ to $R = 1 \cdot 5 \times 10^6$ the changes in C_L with R are very large just above the stall. With decreasing incidence there seem to be indications of two stalls in that neighbourhood.

The lift curves for N.A.C.A. 0012 with chromium plated surface are very similar to those for the hand finished aerofoil except that there is a more sudden transition above the stall from the curves for low to those for high values of R. The maximum value of C_L at $R = 5 \cdot 56 \times 10^6$ with increasing incidence was obtained in this case—it could not be found for the hand finished aerofoil. The absolute maximum reached was 1·445, 0·020 higher than for the first aerofoil.

Table 3 includes a set of observations at $R = 1 \cdot 47 \times 10^6$ taken at 22·8 atmospheres, but these results have not been plotted in the figures as this set is thought to be less reliable than the one at $R = 1 \cdot 44 \times 10^6$ at 4·8 atmospheres pressure. The wind speed for the high pressure set was 17·1 f./s. and results in the Compressed Air Tunnel are not very trustworthy for low wind speeds. The lift curves for N.A.C.A. 0012 with the two degrees of surface roughness are given in Figs. 6 and 7. They are only plotted in the neighbourhood of maximum lift and all the cases examined show the phenomenon of double flow.

The diagrams of drag against lift are shown in Fig. 8 up to $C_L = 0 \cdot 4$. The minimum drag decreases from 0·012 at $R = 0 \cdot 164 \times 10^6$ to 0·0065 at $R = 1 \times 10^6$ and $R = 2 \times 10^6$ and then increases with R to 0·0078 at $R = 7 \cdot 2 \times 10^6$. The form of the polar curves varies somewhat with R, the profile drag being more nearly constant for high values of R than for the low. The curve for $R = 0 \cdot 164 \times 10^6$ has a distinctly different shape from the others, due to high lift coefficients near 4° and 6° incidence. These results have been repeated showing that the irregularity is not due to errors of observation.

The curve for the induced drag $0 \cdot 0555\ C_L^2$ has been included in the diagram.

The moment coefficient shows a marked scale effect at small angles of incidence, and the slope of the moment curve at the origin decreases as R increases up to $R = 1 \times 10^6$, after which it remains sensibly constant.

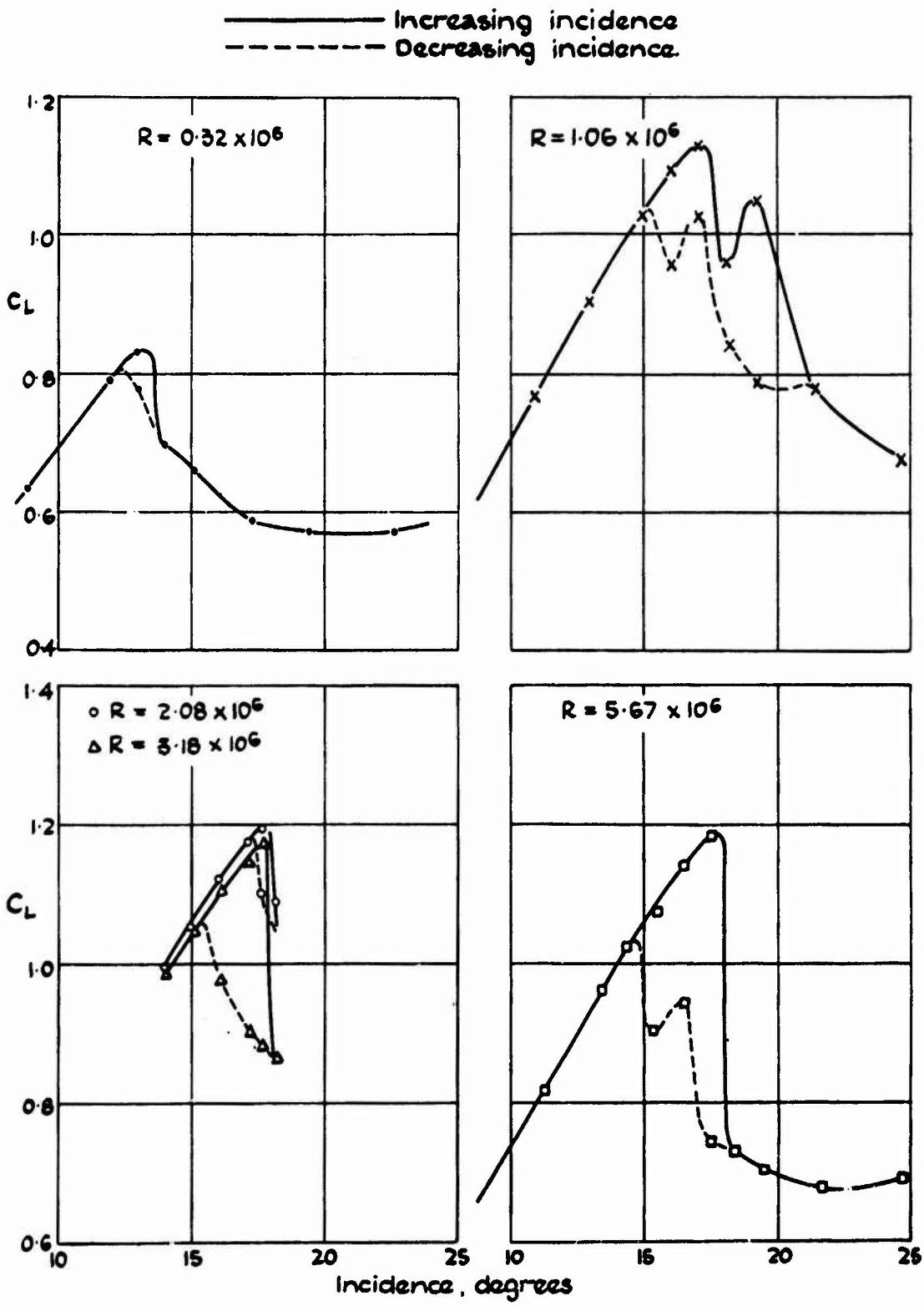


FIG. 6.—Lift on N.A.C.A. 0012 Roughened with 0·0004 in. grains Carborundum Powder (FFF). Aspect Ratio 6, Chord 8 in.

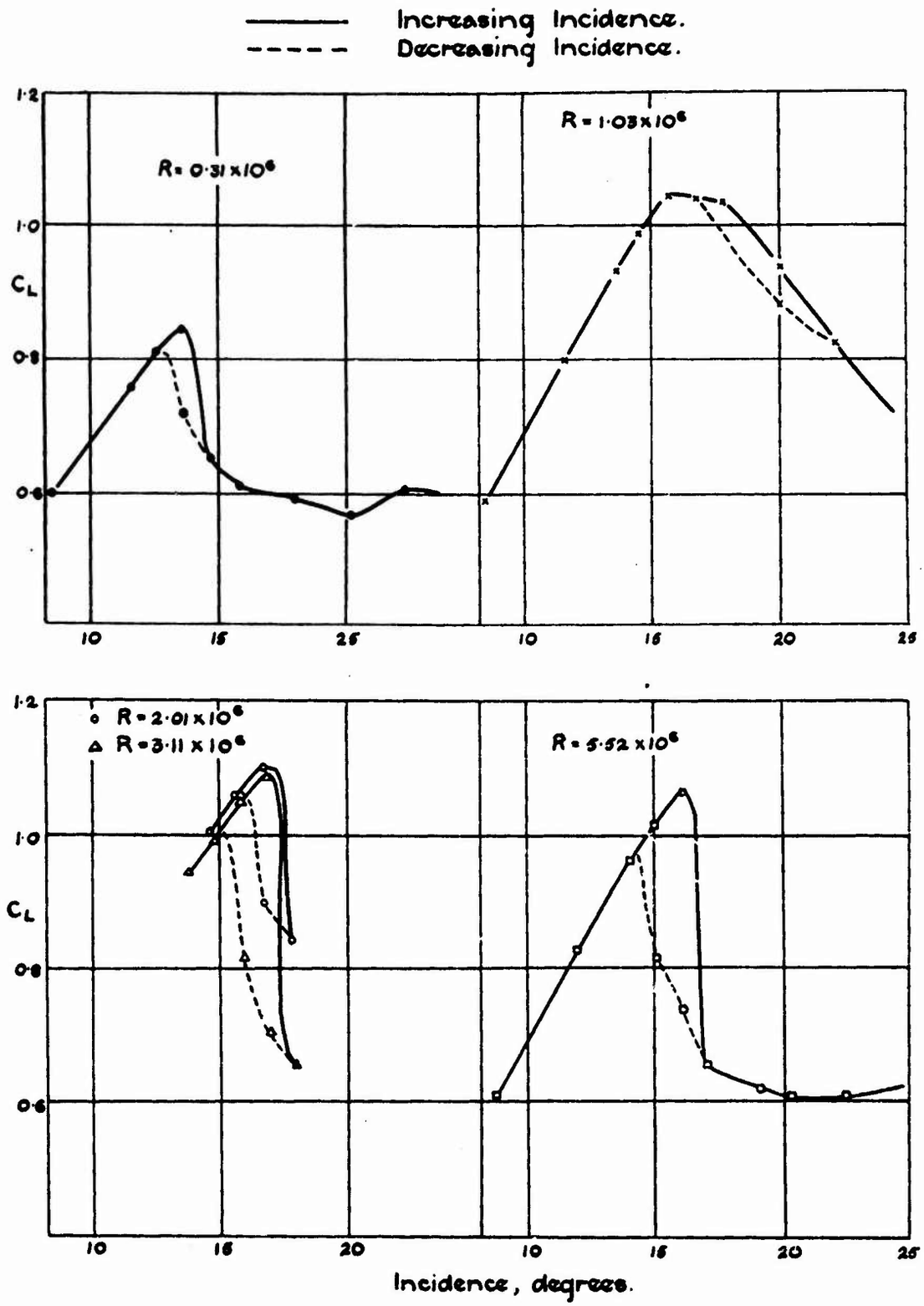


FIG. 7.—Lift on N.A.C.A. 0012 Roughened with 0·001 in. grains Carborundum Powder (FF). Aspect Ratio 6, Chord 8 in.

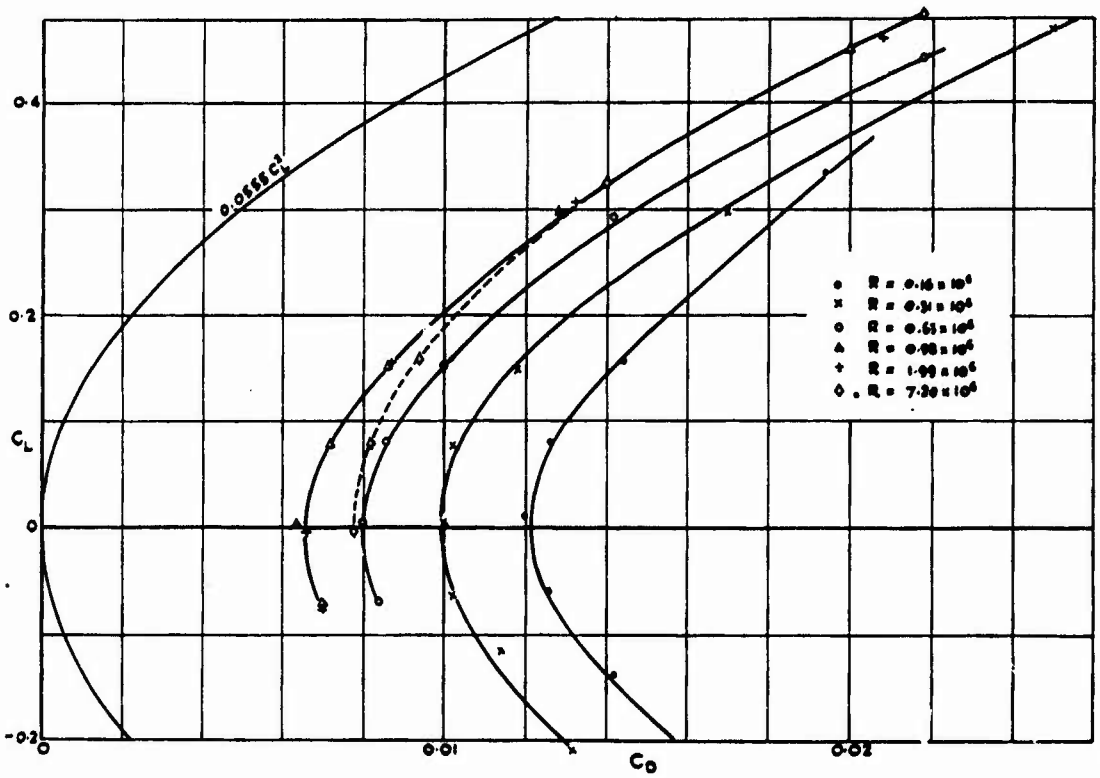
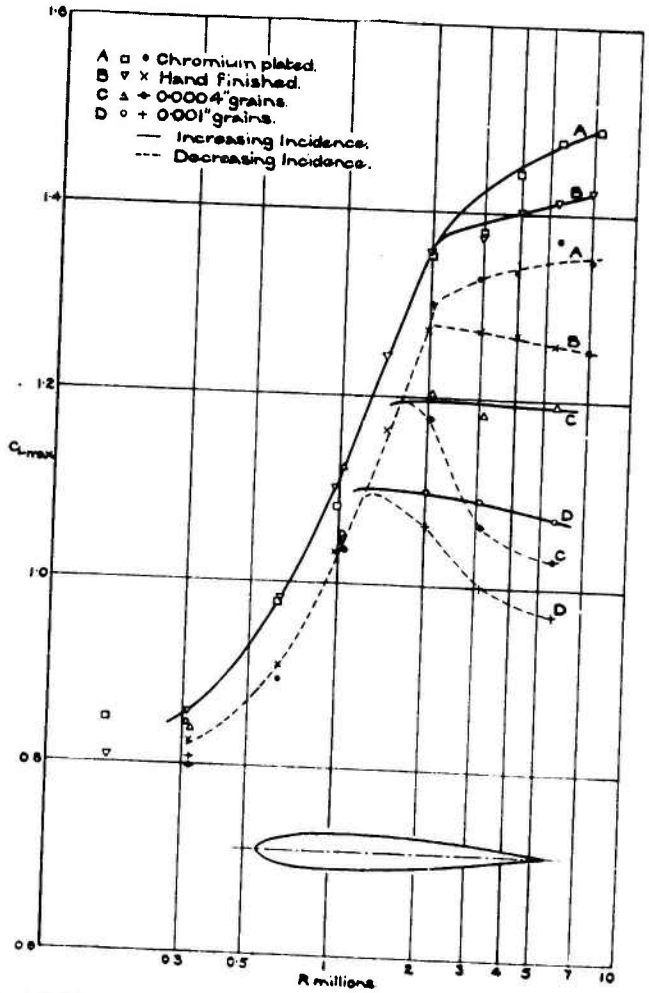


Fig. 8.—Drag of N.A.C.A. 0012.
Aspect Ratio 6. Chord 8 in.
Hand Finished.

6. *Effect of roughness on maximum lift.*—In Fig. 9 the maximum lift coefficients for the aerofoil N.A.C.A. 0012 are plotted against Reynolds number, the full lines representing maximum lift with increasing incidence and the broken lines that with incidence decreasing. Owing to the uncertainties in obtaining the alternative readings, the broken line curves cannot be considered as accurate as the full lines. The effect of surface roughness is immediately evident and makes itself felt on maximum lift at about the same value of Reynolds number as does the effect on minimum drag (see Fig. 10). The maximum lift appears to increase uniformly with increase in R up to a definite value of R, depending on the degree of surface roughness, and then to remain practically constant as R increases further. The sudden change in the form of the curve (B in Fig. 9) for the hand finished aerofoil points to the possibility that this aerofoil was rough for high values of R, and to the desirability of testing a model made as smooth as can be obtained. As the maximum lift of the majority of aerofoils tested in the Compressed Air Tunnel has been of the order of $C_L = 1{\cdot}4$ at $R = 7 \times 10^6$, it suggests that this limit may be due to small roughnesses on the surface common to all these aerofoils, and this idea is strengthened by the increase of about 5 per cent. on $C_{L\,max.}$ which was effected by chromium plating the surface (curve A in Fig 9).

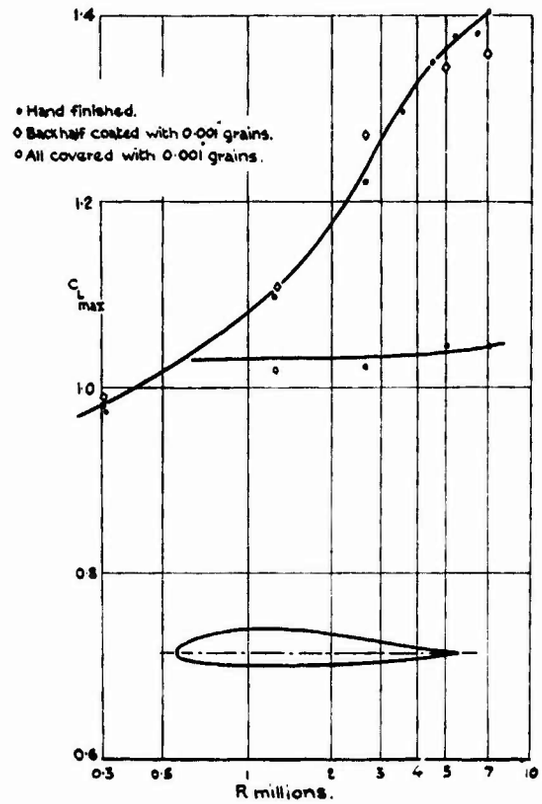


Hand finished aerofoil and aerofoil coated with carborundum powder.

FIG. 9.—Maximum Lift on N.A.C.A. 0012. 8 in. Chord.

Roughening the surface with FFF carborundum (0·0004 in. grains) lowered the maximum lift by some 15 per cent., to 1·20 from 1·42 for the hand finished aerofoil. The coarser roughening with FF carborundum (0·001 in. grains) reduced the maximum lift coefficient to 1·15, a reduction of 20 per cent. on that of the aerofoil with the usual finish. A comparison of this diagram with that for R.A.F. 34 (Fig. 10) shows that the rate of increase of $C_{L\,max.}$ at the lower values of R is much greater for the symmetrical aerofoil N.A.C.A. 0012 than it is for ordinary aerofoils of the same thickness ratio. The aerofoils previously tested do not reach a value of 1·4 for $C_{L\,max.}$ until R gets to a value of 4×10^6 or higher, whereas the N.A.C.A. 0012 attains that value at $R = 2 \times 10^6$.

Fig. 10 gives the maximum lift curves for the aerofoil R.A.F. 34. Roughening the surface of this aerofoil with FF carborundum has a much greater effect on $C_{L\,max.}$ than it had on N.A.C.A. 0012. The curve for the roughened aerofoil leaves



Hand finished aerofoil and aerofoil coated with carborundum powder.

FIG. 10.—Maximum Lift on R.A.F. 34. 8 in. Chord.

that for the hand finished one at about $R = 1 \times 10^6$, as it did for N.A.C.A. 0012, but the lift coefficient there is considerably lower than for the symmetrical aerofoil. The maximum lift falls from 1·40 to 1·04 when the surface is roughened, a loss of 26 per cent. in $C_{L\,max.}$

The effect of roughening the back-half of the wing makes no appreciable difference to the maximum lift up to $R = 7 \times 10^6$, though there is an indication that the maximum lift may be beginning to fall off at the highest values of R.

As one aerofoil was of steel and the other of aluminium, it may be that the surfaces of the two aerofoils hand finished are not the same, though the fact that the minimum drag curves are very similar indicates that they are of the same order of smoothness aerodynamically.

7. *Effect of surface roughness on minimum drag.*—The results of the tests on minimum drag are given in Tables 10–16 and they are plotted against Reynolds number in Figs. 11 and 12 for N.A.C.A. 0012 and R.A.F. 34 respectively. The diagrams also include the minimum values of C_D from the sets taken over the full range of incidence, taken from Tables 3–9. In order to determine the curves as

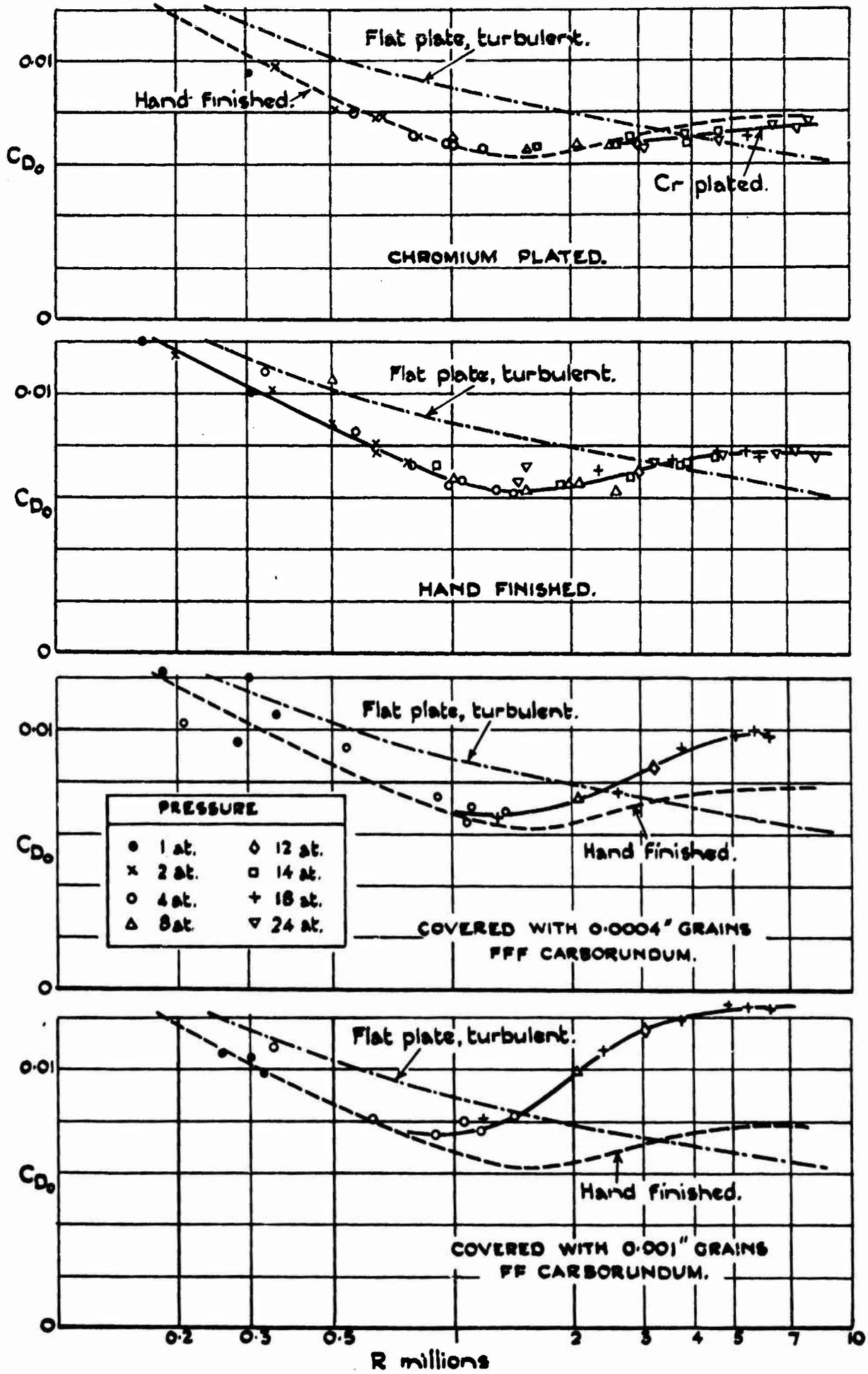


FIG. 11.—Minimum Drag of N.A.C.A. 0012 with Various Degrees of Surface Roughness. Aspect Ratio 6. Chord 8 in.

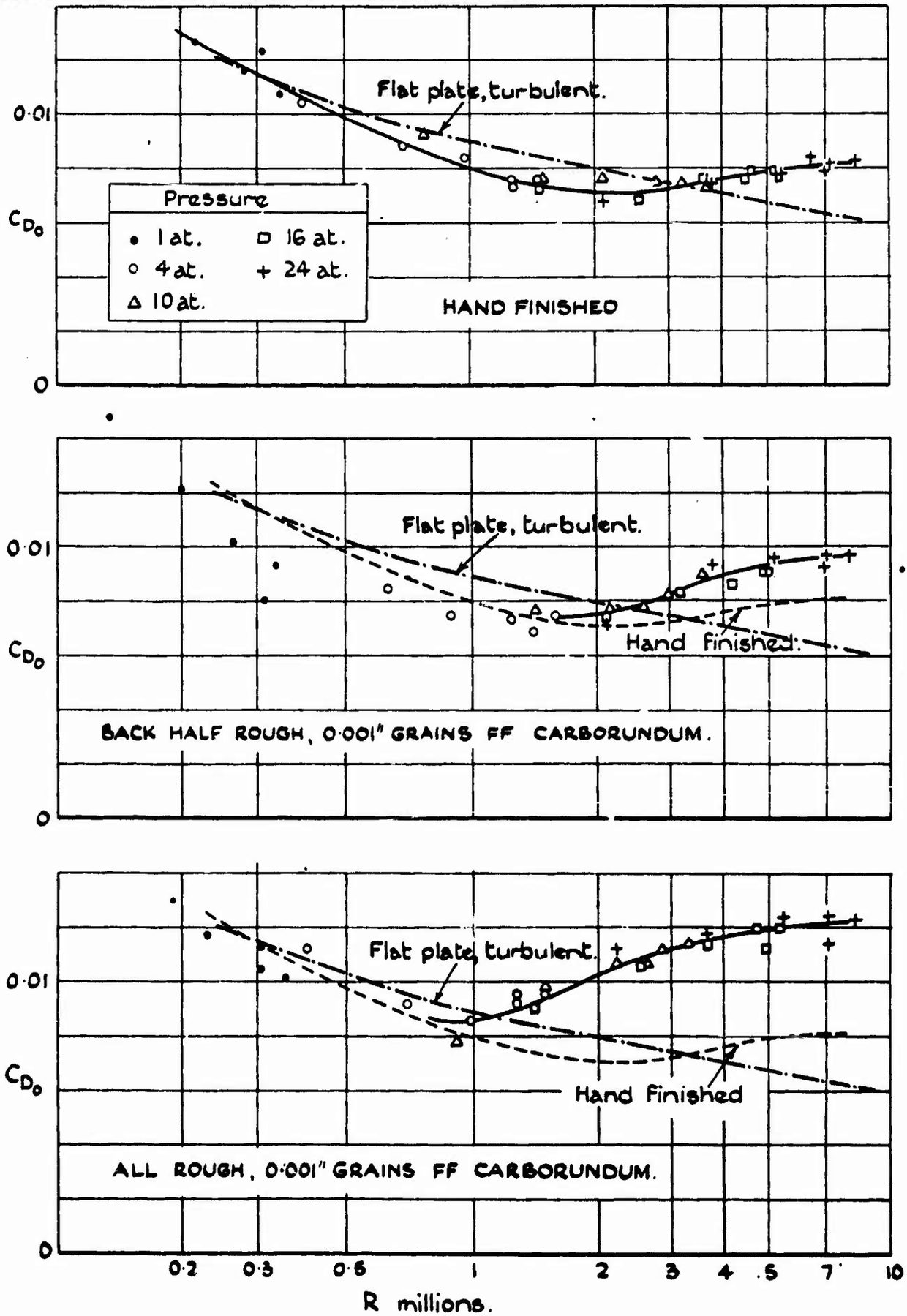


FIG. 12.—Minimum Drag of R.A.F. 34. Aspect Ratio 6. Chord 8 in. Aerofoil Hand Finished and Coated with Carborundum (FF) Powder. 0·001 in. Grains.

fully as possible, readings were taken at a number of wind speeds for each tunnel pressure so that there would be an overlapping of points. The system of points chosen in the diagrams has one type of point for each tunnel pressure and in general, at any pressure, more weight has been attached to points taken at high wind speeds than to those taken at low speeds.

Minimum drag and minimum profile drag agree on the symmetrical aerofoil but not on R.A.F. 34. In the latter case, it is minimum drag and not minimum profile drag that is plotted in the figures, as the observations at numerous Reynolds numbers were taken in the neighbourhood of minimum drag and did not cover a large enough range necessarily to include minimum profile drag.

In each diagram, the curve for the hand finished aerofoil has been included as a standard and the curve for turbulent skin friction of a smooth plate has been drawn in.

For the N.A.C.A. 0012 aerofoil it is seen that roughening, to the extent tried, has no effect on the minimum drag up to a Reynolds number of 1×10^6, but after that the curves for the roughened aerofoils break away from that for the hand finished aerofoil and the Reynolds number, at which the divergence occurs, becomes less as the roughness increases. After the divergence the minimum drag increases rapidly with Reynolds number up to a constant value, the greater the roughening the greater the rise in $C_{D\,min.}$ at high Reynolds numbers. These results agree with the predictions of Prandtl and Schlichting[2] as to the point of the divergence and with Fage's[9] calculations of the amount of the increase. The increase at the highest Reynolds number is about 26 per cent. for the FFF roughening (0·0004 in. grains) and 59 per cent. for the coarser roughening FF (0·001 in. grains). Fage's predictions for the increases at $R = 9 \cdot 4 \times 10^6$ for these roughnesses are 28 per cent. and 64 per cent. respectively.

The curves for R.A.F. 34, shown in Fig. 12, give similar results. The divergence for the coarse roughening occurs at the same value of R as it did for the symmetrical aerofoil and the increase is of the same order (53 per cent.). Roughening only the back-half of the aerofoil causes the divergence to happen at a higher Reynolds number and causes considerably less than half the increase in minimum drag, as would be expected, since the boundary layer thickness would be larger by the time it reached the roughened part of the aerofoil.

The curve for the turbulent skin friction of a smooth flat plate has been added to show that the flattening of the curve for the hand finished aerofoil is not, as might be supposed, due to insufficient smoothness about $R = 1 \times 10^6$, but to the fact that the drag results lie on a transition curve. As this curve is above the turbulent skin friction curve at high values of R, the aerofoil may not have been aerodynamically " smooth " for those values. This is borne out to some extent by the curve for the chromium plated aerofoil, where the minimum drag has been reduced 5 per cent.

8. *Profile drag.*—The curves for profile drag of the aerofoil N.A.C.A. 0012 at lift coefficients of 0, 0·2, 0·4, 0·6, 0·8 are plotted against Reynolds number in Fig. 13, and those for R.A.F. 34 in Fig. 14. The full heavy lines are the curves for the aerofoil with hand finished surface. The forms of the curves are different for the two aerofoils except for low values of C_L.

The values of the profile drag for the rougher surface conditions are also shown. For the symmetrical aerofoil, they were only found at three Reynolds numbers, about 0·3, 1·0 and 5·5 millions. These values are shown in Fig. 13 by points joined up by thin lines for roughening with FFF carborundum and by heavy chain-dotted lines for FF carborundum. The exact form of this curve is unknown between $R = 1 \times 10^6$ and $R = 5{\cdot}5 \times 10^6$. It is probable, however, that the curves drawn are fairly correct, as they agree with those in Fig. 14 for R.A.F. 34 for which a sufficient number of observations was taken to establish the form of the curves.

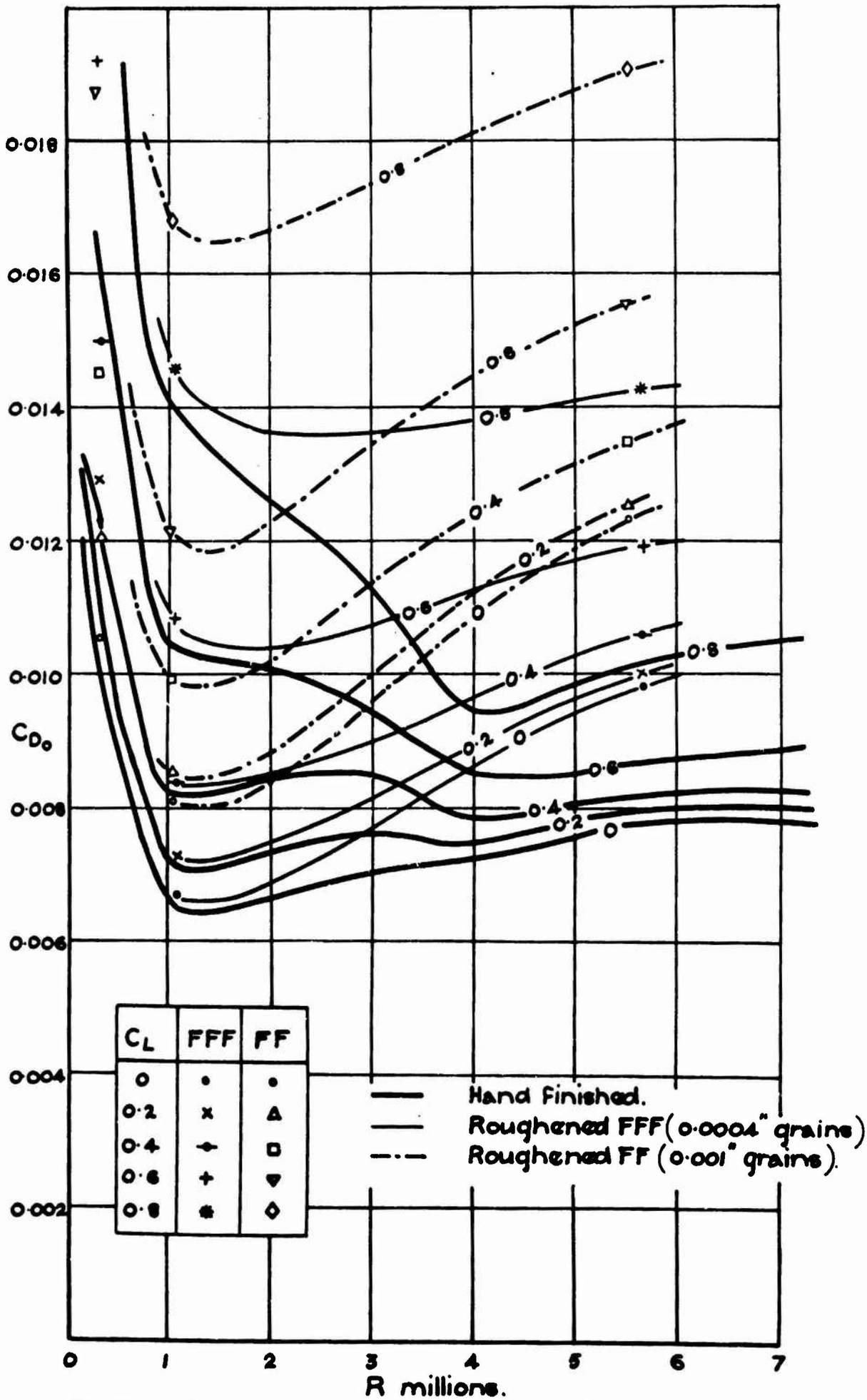
Curves for the chromium plated aerofoil have not been included, as they would lie close to those for the hand finished aerofoil.

9. *Conclusion.*—From a practical point of view, the degrees of roughness used on the model are perhaps rather great, as they correspond to distributed excrescences of 0·01 in. and 0·004 in. on an actual wing of moderate chord. But, as mentioned above, the main object of the experiments was to test the validity of the application of the deductions from the pipe work to an aerofoil. The result of most practical utility is that the Reynolds number, at which divergence from the smooth drag curves occurs, agrees fairly closely with the pipe predictions, and therefore that these can be used to establish a measure of maximum roughness which will not affect the drag at any given Reynolds number. Actual wings and bodies should be made as smooth as this procedure indicates, but there is no necessity to produce a more highly finished surface. The smoothness desirable will be greater with greater speed and also with greater chord. The table below has been compiled from results given by Prandtl[2] in order to provide a guide to the degree of roughness permissible.

Reynolds number in millions.	Thickness of permissible excrescences in millionths of the chord.
1	81·0
2	44·0
5	19·0
10	10·0
20	5·4
50	2·3
100	1·2

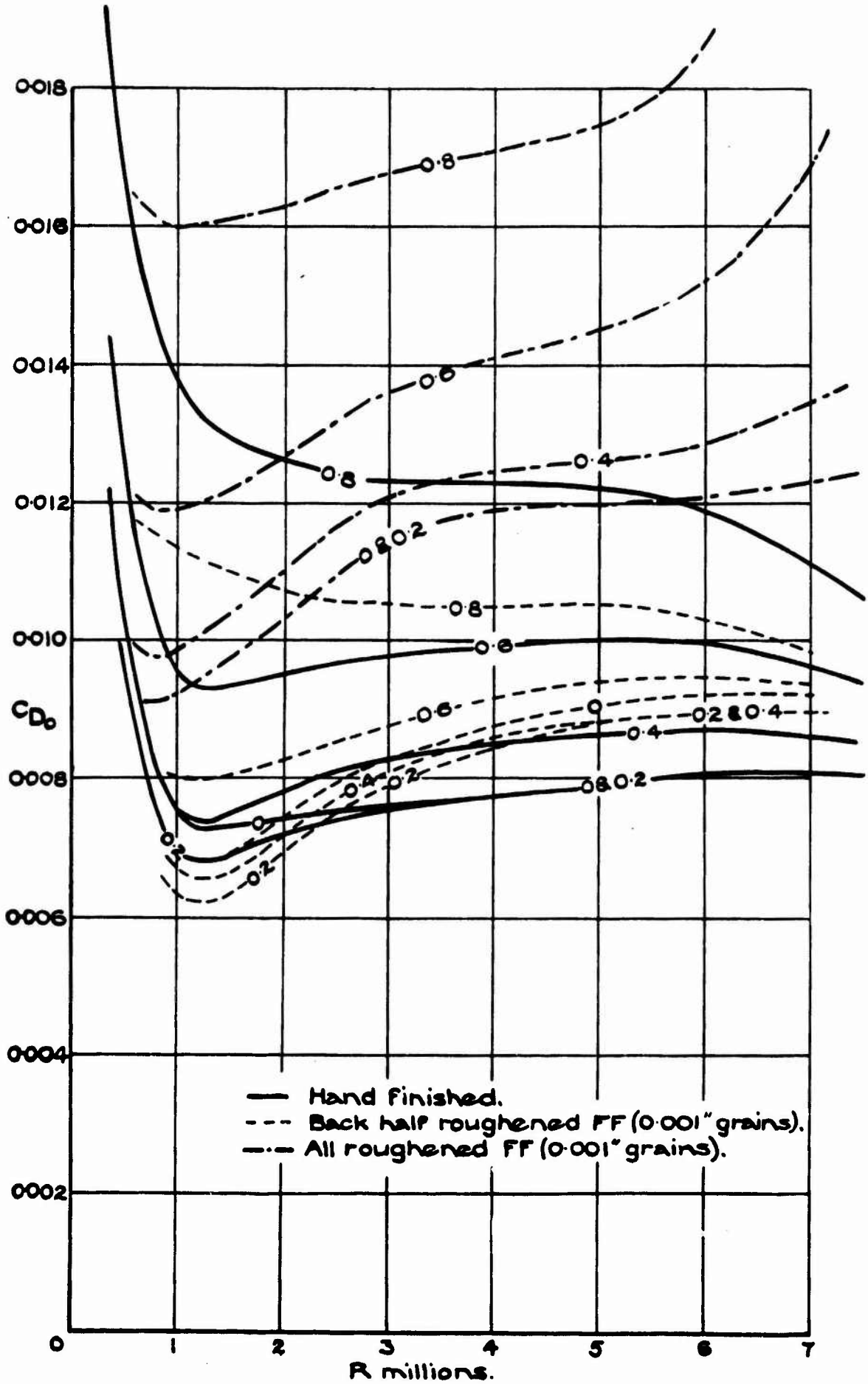
Note.—Near $R = 10^7$, which is the interesting region in practice, a rough rule is

$$\text{Thickness in millionths of chord} = \frac{100}{R \text{ in millions}}$$



Hand finished and roughened with carborundum powder. The numbers on the curves give the values of C_L.

FIG. 13.—Profile Drag of N.A.C.A. 0012 at Various Values of C_L and Reynolds Number.
Aspect Ratio 6. Chord 8 in.



Hand finished and roughened with FF carborundum powder 0·001 in. grains.
The numbers on the curves give the value of C_L.

FIG. 14.—Profile Drag of R.A.F. 34 at Various Values of C_L and Reynolds Number.
Aspect Ratio 6. Chord 8 in.

It must be remembered that this applies to a distributed roughness such as is produced by closely spaced irregular particles like sand or carborundum grains. It does not follow that more rounded irregularities such as are produced by the threads of a fabric will produce the same results for the same variation of height, nor can the results be applied to widely spaced irregularities such as rivet heads; the determination of such effects would have to be tested separately.

The effect of surface roughness is also important on maximum lift, but only on the front part of the surface. If the roughness is aft of the breakaway point, its effect will not be marked. The exact proportion of the upper surface for which extreme smoothness of the wing is important will have to be determined by further experiment.

The experiments have established that surface roughness has no effect on minimum drag or maximum lift for Reynolds numbers up to a value depending on the degree of roughness. Above that value, surface roughness increases the drag and decreases the maximum lift of an aerofoil to an extent which increases as the roughness increases.

The authors wish to express their indebtedness to Messrs. A. H. Bell, A. F. Brown and E. Smyth, who took their full share in all the work described in this report.

REFERENCES

No.	*Author.*	*Title.*
1	Nikuradse	Laws of flow in rough tubes. V.D.I.—Forschungsheft 361. 1933.
2	Prandtl and Schlichting ..	The resistance law of rough plates. Werft Reederei Hafen. January, 1934.
3	Schrenk	On the measurement of profile drag in flight by the method of momentum. Luftfahrtforschung. March 18, 1928. 102nd D.V.L. Report.
4	Ebert	Measurements in flight for the determination of the effect of surface roughness. Z.F.M. October 14, 1933. 343rd D.V.L. Report.
5	Relf, Jones and Bell	Tests on six aerofoil sections at various Reynolds numbers in the Compressed Air Tunnel. R. & M. 1706. April, 1936.
6	Relf and Jones	Tests on a roughened aerofoil in the Compressed Air Tunnel. 1815 (T.3663). May, 1935. (Unpublished.)
7	Jacobs, Ward and Pinkerton ..	The characteristics of 78 related airfoil sections from tests in the Variable Density Tunnel. T.R. No. 460, N.A.C.A. 1933.
8	Davies	Wind tunnel test of aerofoil R.A.F. 34. R. & M. 1071. October, 1926.
9	Fage	Effect of surface roughness on profile drag. 1662 (Ae. Techl. 907). February, 1935. (Unpublished.)

TABLES

1. Dimensions of aerofoil N.A.C.A. 0012 (§ 2).
2. Dimensions of aerofoil R.A.F. 34 (§ 2).
3. N.A.C.A. 0012, hand finished surface.
4. N.A.C.A. 0012, roughened FFF carborundum.
5. N.A.C.A. 0012, roughened FF carborundum.
6. N.A.C.A. 0012, chromium plated.
7. R.A.F. 34, hand finished surface.
8. R.A.F. 34, back-half roughened FF carborundum.
9. R.A.F. 34, all roughened FF carborundum.
10. Minimum drag, N.A.C.A. 0012, hand finished.
11. Minimum drag, N.A.C.A. 0012, roughened FFF.
12. Minimum drag, N.A.C.A. 0012, roughened FF.
13. Minimum drag, N.A.C.A. 0012, chromium plated.
14. Minimum drag, R.A.F. 34, hand finished.
15. Minimum drag, R.A.F. 34, back-half roughened FF.
16. Minimum drag, R.A.F. 34, all roughened FF.

TABLE 3

N.A.C.A. 0012, *hand finished surface*

$R = 0{\cdot}164 \times 10^6$. $P = 1$ atmos. $\varrho V^2 = 4{\cdot}30$. $V = 42{\cdot}9$ f./s.

α°	C_L	C_D	C_m	C.P.
−3·1	−0·228	0·0166	−0·0038	0·233
−2·1	−0·138	0·0142	−0·0060	0·207
−1·0	−0·060	0·0126	−0·0030	0·200
0	+0·010	0·0120	+0·0014	0·110
+1·0	0·080	0·0126	0·0054	0·183
2·0	0·156	0·0144	0·0064	0·209
$4{\cdot}0_5$	0·334	0·0194	0·0008	0·248
6·1	0·494	0·0278	−0·0002	0·250
$8{\cdot}2_5$	0·606	0·0414	+0·0036	0·244
$10{\cdot}2_5$	0·724	0·0572	0·0126	0·233
11·3	0·770	0·0660	0·0156	0·230
12·3	0·812	0·0764	+0·0198	0·226
13·5	0·618	0·152	−0·0372	0·307
15·6	0·584	0·198	−0·0592	0·346
17·7	0·582	0·224	−0·0622	0·350
$19{\cdot}8_5$	0·574	0·254	−0·0662	0·356
$22{\cdot}0_5$	0·574	0·306	−0·0612	0·360
$25{\cdot}2_5$	0·594	0·346	−0·0768	0·362
$28{\cdot}4_5$	0·644	0·410	−0·0944	0·374

$R = 0{\cdot}312 \times 10^6$. $P = 1$ atmos. $\varrho V^2 = 13{\cdot}35$. $V = 75{\cdot}5$ f./s.

α°	C_L	C_D	C_m	C.P.
−3·1	−0·212	0·0132	−0·0080	0·212
−2·1	−0·136	0·0114	−0·0054	0·211
−1·0	−0·064	0·0102	−0·0022	0·216
0	+0·004	0·0100	+0·0004	0·150
+1·0	0·076	0·0102	0·0030	0·211
$2{\cdot}0_5$	0·148	0·0118	0·0060	0·210
$4{\cdot}1_5$	0·298	0·0170	0·0090	0·219
6·2	0·468	0·0250	0·0048	0·240
$8{\cdot}2_5$	0·608	0·0378	0·0046	0·243
10·3	0·718	0·0514	0·0122	0·233
12·3	0·824	0·0660	0·0214	0·224
13·3	0·856	0·0756	+0·0236	0·223
13·4	0·744	0·146	−0·0310	0·291
14·5	0·656	$0{\cdot}181_5$	−0·0522	0·326
15·6	0·606	0·204	−0·0620	0·347
17·7	0·582	0·230	−0·0678	0·359
$19{\cdot}8_5$	0·574	0·260	−0·0710	0·363
$22{\cdot}0_5$	0·576	0·290	−0·0748	0·366
$25{\cdot}2_5$	0·592	0·344	−0·0816	0·369
$28{\cdot}4_5$	0·650	0·414	−0·0982	0·378

TABLE 3 (*contd.*)

N.A.C.A. 0012, *hand finished surface*

$R = 0{\cdot}63 \times 10^6$. $P = 2{\cdot}15$ atmos. $\varrho V^2 = 26{\cdot}8_5$. $V = 73{\cdot}7$ f./s.

α°	C_L	C_D	C_m	C.P.
−1·0	−0·070	0·0084	−0·0026	0·287
0	+0·004	0·0080	−0·0006	0·400
+1·0	0·080	0·0086	+0·0012	0·235
$2{\cdot}0_5$	0·152	0·0100	0·0034	0·228
4·1	0·292	0·0142	0·0074	0·225
6·2	0·442	0·0218	0·0102	0·227
$8{\cdot}2_5$	0·594	0·0330	0·0096	0·234
10·3	0·732	0·0468	0·0120	0·234
12·3	0·850	0·0614	0·0168	0·230
$13{\cdot}3_5$	0·906	0·0694	0·0184	0·230
$14{\cdot}3_5$	0·950	0·0782	0·0210	0·228
14·4	0·880	$0{\cdot}137_5$	−0·0272	0·281
15·4	0·982	0·0892	+0·0196	0·230
15·5	0·746	0·188	−0·0558	0·323
16·6	0·822	$0{\cdot}159_5$	−0·0232	0·278
16·6	0·706	0·206	−0·0638	0·335
$17{\cdot}6_5$	0·680	0·226	−0·0654	0·342
19·8	0·658	0·270	−0·0738	0·354
$22{\cdot}0_5$	0·620	0·300	−0·0750	0·360
$25{\cdot}2_5$	0·618	0·348	−0·0824	0·366
$28{\cdot}4_5$	0·660	0·416	−0·0956	0·373

$R = 0{\cdot}98 \times 10^6$. $P = 3{\cdot}58$ atmos. $\varrho V^2 = 38{\cdot}7$. $V = 68{\cdot}7$ f. s.

α°	C_L	C_D	C_m	C.P.
−1·0	−0·072	0·0070	−0·0016	0·228
0	+0·002	0·0064	0	0·250
+1·0	0·078	0·0072	+0·0016	0·230
$2{\cdot}0_5$	0·150	0·0086	0·0032	0·229
4·1	0·296	0·0128	0·0070	0·226
6·2	0·450	0·0200	0·0098	0·228
$8{\cdot}2_5$	0·596	0·0306	0·0118	0·230
10·3	0·740	0·0438	0·0134	0·232
12·3	0·876	0·0588	0·0158	0·232
$14{\cdot}3_5$	0·998	0·0768	0·0186	0·231
15·4	1·054	0·0870	0·0196	0·231
15·4	—	0·122	−0·0116	—
16·4	1·102	0·0970	+0·0200	0·232
$16{\cdot}4_5$	0·928	0·139	−0·0126	0·264
$17{\cdot}4_5$	1·042	0·132	−0·0070	0·257
17·5	0·974	0·165	−0·0130	0·268
$18{\cdot}5_5$	0·994	0·169	−0·0166	0·267
18·6	0·912	0·200	−0·0550	0·309
$20{\cdot}8_5$	0·754	0·281	−0·0786	0·348
$23{\cdot}0_5$	0·702	0·322	−0·0808	0·355
$25{\cdot}2_5$	0·624	0·350	−0·0870	0·369
$28{\cdot}4_5$	0·676	0·424	−0·101	0·377

TABLE 3 (*contd.*)

N.A.C.A. 0012, *hand finished surface*

$R = 1 \cdot 47 \times 10^6$. $P = 22 \cdot 8_5$ atmos. $\varrho V^2 = 14 \cdot 81$. $V = 17 \cdot 11$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
0	0·002	0·0066	—0·0002	0·350
1·0	0·074	0·0082	+0·0010	0·237
2·0	0·148	0·0094	0·0026	0·232
4·1	0·294	0·0128	0·0068	0·227
$6 \cdot 1_5$	0·434	0·0198	0·0094	0·228
8·2	0·582	0·0304	0·0116	0·230
10·3	0·728	0·0424	0·0142	0·230
12·2	0·864	0·0570	0·0160	0·231
14·3	1·012	0·0764	0·0178	0·232
16·3	1·132	0·0934	0·0186	0·233
$18 \cdot 3_5$	1·246	0·111	+0·0206	0·233
18·5	0·924	0·204	—0·0512	0·305
19·6	1·056	$0 \cdot 173_5$	—0·0312	0·280
$19 \cdot 7_5$	0·844	0·223	—0·0556	0·314
20·8	0·958	0·203	—0·0450	0·297
20·9	0·830	0·259	—0·0694	0·330
23·0	0·828	0·288	—0·0839	0·348
$25 \cdot 1_5$	0·750	0·343	—0·0798	0·347
25·2	0·684	—	—	—
$28 \cdot 4_5$	0·692	0·424	—0·0986	0·371

$R = 1 \cdot 44_5 \times 10^6$. $P = 4 \cdot 81$ atmos. $\varrho V^2 = 64 \cdot 9$. $V = 77 \cdot 3$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
0	—0·008	0·0062	0·0002	0·275
1·0	+0·070	0·0070	0·0018	0·224
2·0	0·146	0·0080	0·0034	0·227
$4 \cdot 1_5$	0·296	0·0124	0·0068	0·227
6·2	0·444	0·0200	0·0092	0·229
8·3	0·594	0·0304	0·0118	0·230
10·4	0·740	0·0430	0·0138	0·231
12·3	0·884	0·0592	0·0156	0·232
14·4	1·020	0·0770	0·0172	0·233
16·4	1·150	0·0970	0·0192	0·233
18·5	1·246	0·120	+0·0192	0·234
$18 \cdot 6_5$	0·888	$0 \cdot 180_5$	—0·0194	0·272
19·7	1·074	0·178	—0·0246	0·273
$19 \cdot 7_5$	0·930	0·231	—0·0574	0·310
20·9	0·916	0·246	—0·0656	0·320
$23 \cdot 0_5$	0·776	0·326	—0·0900	0·357
25·2	0·732	0·356	—0·0860	0·355
$28 \cdot 4_5$	0·660	0·416	—0·0988	0·377

TABLE 3 (*contd.*)

N.A.C.A. 0012, *hand finished surface*

$R = 1 \cdot 99 \times 10^6$. $P = 7 \cdot 75$ atmos. $\rho V^2 = 73 \cdot 7$. $V = 64 \cdot 4$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
−1·0	−0·078	0·0070	−0·0014	0·233
0	−0·004	0·0066	+0·0002	0·200
+1·0	+0·076	0·0072	0·0016	0·229
$1 \cdot 9_5$	0·152	0·0086	0·0030	0·230
$4 \cdot 1_5$	0·306	0·0132	0·0058	0·231
6·2	0·460	0·0208	0·0082	0·232
$8 \cdot 3_5$	0·608	0·0310	0·0100	0·234
$10 \cdot 3_5$	0·758	0·0444	0·0118	0·234
12·4	0·914	0·0598	0·0134	0·235
14·5	1·054	0·0786	0·0156	0·235
$16 \cdot 4_5$	1·194	0·0992	0·0156	0·237
$17 \cdot 4_5$	1·258	$0 \cdot 110_5$	0·0156	0·237
$18 \cdot 4_5$	1·314	0·122	0·0168	0·237
$19 \cdot 5_5$	1·358	0·134	0·0164	0·238
19·6	1·156	0·186	−0·0336	0·279
$20 \cdot 7_5$	1·038	0·220	−0·0506	0·298
$23 \cdot 0_5$	0·962	0·268	−0·0692	0·320
25·1	0·852	0·328	−0·0822	0·339
28·4	0·756	0·432	−0·104	0·370

$R = 3 \cdot 02 \times 10^6$. $P = 11 \cdot 53$ atmos. $\rho V^2 = 120 \cdot 2$. $V = 68 \cdot 2$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
0	0·002	0·0070	−0·0002	0·350
1·0	0·082	0·0074	+0·0012	0·235
$2 \cdot 0_5$	0·156	0·0090	0·0026	0·233
4·2	0·308	0·0136	0·0050	0·234
$6 \cdot 2_5$	0·462	0·0210	0·0078	0·233
$8 \cdot 3_5$	0·614	0·0310	0·0096	0·234
$10 \cdot 4_5$	0·764	0·0442	0·0108	0·236
12·4	0·916	0·0600	0·0118	0·237
14·5	1·058	0·0784	0·0122	0·238
$16 \cdot 5_5$	1·198	0·0994	0·0130	0·239
$17 \cdot 5_5$	1·254	0·110	0·0136	0·239
18·6	1·314	0·122	0·0142	0·239
19·7	1·366	0·135	0·0146	0·239
$19 \cdot 7_5$	1·130	0·196	−0·0368	0·282
20·8	1·030	0·228	−0·0500	0·298
23·0	0·942	0·282	−0·0722	0·324
25·2	0·794	0·320	−0·0816	0·346
$28 \cdot 4_5$	0·738	0·388	−0·0936	0·362

TABLE 3 (*contd.*)

N.A.C.A. 0012, *hand finished surface*

$R = 3{\cdot}94 \times 10^6$. $P = 14{\cdot}45$ atmos. $\rho V^2 = 162{\cdot}2$. $V = 70{\cdot}7$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}076$	$0{\cdot}0076$	$-0{\cdot}0016$	$0{\cdot}229$
0	0	$0{\cdot}0072$	$-0{\cdot}0002$	—
$+1{\cdot}0_5$	$+0{\cdot}080$	$0{\cdot}0076$	$+0{\cdot}0014$	$0{\cdot}233$
$2{\cdot}1$	$0{\cdot}156$	$0{\cdot}0086$	$0{\cdot}0030$	$0{\cdot}231$
$4{\cdot}2$	$0{\cdot}312$	$0{\cdot}0132$	$0{\cdot}0056$	$0{\cdot}232$
$6{\cdot}3$	$0{\cdot}468$	$0{\cdot}0206$	$0{\cdot}0080$	$0{\cdot}233$
$8{\cdot}3_5$	$0{\cdot}628$	$0{\cdot}0310$	$0{\cdot}0098$	$0{\cdot}234$
$10{\cdot}4_5$	$0{\cdot}776$	$0{\cdot}0444$	$0{\cdot}0108$	$0{\cdot}236$
$12{\cdot}5$	$0{\cdot}932$	$0{\cdot}0598$	$0{\cdot}0116$	$0{\cdot}237$
$14{\cdot}5_5$	$1{\cdot}082$	$0{\cdot}0790$	$0{\cdot}0122$	$0{\cdot}239$
$16{\cdot}6$	$1{\cdot}220$	$0{\cdot}100$	$0{\cdot}0130$	$0{\cdot}239$
$18{\cdot}7$ }	$1{\cdot}344$	$0{\cdot}125$	$0{\cdot}0132$	$0{\cdot}240$
$18{\cdot}6_5$ }	—	$0{\cdot}164$	—	—
$19{\cdot}7_5$ }	$1{\cdot}396$	$0{\cdot}137_5$	$+0{\cdot}0120$	$0{\cdot}241$
$19{\cdot}8$ }	$1{\cdot}064$	$0{\cdot}216$	$-0{\cdot}0500$	$0{\cdot}297$
$20{\cdot}9_5$	$1{\cdot}010$	$0{\cdot}244$	$-0{\cdot}0616$	$0{\cdot}310$
$23{\cdot}1$	$0{\cdot}904$	$0{\cdot}288$	$-0{\cdot}0718$	$0{\cdot}326$
$25{\cdot}2_5$	$0{\cdot}764$	$0{\cdot}326$	$-0{\cdot}0836$	$0{\cdot}351$
$28{\cdot}4_5$	$0{\cdot}720$	$0{\cdot}382$	$-0{\cdot}0988$	$0{\cdot}371$

$R = 5{\cdot}52 \times 10^6$. $P = 18{\cdot}4$ atmos. $\rho V^2 = 256{\cdot}0$. $V = 79{\cdot}2$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
0	0	$0{\cdot}0078$	$-0{\cdot}0004$	—
$1{\cdot}0_5$	$0{\cdot}078$	$0{\cdot}0080$	$0{\cdot}0010$	$0{\cdot}237$
$2{\cdot}0_5$	$0{\cdot}158$	$0{\cdot}0094$	$0{\cdot}0022$	$0{\cdot}236$
$4{\cdot}2_5$	$0{\cdot}320$	$0{\cdot}0140$	$0{\cdot}0050$	$0{\cdot}234$
$6{\cdot}3_5$	$0{\cdot}478$	$0{\cdot}0214$	$0{\cdot}0074$	$0{\cdot}235$
$8{\cdot}5$	$0{\cdot}638$	$0{\cdot}0316$	$0{\cdot}0088$	$0{\cdot}236$
$10{\cdot}6_5$	$0{\cdot}794$	$0{\cdot}0454$	$0{\cdot}0100$	$0{\cdot}237$
$12{\cdot}6_5$	$0{\cdot}948$	$0{\cdot}0626$	$0{\cdot}0104$	$0{\cdot}239$
$14{\cdot}7_5$	$1{\cdot}094$	$0{\cdot}0816$	$0{\cdot}0110$	$0{\cdot}240$
$16{\cdot}8_5$	$1{\cdot}240$	$0{\cdot}104$	$0{\cdot}0110$	$0{\cdot}241$
$18{\cdot}9_5$ }	$1{\cdot}356$ }	$0{\cdot}127_5$ }	$0{\cdot}0124$ }	$0{\cdot}241$ }
$18{\cdot}8_5$ }	$1{\cdot}152$ }	$0{\cdot}181$ }	$-0{\cdot}0290$ }	$0{\cdot}275$ }
$20{\cdot}2$ }	—	$0{\cdot}142$ }	—	—
$20{\cdot}0$ }	$1{\cdot}046$	$0{\cdot}227$ }	$-0{\cdot}0562$	$0{\cdot}303$
$21{\cdot}1$	$0{\cdot}976$	$0{\cdot}251$	$-0{\cdot}0616$	$0{\cdot}312$
$23{\cdot}1_5$	$0{\cdot}840$	$0{\cdot}296$	$-0{\cdot}0760$	$0{\cdot}336$
$25{\cdot}3$	$0{\cdot}736$	$0{\cdot}330$	$-0{\cdot}0854$	$0{\cdot}356$
$28{\cdot}5$	$0{\cdot}712$	$0{\cdot}388$	$-0{\cdot}0952$	$0{\cdot}368$

TABLE 3 (*contd.*)

N.A.C.A. 0012, *hand finished surface*

$R = 7 \cdot 20 \times 10^6$. $P = 24 \cdot 1$ atmos. $\varrho V^2 = 338 \cdot 0$. $V = 79 \cdot 6$ f./s.

α°	C_L	C_D	C_m	C.P.
0	−0·004	0·0078	−0·0004	0·150
$1 \cdot 0_5$	+0·078	0·0082	+0·0010	0·237
2·1	0·158	0·0094	0·0024	0·235
4·3	0·324	0·0140	0·0052	0·234
$6 \cdot 4_5$	0·486	0·0218	0·0074	0·234
8·6	0·646	0·0328	0·0088	0·236
10·8	0·802	0·0472	0·0096	0·238
12·8	0·962	0·0640	0·0100	0·239
$14 \cdot 9_5$	1·114	0·0844	0·0106	0·240
$17 \cdot 0_5$	1·254	$0 \cdot 107_5$	0·0112	0·241
$19 \cdot 1_5$	1·374	0·128	+0·0114	0·242
$18 \cdot 9_5$	1·112	0·204	−0·0490	0·294
20·3	1·424	0·159	+0·0132	0·240
$20 \cdot 0_5$	0·982	0·234	−0·0580	0·307
$21 \cdot 0_5$	0·910	0·256	−0·0634	0·317
$23 \cdot 2_5$	0·772	0·298	−0·0792	0·346
25·3	0·710	0·334	−0·0886	0·363
28·5	0·712	0·394	−0·100	0·374

TABLE 4

N.A.C.A. 0012, *roughened FFF carborundum* (0·0004 in. *grains*)

$R = 0{\cdot}319 \times 10^6$. $P = 1$ atmos. $\varrho V^2 = 13{\cdot}34$. $V = 74{\cdot}9$ f./s.

α°	C_L	C_D	C_m	C.P.
−0·4	−0·036	0·0120	−0·0008	0·228
+0·6	+0·034	0·0128	0	0·250
$1{\cdot}6_5$	0·108	0·0138	+0·0032	0·221
$3{\cdot}6_5$	0·252	0·0170	0·0086	0·216
5·8	0·416	0·0250	0·0062	0·235
$8{\cdot}8_5$	0·636	0·0428	0·0048	0·342
11·9	0·792	0·0618	0·0178	0·227
12·9	0·834	0·0694	+0·0216	0·224
$12{\cdot}9_5$	0·778	0·0948	−0·0086	0·261
14·0	0·698	0·164	−0·0570	0·330
15·1	0·662	0·190	−0·0600	0·337
17·3	0·590	0·218	−0·0682	0·359
19·4	0·574	0·252	−0·0724	0·365
22·6	0·576	0·300	−0·0782	0·371
$25{\cdot}7_5$	0·602	0·350	−0·0862	0·354
$28{\cdot}9_5$	0·658	0·420	−0·0988	0·377

$R = 1{\cdot}06_5 \times 10^6$. $P = 4{\cdot}03$ atmos. $\varrho V^2 = 38{\cdot}67$. $V = 64{\cdot}1$ f./s.

α°	C_L	C_D	C_m	C.P.
$-0{\cdot}3_5$	−0·046	0·0068	−0·0006	0·237
+0·6	+0·036	0·0066	+0·0012	0·217
2·7	0·184	0·0092	0·0046	0·225
$4{\cdot}7_5$	0·336	0·0144	0·0080	0·226
7·8	0·564	0·0278	0·0114	0·230
10·9	0·770	0·0480	0·0146	0·231
12·9	0·906	0·0634	0·0168	0·231
$14{\cdot}9_5$	1·030	0·0814	0·0190	0·231
$15{\cdot}9_5$	1·094	0·0920	+0·0190	0·232
16·0	0·958	$0{\cdot}138_5$	−0·0120	0·263
17·0	1·128	0·102	+0·0182	0·234
$17{\cdot}0_5$	1·030	0·183	−0·0190	0·268
$18{\cdot}1_5$	0·960	0·139	−0·0096	0·260
$18{\cdot}1_5$	0·842	0·214	−0·0608	0·320
19·2	1·010	0·181	−0·0046	0·255
19·3	0·788	0·236	−0·0614	0·325
21·4	0·784	0·278	−0·0806	0·347
$24{\cdot}6_5$	0·678	0·344	−0·0832	0·360
$28{\cdot}9_5$	0·674	0·442	−0·103	0·377

TABLE 4 (*contd*)

N.A.C.A. 0012, *roughened FFF carborundum* (0·0004 in. *grains*)

$R = 2{\cdot}08 \times 10^6$. $P = 8{\cdot}38$ atmos. $\varrho V^2 = 73{\cdot}7$. $V = 62{\cdot}0$ f./s.

α°	C_L
$13{\cdot}9_5$	0·998
15·0	1·054
16·0	1·124
17·1	1·178
$17{\cdot}5_5$	1·198
17·6	1·104
18·1	1·090

$R = 3{\cdot}18 \times 10^6$. $P = 11{\cdot}7$ atmos. $\varrho V^2 = 121{\cdot}4$. $V = 67{\cdot}3$ f./s.

α°	C_L
$14{\cdot}0_5$	0·988
15·1	1·046
16·1	1·106
$16{\cdot}1_5$	0·980
17·2	1·150
$17{\cdot}2_5$	0·910
17·7	1·176
$17{\cdot}7_5$	0·880
$18{\cdot}2_5$	0·862

$R = 5{\cdot}67 \times 10^6$. $P = 18{\cdot}2$ atmos. $\varrho V^2 = 256{\cdot}0$. $V = 78{\cdot}4$ f./s.

α°	C_L	C_D	C_m	C.P.
−0·4	−0·042	0·0100	−0·0002	0·202
$+0{\cdot}6_5$	+0·036	0·0100	+0·0012	0·217
$2{\cdot}7_5$	0·194	0·0124	0·0044	0·227
$4{\cdot}9_5$	0·354	0·0176	0·0063	0·222
$8{\cdot}0_5$	0·586	0·0312	0·0100	0·233
$11{\cdot}2_5$	0·818	0·0520	0·0128	0·234
13·3	0·956	0·0692	0·0136	0·236
$14{\cdot}3_5$	1·026	0·0792	0·0148	0·235
15·4	1·074	0·0894	+0·0154	0·235
15·3	0·904	0·134	−0·0196	0·272
$16{\cdot}4_5$	1·142	0·101	+0·0166	0·235
$16{\cdot}4_5$	0·942	0·177	−0·0460	0·298
$17{\cdot}5_5$	1·188	0·112	+0·0166	0·238
17·4	0·744	0·210	−0·0626	0·331
$18{\cdot}4_5$	0·692	0·226	+0·0632	0·337
19·5	0·664	0·246	−0·0684	0·348
$21{\cdot}5_5$	0·640	0·280	−0·0758	0·359
$24{\cdot}7_5$	0·654	0·338	−0·0858	0·367
$28{\cdot}9_5$	0·700	0·430	−0·101$_5$	0·374

TABLE 5

N.A.C.A. 0012, *roughened FF carborundum* (0·001 in. *grains*)

$R = 0{\cdot}308 \times 10^6$. $P = 1$ atmos. $\varrho V^2 = 13{\cdot}34$. $V = 76{\cdot}2$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}076$	0·0106	$-0{\cdot}0028$	0·210
0	$-0{\cdot}002$	0·0107	0	0·250
$+1{\cdot}0$	$+0{\cdot}068$	0·0108	$+0{\cdot}0028$	0·209
$3{\cdot}0_5$	0·208	0·0146	0·0078	0·213
5·2	0·366	0·0216	0·0066	0·232
8·2	0·596	0·0388	0·0036	0·244
$11{\cdot}3_5$	0·756	0·0576	0·0178	0·226
$12{\cdot}2_5$	0·808			
$13{\cdot}3_5$	0·840	0·0752	$+0{\cdot}0256$	0·219
$13{\cdot}4_5$	0·720	$0{\cdot}142_5$	$-0{\cdot}0270$	0·287
14·5	0·648	0·177	$-0{\cdot}0492$	0·323
15·6	0·612	$0{\cdot}197_5$	$-0{\cdot}0590$	0·342
17·7	0·588	0·226	$-0{\cdot}0652$	0·354
19·9	0·564	0·256	$-0{\cdot}0686$	0·361
22·0	0·602	0·282	$-0{\cdot}0740$	0·361
$25{\cdot}2_5$	0·584	0·338	$-0{\cdot}0804$	0·369
$28{\cdot}4_5$	0·634	0·406	$-0{\cdot}0942$	0·375

$R = 1{\cdot}03 \times 10^6$. $P = 3{\cdot}94$ atmos. $\varrho V^2 = 38{\cdot}67$. $V = 65{\cdot}4$ f. s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}074$	0·0088	$-0{\cdot}0026$	0·285
$-0{\cdot}0_5$	0	0·0080	0	—
$+1{\cdot}0$	$+0{\cdot}074$	0·0086	$+0{\cdot}0014$	0·231
$3{\cdot}1_5$	0·220	0·0114	0·0056	0·225
5·2	0·364	0·0172	0·0090	0·225
8·2	0·586	0·0314	0·0128	0·228
$11{\cdot}3_5$	0·798	0·0528	0·0152	0·230
$13{\cdot}3_5$	0·928	0·0684	0·0186	0·230
$14{\cdot}3_5$	0·986	0·0782	0·0192	0·230
15·4	1·040	0·0878	0·0188	0·232
$16{\cdot}4_5$	1·038	0·110	$+0{\cdot}0102$	0·240
17·5	1·032	0·149	$-0{\cdot}0136$	0·263
19·7	0·914	0·226	$-0{\cdot}0540$	0·306
21·9	0·822	0·282	$-0{\cdot}0748$	0·336
25·2	0·686	0·348	$-0{\cdot}0838$	0·359
28·4	0·702	0·422	$-0{\cdot}0888$	0·369

TABLE 5 (*contd.*)

N.A.C.A. 0012, *roughened FF carborundum* (0·001 in. *grains*)

$R = 2{\cdot}01_5 \times 10^6$. $P = 7{\cdot}91$ atmos.
$\varrho V^2 = 73{\cdot}7$. $V = 63{\cdot}7$ f./s.

$\alpha°$	C_L
14·4	0·998
$15{\cdot}4_5$	1·058
16·5	1·098
16·5	0·898
17·6	0·838

$R = 3{\cdot}11 \times 10^6$. $P = 11{\cdot}58$ atmos.
$\varrho V^2 = 121{\cdot}4$. $V = 67{\cdot}8$ f./s.

$\alpha°$	C_L
13·5	0·942
$14{\cdot}5_5$	0·994
$15{\cdot}5_5$	1·052
15·7	0·812
16·6	1·086
16·7	0·712
17·7	0·648

$R = 5{\cdot}52 \times 10^6$. $P = 18{\cdot}3_5$ atmos. $\varrho V^2 = 256{\cdot}0$. $V = 79{\cdot}2$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
0	−0·006	0·0124	0·0002	0·283
$1{\cdot}0_5$	+0·072	0·0128	0·0020	0·222
$3{\cdot}1_5$	0·228	0·0156	0·0056	0·225
$5{\cdot}3_5$	0·380	0·0216	0·0090	0·226
8·5	0·608	0·0366	0·0132	0·228
$11{\cdot}7_5$	0·828	0·0582	0·0162	0·230
$13{\cdot}7_5$	0·962	0·0754	0·0192	0·230
14·8	1·014	0·0854	+0·0208	0·229
$14{\cdot}7_5$	0·814	0·138	−0·0222	0·277
$15{\cdot}8_5$	1·064	0·0934	+0·0222	0·229
$15{\cdot}7_5$	0·738	0·173	−0·0400	0·303
$16{\cdot}7_5$	0·654	0·203	−0·0576	0·334
17·8	0·622	0·224	−0·0654	0·349
20·0	0·610	0·258	−0·0704	0·356
$22{\cdot}0_5$	0·610	0·290	−0·0812	0·371
25·3	0·632	0·348	−0·0852	0·368
29·5	0·666	0·408	−0·0990	0·377

TABLE 6

N.A.C.A. 0012, *chromium plated*

$R = 0{\cdot}313 \times 10^6$. $P = 1$ atmos. $\rho V^2 = 13{\cdot}35$. $V = 75{\cdot}9$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—3·1	—0·209	0·0125	—0·0088	0·208
—2·1	—0·137	0·0112	—0·0062	0·205
—1·0_5	—0·064	0·0100	—0·0034	0·197
—0·0_5	+0·006	0·0094	—0·0002	0·283
+0·9_5	0·076	0·0100	+0·0028	0·213
2·0	0·149	0·0104	0·0060	0·210
4·0	0·299	0·0152	0·0098	0·217
6·0_5	0·464	0·0244	0·0058	0·237
8·0_5	0·606	0·0344	0·0072	0·239
10·0_5	0·725	0·0490	0·0152	0·229
12·2	0·822	0·0640	0·0224	0·0223
13·2	0·852	0·0922	+0·0256	0·220
13·3	0·716	0·153	—0·0204	0·278
14·4_5	0·651	0·188	—0·0428	0·313
15·5_5	0·608	0·217_5	—0·0482	0·325
17·7	0·578	0·236	—0·0518	0·333
19·8	0·574	0·255	—0·0516	0·332
21·9_5	0·572	0·283	—0·0524	0·333
24·1	0·588	0·314	—0·0524	0·329
27·2_5	0·630	0·380	—0·0558	0·325

$R = 0{\cdot}642 \times 10^6$. $P = 2{\cdot}25$ atmos. $\rho V^2 = 26{\cdot}8$. $V = 71{\cdot}3$ f. s.

$\alpha°$	C_L	C_D	C_m	C.P.
—2·1	—0·145	0·0093	—0·0046	0·218
—1·0_5	—0·071	0·0082	—0·0024	0·216
—0·0_5	+0·001	0·0078	—0·0004	0·650
+0·9_5	0·076	0·0080	+0·0018	0·226
2·0	0·150	0·0088	0·0042	0·222
4·0	0·292	0·0134	0·0086	0·220
6·1	0·437	0·0204	0·0120	0·223
8·1	0·591	0·0322	0·0116	0·230
10·1	0·732	0·0446	0·0148	0·230
12·2	0·856	0·0575	0·0188	0·228
14·3	0·932	0·0793	+0·0180	0·230
14·4_5	0·752	0·161	—0·0308	0·290
15·3_5	0·976	0·0882	+0·0202	0·229
15·5_5	0·646	0·194_5	—0·0448	0·316
16·6	0·608	0·214	—0·0524	0·332
17·7	0·594	0·229	—0·0540	0·335
19·8	0·584	0·260	—0·0546	0·336
23·0	0·590	0·308	—0·0532	0·330
27·2_5	0·638	0·392_5	—0·0564	0·325

TABLE 6 (*contd.*)

N.A.C.A. 0012, *chromium plated*

$R = 0{\cdot}980 \times 10^6$. $P = 3{\cdot}6$ atmos. $\rho V^2 = 38{\cdot}6$. $V = 68{\cdot}0$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}072$	$0{\cdot}0072$	$-0{\cdot}0022$	$0{\cdot}219$
$-0{\cdot}0_5$	$+0{\cdot}002$	$0{\cdot}0068$	$-0{\cdot}0004$	$0{\cdot}450$
$+0{\cdot}9_5$	$0{\cdot}076$	$0{\cdot}0074$	$+0{\cdot}0016$	$0{\cdot}229$
$2{\cdot}0$	$0{\cdot}153$	$0{\cdot}0085$	$0{\cdot}0036$	$0{\cdot}226$
$4{\cdot}0$	$0{\cdot}298$	$0{\cdot}0125$	$0{\cdot}0076$	$0{\cdot}224$
$6{\cdot}0_5$	$0{\cdot}446$	$0{\cdot}0194$	$0{\cdot}0106$	$0{\cdot}226$
$8{\cdot}1$	$0{\cdot}592$	$0{\cdot}0300$	$0{\cdot}0132$	$0{\cdot}228$
$10{\cdot}1$	$0{\cdot}728$	$0{\cdot}0430$	$0{\cdot}0154$	$0{\cdot}229$
$12{\cdot}2_5$	$0{\cdot}864$	$0{\cdot}0580$	$0{\cdot}0172$	$0{\cdot}230$
$14{\cdot}3$	$0{\cdot}984$	$0{\cdot}0766$	$+0{\cdot}0204$	$0{\cdot}229$
$14{\cdot}4$	$0{\cdot}806$	$0{\cdot}116$	$-0{\cdot}0168$	$0{\cdot}271$
$15{\cdot}3_5$	$1{\cdot}032$	$0{\cdot}0808$	$+0{\cdot}0194$	$0{\cdot}231$
$15{\cdot}5$	$0{\cdot}682$	$0{\cdot}186$	$-0{\cdot}0404$	$0{\cdot}307$
$16{\cdot}3_5$	$1{\cdot}066$	$0{\cdot}0952$	$+0{\cdot}0204$	$0{\cdot}230$
$16{\cdot}6_5$	$0{\cdot}634$	$0{\cdot}212$	$-0{\cdot}0492$	$0{\cdot}324$
$16{\cdot}5_5$	$1{\cdot}082$	$0{\cdot}0980$	$+0{\cdot}0188$	$0{\cdot}232$
$17{\cdot}7_5$	$0{\cdot}610$	$0{\cdot}229$	$-0{\cdot}0540$	$0{\cdot}333$
$18{\cdot}8$	$0{\cdot}600$	$0{\cdot}246$	$-0{\cdot}0560$	$0{\cdot}337$
$20{\cdot}8_5$	$0{\cdot}596$	$0{\cdot}278$	$-0{\cdot}0588$	$0{\cdot}340$
$23{\cdot}0$	$0{\cdot}606$	$0{\cdot}307_5$	$-0{\cdot}0560$	$0{\cdot}332$
$27{\cdot}2_5$	$0{\cdot}644$	$0{\cdot}388$	$-0{\cdot}0582$	$0{\cdot}330$

$R = 1{\cdot}39 \times 10^6$. $P = 4{\cdot}35$ atmos. $\rho V^2 = 64{\cdot}8$. $V = 80{\cdot}9$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}078$	$0{\cdot}0072$	$-0{\cdot}0020$	$0{\cdot}224$
$-0{\cdot}0_5$	$+0{\cdot}002$	$0{\cdot}0068$	$-0{\cdot}0002$	$0{\cdot}350$
$+0{\cdot}9_5$	$0{\cdot}075$	$0{\cdot}0072$	$+0{\cdot}0014$	$0{\cdot}231$
$2{\cdot}0$	$0{\cdot}152$	$0{\cdot}0084$	$0{\cdot}0032$	$0{\cdot}229$
$4{\cdot}0_5$	$0{\cdot}302$	$0{\cdot}0128$	$0{\cdot}0068$	$0{\cdot}228$
$6{\cdot}0_5$	$0{\cdot}448$	$0{\cdot}0200$	$0{\cdot}0098$	$0{\cdot}228$
$8{\cdot}1_5$	$0{\cdot}598$	$0{\cdot}0296$	$0{\cdot}0120$	$0{\cdot}230$
$10{\cdot}1_5$	$0{\cdot}742$	$0{\cdot}0424$	$0{\cdot}0142$	$0{\cdot}231$
$12{\cdot}2_5$	$0{\cdot}880$	$0{\cdot}0576$	$0{\cdot}0160$	$0{\cdot}232$
$14{\cdot}3_5$	$1{\cdot}014$	$0{\cdot}0754$	$0{\cdot}0174$	$0{\cdot}233$
$16{\cdot}4$	$1{\cdot}140$	$0{\cdot}0958$	$0{\cdot}0178$	$0{\cdot}234$
$17{\cdot}4_5$	$1{\cdot}194$	$0{\cdot}107$	$+0{\cdot}0170$	$0{\cdot}235$
$17{\cdot}7$	$0{\cdot}778$	$0{\cdot}200$	$-0{\cdot}0212$	$0{\cdot}276$
$18{\cdot}0$	$1{\cdot}230$	$0{\cdot}115$	$+0{\cdot}0164$	$0{\cdot}236$
$18{\cdot}5_5$	$1{\cdot}078$	$0{\cdot}148$	$-0{\cdot}0122$	$0{\cdot}261$
$18{\cdot}7_5$	$0{\cdot}762$	$0{\cdot}254$	$-0{\cdot}0608$	$0{\cdot}326$
$19{\cdot}6$	$1{\cdot}000$	$0{\cdot}175$	$-0{\cdot}0230$	$0{\cdot}273$
$19{\cdot}8$	$0{\cdot}690$	$0{\cdot}271$	$-0{\cdot}0590$	$0{\cdot}330$
$21{\cdot}9_5$	$0{\cdot}617$	$0{\cdot}297$	$-0{\cdot}0566$	$0{\cdot}333$
$24{\cdot}1$	$0{\cdot}618$	$0{\cdot}328$	$-0{\cdot}0560$	$0{\cdot}330$
$27{\cdot}2_5$	$0{\cdot}644$	$0{\cdot}392$	$-0{\cdot}0572$	$0{\cdot}326$

TABLE 6 (*contd.*)

N.A.C.A. 0012, chromium plated

$R = 1{\cdot}98_5 \times 10^6$. $P = 7{\cdot}73$ atmos. $\rho V^2 = 73{\cdot}7$. $V = 64{\cdot}5$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}0_5$	$-0{\cdot}079$	$0{\cdot}0072$	$-0{\cdot}0018$	$0{\cdot}227$
$-0{\cdot}0_5$	$-0{\cdot}002$	$0{\cdot}0067$	$-0{\cdot}0002$	$0{\cdot}150$
$+0{\cdot}9_5$	$+0{\cdot}073$	$0{\cdot}0070$	$+0{\cdot}0014$	$0{\cdot}231$
$2{\cdot}0$	$0{\cdot}149$	$0{\cdot}0084$	$0{\cdot}0030$	$0{\cdot}230$
$4{\cdot}0_5$	$0{\cdot}301$	$0{\cdot}0130$	$0{\cdot}0060$	$0{\cdot}230$
$6{\cdot}0_5$	$0{\cdot}458$	$0{\cdot}0206$	$0{\cdot}0088$	$0{\cdot}231$
$8{\cdot}1_5$	$0{\cdot}602$	$0{\cdot}0304$	$0{\cdot}0110$	$0{\cdot}232$
$10{\cdot}1_5$	$0{\cdot}750$	$0{\cdot}0426$	$0{\cdot}0123$	$0{\cdot}233$
$12{\cdot}3$	$0{\cdot}904$	$0{\cdot}0596$	$0{\cdot}0126$	$0{\cdot}236$
$14{\cdot}3_5$	$1{\cdot}048$	$0{\cdot}0772$	$0{\cdot}0134$	$0{\cdot}237$
$16{\cdot}4$	$1{\cdot}178$	$0{\cdot}0978$	$0{\cdot}0128$	$0{\cdot}239$
$18{\cdot}5_5$	$1{\cdot}302$	$0{\cdot}122_5$	$0{\cdot}0114$	$0{\cdot}241$
$19{\cdot}5$	$1{\cdot}358$	$0{\cdot}135$	$+0{\cdot}0106$	$0{\cdot}242$
$19{\cdot}6$	$1{\cdot}094$	$0{\cdot}186$	$-0{\cdot}0290$	$0{\cdot}277$
$20{\cdot}6_5$	$1{\cdot}040$	$0{\cdot}212$	$-0{\cdot}0424$	$0{\cdot}290$
$21{\cdot}6_5$	$1{\cdot}004$	$0{\cdot}240_5$	$-0{\cdot}0518$	$0{\cdot}301$
$23{\cdot}9_5$	$0{\cdot}904$	$0{\cdot}292$	$-0{\cdot}0612$	$0{\cdot}315$
$27{\cdot}3$	$0{\cdot}652$	$0{\cdot}391_5$	$-0{\cdot}0596$	$0{\cdot}329$

$R = 2{\cdot}94 \times 10^6$. $P = 11{\cdot}2$ atmos. $\rho V^2 = 120$. $V = 69{\cdot}4$ f./s.

α°	C_L	C_D	C_m	C.P.
$-0{\cdot}0_5$	$0{\cdot}004$	$0{\cdot}0068$	$-0{\cdot}0002$	$0{\cdot}200$
$+0{\cdot}9_5$	$0{\cdot}077$	$0{\cdot}0070$	$+0{\cdot}0014$	$0{\cdot}232$
$2{\cdot}0_5$	$0{\cdot}157$	$0{\cdot}0084$	$0{\cdot}0030$	$0{\cdot}231$
$4{\cdot}0_5$	$0{\cdot}304$	$0{\cdot}0132$	$0{\cdot}0062$	$0{\cdot}230$
$6{\cdot}1$	$0{\cdot}454$	$0{\cdot}0202$	$0{\cdot}0090$	$0{\cdot}230$
$8{\cdot}2$	$0{\cdot}608$	$0{\cdot}0300$	$0{\cdot}0110$	$0{\cdot}232$
$10{\cdot}2_5$	$0{\cdot}754$	$0{\cdot}0432$	$0{\cdot}0120$	$0{\cdot}234$
$12{\cdot}3_5$	$0{\cdot}904$	$0{\cdot}0592$	$0{\cdot}0124$	$0{\cdot}236$
$14{\cdot}4_5$	$1{\cdot}046$	$0{\cdot}0774$	$0{\cdot}0120$	$0{\cdot}238$
$16{\cdot}5$	$1{\cdot}180$	$0{\cdot}0990$	$0{\cdot}0108$	$0{\cdot}241$
$18{\cdot}6$	$1{\cdot}308$	$0{\cdot}121$	$0{\cdot}0094$	$0{\cdot}243$
$19{\cdot}6$	$1{\cdot}382$	$0{\cdot}134$	$+0{\cdot}0080$	$0{\cdot}244$
$19{\cdot}6_5$	$1{\cdot}154$	$0{\cdot}172_5$	$-0{\cdot}0194$	$0{\cdot}267$
$20{\cdot}6_5$	$1{\cdot}156$	$0{\cdot}211_5$	$-0{\cdot}0444$	$0{\cdot}288$
$21{\cdot}8$	$1{\cdot}030$	$0{\cdot}251$	$-0{\cdot}0550$	$0{\cdot}302$
$24{\cdot}0$	$0{\cdot}906$	$0{\cdot}297$	$-0{\cdot}0618$	$0{\cdot}315$
$27{\cdot}2_5$	$0{\cdot}734$	$0{\cdot}351$	$-0{\cdot}0652$	$0{\cdot}330$

TABLE 6 (*contd.*)

N.A.C.A. 0012, *chromium plated*

$R = 3{\cdot}94 \times 10^6$. $P = 14{\cdot}7$ atmos. $\varrho V^2 = 162{\cdot}0$. $V = 70{\cdot}5$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
$-0{\cdot}0_5$	0·003	0·0068	−0·0002	0·317
+1·0	0·078	0·0072	+0·0012	0·235
$2{\cdot}0_5$	0·158	0·0084	0·0026	0·234
4·1	0·312	0·0126	0·0058	0·231
$6{\cdot}1_5$	0·466	0·0204	0·0204	0·231
$8{\cdot}2_5$	0·622	0·0302	0·0106	0·233
10·3	0·774	0·0436	0·0114	0·235
$12{\cdot}4_5$	0·924	0·0582	0·0112	0·238
$14{\cdot}5_5$	1·074	0·0756	0·0104	0·240
$16{\cdot}6_5$	1·212	0·0976	0·0086	0·243
18·7	1·336	0·121	0·0070	0·245
19·7	1·402	0·131	+0·0062	0·245
$19{\cdot}6_5$	1·164	0·176	−0·0278	0·268
$20{\cdot}7_5$	1·446	0·145	+0·0054	0·246
$20{\cdot}6_5$	1·068	0·221	−0·0448	0·290
$21{\cdot}8_5$	1·024	0·256	−0·0550	0·300
$24{\cdot}0_5$	0·880	0·305	−0·0604	0·316
$27{\cdot}2_5$	0·724	0·353	−0·0596	0·324

$R = 5{\cdot}56 \times 10^6$. $P = 18{\cdot}4$ atmos. $\varrho V^2 = 256{\cdot}0$. $V = 78{\cdot}9$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
$-0{\cdot}0_5$	0·003	0·0070	−0·0002	0·317
+1·0	0·085	0·0074	+0·0012	0·236
$2{\cdot}0_5$	0·166	0·0086	0·0028	0·233
$4{\cdot}1_5$	0·324	0·0130	0·0058	0·232
6·2	0·482	0·0204	0·0084	0·233
$8{\cdot}3_5$	0·642	0·0312	0·0102	0·234
10·4	0·796	0·0448	0·0106	0·237
12·6	0·950	0·0610	0·0104	0·239
14·7	1·102	0·0806	0·0092	0·242
16·8	1·242	0·103	0·0076	0·244
17·9	1·314	—	—	—
18·9	1·370	0·129	0·0060	0·246
20·0	1·434	0·142	+0·0058	0·246
19·7	1·142	$0{\cdot}185_5$	−0·0312	0·273
21·0	1·478	0·155	+0·0074	0·245
20·8	1·038	0·239	−0·0554	0·302
21·9	0·990	0·260	−0·0586	0·308
24·1	0·856	0·301	−0·0660	0·323
27·3	0·718	0·344	−0·0642	0·331

TABLE 6 (*contd.*)

N.A.C.A. 0012, *chromium plated*

$R = 7 \cdot 43 \times 10^6$. $P = 24 \cdot 6$ atmos. $\rho V^2 = 338$. $V = 78 \cdot 1$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
$-0 \cdot 0_5$	0·003	0·0074	−0·0002	0·317
+1·0	0·082	0·0078	+0·0014	0·233
2·1	0·164	0·0090	0·0030	0·232
4·2	0·324	0·0136	0·0060	0·232
6·3	0·487	0·0212	0·0084	0·233
$8 \cdot 4_5$	0·646	0·0320	0·0098	0·235
$10 \cdot 5_5$	0·806	0·0454	0·0102	0·237
$12 \cdot 7_5$	0·958	0·0632	0·0094	0·240
14·9	1·118	0·0852	0·0080	0·243
17·0	1·250	$0 \cdot 105_5$	0·0060	0·245
$19 \cdot 1_5$	1·386	0·130	0·0040	0·247
18·9	1·148	—	—	—
20·2	1·442	$0 \cdot 144_5$	+0·0034	0·248
19·9	1·086	0·207	−0·0340	0·281
21·2	1·490	0·155	+0·0020	0·249
20·8	0·984	0·249	−0·0520	0·302
21·9	0·948	$0 \cdot 273_5$	−0·0552	0·306
$24 \cdot 1_5$	0·788	0·312	−0·0584	0·319
$27 \cdot 3_5$	0·702	0·361	−0·0674	0·335

TABLE 7

R.A.F. 34, hand finished

$R = 0{\cdot}31 \times 10^6$. $P = 1$ atmos. $\rho V^2 = 13{\cdot}34$. $V = 75{\cdot}8$ f./s.

α°	C_L	C_D	C_m	C.P.
—4·7	—0·270	0·0176	—0·0108	0·210
—2·6	—0·120	0·0131	—0·0093	0·173
—0·5	+0·023	0·0123	—0·0053	0·480
$+1{\cdot}5_5$	0·172	0·0130	+0·0028	0·234
$3{\cdot}5_5$	0·354	0·0194	—0·0090	0·275
$5{\cdot}6_5$	0·522	0·0296	—0·0140	0·277
$7{\cdot}6_5$	0·654	0·0386	—0·0094	0·264
9·7	0·782	0·0526	—0·0068	0·259
$11{\cdot}7_5$	0·894	0·0692	—0·0010	0·251
13·8	0·944	0·0848	+0·0058	0·244
$15{\cdot}9_5$	0·974	0·107	+0·0032	0·247
18·2	0·734	0·233	—0·0672	0·337
20·4	0·652	$0{\cdot}272_5$	—0·0774	0·360
$22{\cdot}5_5$	0·628	0·300	—0·0808	0·366
24·8	0·610	0·341	—0·0714	0·353
27·0	0·622	0·369	—0·0772	0·358
$29{\cdot}0_5$	0·648	0·413	—0·0824	0·357

$R = 1{\cdot}25_5 \times 10^6$. $P = 4{\cdot}35$ atmos. $\rho V^2 = 50{\cdot}6_5$. $V = 70{\cdot}9$ f./s.

α°	C_L	C_D	C_m	C.P.
$-2{\cdot}6_5$	—0·133	0·0089	—0·0070	0·198
—0·5	+0·024	0·0073	—0·0046	0·441
$+1{\cdot}5_5$	0·173	0·0084	—0·0018	0·260
$3{\cdot}6_5$	0·327	0·0130	+0·0002	0·249
$5{\cdot}7_5$	0·482	0·0205	—0·0004	0·251
7·8	0·630	0·0320	+0·0010	0·248
9·8	8·768	0·0456	0·0018	0·248
$11{\cdot}8_5$	0·904	0·0618	0·0024	0·247
13·9	1·022	0·0800	+0·0018	0·248
16·0	1·096	0·103	—0·0100	0·259
$18{\cdot}1_5$	1·098	0·143	—0·0220	0·270
20·3	1·060	0·182	—0·0338	0·282
$22{\cdot}4_5$	1·018	0·242	—0·0492	0·298
24·7	0·944	0·302	—0·0794	0·331
$26{\cdot}9_5$	0·786	0·371	—0·0904	0·354
$29{\cdot}0_5$	0·736	0·423	—0·0956	0·363

TABLE 7 (*contd.*)

R.A.F. 34, *hand finished*

$R = 2{\cdot}56 \times 10^6$. $P = 8{\cdot}3$ atmos. $\varrho V^2 = 108{\cdot}1$. $V = 75{\cdot}0$ f./s.

α°	C_L	C_D	C_m	C.P.
—1·6	—0·057	0·0078	—0·0054	0·155
—0·5	+0·022	0·0076	—0·0042	0·440
+1·6	0·179	0·0094	—0·0020	0·261
3·7	0·334	0·0144	0	0·250
$5{\cdot}8_5$	0·492	0·0224	+0·0012	0·248
7·9	0·642	0·0334	0·0018	0·247
10·0	0·794	0·0474	+0·0008	0·249
$12{\cdot}0_5$	0·938	0·0642	—0·0010	0·251
14·1	1·074	0·0850	—0·0024	0·252
$16{\cdot}2_5$	1·196	0·106	—0·0054	0·255
18·3	1·192	0·145	—0·0180	0·271
$20{\cdot}4_5$	1·176	0·185	—0·0316	0·277
22·6	1·082	0·234	—0·0586	0·304
24·8	1·012	0·291	—0·0786	0·326
27·0	0·888	0·339	—0·0914	0·348
$29{\cdot}1_5$	0·792	0·369	—0·0924	0·356

$R = 3{\cdot}52 \times 10^6$. $P = 13{\cdot}2$ atmos. $\varrho V^2 = 141{\cdot}3$. $V = 69{\cdot}0$ f./s.

α°	C_L	C_D	C_m	C.P.
—1·6	—0·061	+0·0077	—0·0048	0·171
—0·5	+0·019	0·0075	—0·0037	0·446
+1·6	0·179	0·0093	—0·0016	0·258
$3{\cdot}7_5$	0·336	0·0143	0	0·250
5·9	0·496	0·0223	+0·0010	0·248
8·0	0·652	0·0334	0·0014	0·248
10·1	0·800	0·0476	0·0014	0·248
$12{\cdot}1_5$	0·950	0·0652	+0·0010	0·249
$14{\cdot}2_5$	1·094	0·0846	0	0·250
$16{\cdot}3_5$	1·226	0·107	—0·0020	0·252
18·5	1·300	0·132	—0·0058	0·255
20·6	1·224	0·184	—0·0326	0·280
22·7	1·124	0·239	—0·0580	0·301
24·9	1·036	0·297	—0·0816	0·327
27·1	0·894	0·332	—0·0920	0·347
$29{\cdot}2_5$	0·812	0·376	—0·0980	0·360

TABLE 7 (*contd.*)

R.A.F. 34, *hand finished*

$R = 4 \cdot 51 \times 10^6$. $P = 14 \cdot 7$ atmos. $\varrho V^2 = 203 \cdot 1$. $V = 78 \cdot 7$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—1·6	—0·064	0·0080	—0·0047	0·175
—0·5	+0·018	0·0078	—0·0034	0·438
$+1 \cdot 6_5$	0·181	0·0098	—0·0014	0·258
$3 \cdot 8_5$	0·340	0·0147	+0·0002	0·249
$6 \cdot 0_5$	0·502	0·0236	0·0010	0·248
$8 \cdot 1_5$	0·662	0·0352	0·0014	0·248
$10 \cdot 2_5$	0·820	0·0500	+0·0008	0·249
$12 \cdot 3_5$	0·980	0·0680	—0·0006	0·251
14·5	1·122	0·0886	—0·0024	0·252
$16 \cdot 6_5$	1·256	$0 \cdot 111_5$	—0·0038	0·253
18·8	1·334	0·139	—0·0106	0·258
$20 \cdot 8_5$	1·234	$0 \cdot 192_5$	—0·0370	0·280
22·9	1·118	0·257	—0·0680	0·312
$25 \cdot 0_5$	0·986	0·310	—0·0850	0·333
$27 \cdot 2_5$	0·876	0·347	—0·0922	0·348
$29 \cdot 3_5$	0·788	0·384	—0·0964	0·360

$R = 5 \cdot 47 \times 10^6$. $P = 18 \cdot 0$ atmos. $\varrho V^2 = 248 \cdot 0$. $V = 78 \cdot 0$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
$-1 \cdot 6_5$	—0·067	0·0082	—0·0044	0·189
—0·5	+0·016	0·0077	—0·0031	0·442
+1·7	0·184	0·0098	—0·0010	0·255
$3 \cdot 8_5$	0·348	0·0151	+0·0006	0·248
6·1	0·512	0·0238	0·0014	0·247
$8 \cdot 2_5$	0·676	0·0360	0·0016	0·248
10·4	0·814	0·0518	+0·0006	0·249
$12 \cdot 5_5$	0·990	0·0702	—0·0014	0·251
$14 \cdot 6_5$	1·146	0·0902	—0·0018	0·252
$16 \cdot 8_5$	1·274	0·114	—0·0052	0·254
19·0	1·358	$0 \cdot 141_5$	—0·0114	0·259
21·0	1·246	0·174	—0·0416	0·284
$23 \cdot 0_5$	1·112	0·268	—0·0716	0·313
$25 \cdot 1_5$	1·008	0·320	—0·0880	0·334
$27 \cdot 2_5$	0·856	0·358	—0·104	0·363
29·4	0·776	0·387	—0·0968	0·360

TABLE 7 (*contd.*)

R.A.F. 34, *hand finished*

$R = 6{\cdot}47 \times 10^6$. $P = 22{\cdot}5$ atmos. $\varrho V^2 = 277{\cdot}5$. $V = 73{\cdot}8$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1{\cdot}6_5$	$-0{\cdot}066$	0·0087	$-0{\cdot}0047$	0·179
$-0{\cdot}5$	$+0{\cdot}017$	0·0084	$-0{\cdot}0035$	0·455
$+1{\cdot}7$	0·185	0·0103	$-0{\cdot}0014$	0·258
3·9	0·352	0·0159	$+0{\cdot}0004$	0·249
6·2	0·520	0·0249	0·0010	0·248
$8{\cdot}3_5$	0·698	0·0368	0·0012	0·248
10·5	0·848	0·0522	$+0{\cdot}0004$	0·250
$12{\cdot}6_5$	0·998	0·0714	$-0{\cdot}0010$	0·251
14·8	1·150	0·0926	$-0{\cdot}0022$	0·252
17·0	1·286	0·117	$-0{\cdot}0042$	0·253
19·1	1·306	0·153	$-0{\cdot}0198$	0·265
21·1	1·240	0·212	$-0{\cdot}0248$	0·270
23·1	1·090	0·279	$-0{\cdot}0760$	0·319
$25{\cdot}2_5$	0·962	0·330	$-0{\cdot}0860$	0·335
27·4	0·826	0·361	$-0{\cdot}0940$	0·355
$29{\cdot}3_5$	0·760	—	—	—

$R = 2{\cdot}52 \times 10^6$. $P = 20{\cdot}9$ atmos. $\varrho V^2 = 44{\cdot}7$. $V = 30{\cdot}6$ f./s.

α°	C_L	C_D	C_m	C.P.
$13{\cdot}8_5$	1·034	—	—	—
$15{\cdot}9_5$	1·204	—	—	—
18·1	1·224	—	—	—
$20{\cdot}2_5$	1·166	—	—	—
22·4	1·072	—	—	—

$R = 2{\cdot}52 \times 10^6$. $P = 13{\cdot}6$ atmos. $\varrho V^2 = 69{\cdot}3$. $V = 47{\cdot}4$ f./s.

α°	C_L	C_D	C_m	C.P.
$13{\cdot}9_5$	1·046	—	—	—
$16{\cdot}0_5$	1·186	—	—	—
18·2	1·212	—	—	—
$20{\cdot}3_5$	1·186	—	—	—
$22{\cdot}5_5$	1·092	—	—	—

TABLE 7 (*contd.*)

R.A.F. 34, *hand finished*

$R = 7 \cdot 17 \times 10^6$. $P = 23 \cdot 8$ atmos. $\varrho V^2 = 316 \cdot 4$. $V = 76 \cdot 3$ f./s.

α°	C_L	C_D	C_m	C.P.
$-1 \cdot 2_5$	$-0 \cdot 052$	—	—	—
$-0 \cdot 1$	$+0 \cdot 040$	$0 \cdot 0081$	$-0 \cdot 0036$	$0 \cdot 340$
$+2 \cdot 2$	$0 \cdot 210$	$0 \cdot 0106$	$-0 \cdot 0014$	$0 \cdot 257$
$4 \cdot 5$	$0 \cdot 386$	$0 \cdot 0166$	$-0 \cdot 0004$	$0 \cdot 251$
$7 \cdot 8_5$	$0 \cdot 646$	$0 \cdot 0324$	$+0 \cdot 0002$	$0 \cdot 250$
$11 \cdot 0_5$	$0 \cdot 898$	$0 \cdot 0544$	$-0 \cdot 0012$	$0 \cdot 251$
$13 \cdot 2_5$	$1 \cdot 064$	$0 \cdot 0758$	$-0 \cdot 0032$	$0 \cdot 253$
$15 \cdot 4_5$	$1 \cdot 214$	$0 \cdot 0978$	$-0 \cdot 0060$	$0 \cdot 255$
$17 \cdot 6_5$	$1 \cdot 356$	$0 \cdot 122$	$-0 \cdot 0080$	$0 \cdot 256$
$18 \cdot 7$	$1 \cdot 406$	$0 \cdot 135$	$-0 \cdot 0094$	$0 \cdot 257$
$19 \cdot 6_5$	$1 \cdot 350$	$0 \cdot 162$	$-0 \cdot 0240$	$0 \cdot 268$
$21 \cdot 6_5$	$1 \cdot 292$	$0 \cdot 226$	$-0 \cdot 0496$	$0 \cdot 289$
$23 \cdot 6$	$1 \cdot 190$	$0 \cdot 283$	$-0 \cdot 0726$	$0 \cdot 310$
$25 \cdot 5_5$	$1 \cdot 014$	$0 \cdot 344$	$-0 \cdot 0952$	$0 \cdot 339$
$27 \cdot 6_5$	$0 \cdot 872$	$0 \cdot 372$	$-0 \cdot 0956$	$0 \cdot 361$
$29 \cdot 8$	$0 \cdot 772$	$0 \cdot 406$	$-0 \cdot 0990$	$0 \cdot 365$

TABLE 8

R.A.F. 34, back-half roughened FF carborundum (0·001 in. *grains*)

$R = 0{\cdot}312 \times 10^6$. $P = 1$ atmos. $\rho V^2 = 13{\cdot}34$. $V = 76{\cdot}1$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—1·2	—0·018	0·0094	—0·0032	0·075
—0·1_5	+0·044	0·0082	+0·0013	0·223
+1·9_5	0·206	0·0104	+0·0019	0·240
4·0_5	0·394	0·0168	—0·0078	0·270
7·1_5	0·614	0·0300	—0·0088	0·264
10·1_5	0·812	0·0488	—0·0036$_5$	0·254
13·2	0·968	0·0728	+0·0060	0·244
15·3_5	0·976	0·0942	+0·0060	0·244
16·4	0·988	0·108	+0·0024	0·248
17·4_5	0·990	0·126	—0·0038	0·254
17·5_5	0·802	0·205	—0·0552	0·317
18·6	0·728	0·235	—0·0658	0·336
19·7_5	0·688	0·257	—0·0718	0·348
21·9	0·648	0·289	—0·0770	0·358
25·1	0·628	0·334	—0·0818	0·365
29·4_5	0·676	0·425	—0·0984	0·373

$R = 1{\cdot}27 \times 10^6$. $P = 4{\cdot}61$ atmos. $\rho V^2 = 50{\cdot}5$. $V = 69{\cdot}3$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—1·2	—0·032	0·0074	—0·0048	0·151
—0·1	+0·044	0·0072	—0·0034	0·328
+2·0	0·192	0·0080	—0·0003	0·251
4·1_5	0·350	0·0128	+0·0015	0·246
7·2_5	0·580	0·0264	0·0024	0·246
10·3_5	0·798	0·0460	0·0038	0·245
13·3	0·988	0·0712	0·0057	0·244
15·4	1·084	0·0928	+0·0021	0·248
16·4_5	1·110	0·111	—0·0070	0·257
17·5	1·106	0·129	—0·0134	0·262
18·5_5	1·102	0·144	—0·0184	0·267
19·6_5	1·088	0·167	—0·0284	0·276
21·7_5	1·044	0·205	—0·0440	0·292
25·0	0·912	0·336	—0·0842	0·337
29·4_5	0·726	0·419	—0·0932	0·362

TABLE 8 (*contd.*)

R.A.F. 34, *back-half roughened FF carborundum* (0·001 in. *grains*)

$R = 2{\cdot}58 \times 10^6$. $P = 9{\cdot}65$ atmos. $\varrho V^2 = 101{\cdot}3$. $V = 68{\cdot}0$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—0·1	0·050	0·0080	—0·0044	0·338
$+3{\cdot}9_5$	0·126	0·0084	—0·0032	0·272
$2{\cdot}0_5$	0·206	0·0098	—0·0021	0·260
4·2	0·366	0·0152	—0·0005	0·251
$7{\cdot}3_5$	0·602	0·0286	+0·0010	0·248
10·4	0·826	0·0490	0·0015	0·248
13·5	1·052	0·0752	0·0009	0·250
15·6	1·174	0·0962	+0·0004	0·250
$16{\cdot}6_5$	1·226	$0{\cdot}106_5$	—0·0006	0·250
$17{\cdot}6_5$	1·274	0·122	—0·0062	0·255
$18{\cdot}7_5$	1·218	0·148	—0·0188	0·266
19·8	1·212	$0{\cdot}167_5$	—0·0254	0·271
$21{\cdot}8_5$	1·136	0·214	—0·0470	0·292
25·1	1·020	0·298	—0·0776	0·324
29·5	0·798	0·377	—0·0930	0·356

$R = 4{\cdot}99 \times 10^6$. $P = 16{\cdot}2$ atmos. $\varrho V^2 = 237{\cdot}5$. $V = 81{\cdot}3$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—0·1	0·050	0·0092	—0·0048	0·346
+1·0	0·132	0·0098	—0·0037	0·278
$2{\cdot}1_5$	0·218	0·0114	—0·0026	0·262
4·4	0·382	0·0168	—0·0007	0·252
7·7	0·634	0·0316	+0·0008	0·249
$10{\cdot}8_5$	0·870	0·0532	0·0001	0·250
14·0	1·104	0·0816	—0·0018	0·252
16·2	1·240	0·104	—0·0036	0·253
$17{\cdot}2_5$	1·300	0·116	—0·0042	0·253
18·3	1·348	0·128	—0·0053	0·254
19·3	1·284	0·158	—0·0232	0·268
$20{\cdot}3_5$	1·254	0·179	—0·0306	0·275
$22{\cdot}3_5$	1·186	0·240	—0·0568	0·298
25·4	1·010	0·330	—0·0886	0·334
29·7	0·776	0·398	—0·0990	0·364

TABLE 8 (*contd.*)

R.A.F. 34, *back-half roughened FF carborundum* (0·001 in. *grains*)

$R = 6{\cdot}98 \times 10^6$. $P = 23{\cdot}6$ atmos. $\rho V^2 = 316{\cdot}0$. $V = 77{\cdot}5$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—0·1	0·050	0·0094	—0·0046	0·342
+1·0_5	0·140	0·0100	—0·0034	0·270
2·2	0·228	0·0116	—0·0023	0·260
4·5	0·400	0·0174	—0·0005	0·251
7·8_5	0·658	0·0330	+0·0003	0·250
11·1	0·902	0·0562	—0·0003	0·250
11·0	0·748	—	—	—
13·2_5	1·060	0·0760	—0·0025	0·252
13·1_5	0·800	—	—	—
15·5	1·212	0·0982	—0·0044	0·254
15·3_5	0·970	—	—	—
16·5_5	1·272	0·111	—0·0053	0·254
16·4	0·968	—	—0·0023	—
17·6_5	1·328	0·123	—0·0061	0·255
17·5	1·058	—	—0·0029	—
18·7	1·362	0·135_5	—0·0072	0·255
18·6	1·134	—	—0·0047	—
19·6	1·236	0·168	—0·0248	0·270
20·6_5	1·150	0·195	—0·0332	0·279
20·7	1·262	—	—	—
22·5_5	1·090	0·262	—0·0634	0·307
22·6_5	1·184	—	—	—
25·5_5	0·962	0·348	—0·0926	0·341
29·7_5	0·740	0·402	—0·100	0·369

TABLE 9

R.A.F. 34, *all roughened FF carborundum* (0·001 in. *grains*)

$R = 0{\cdot}31 \times 10^6$. $P = 1$ atmos. $\rho V^2 = 13{\cdot}34$. $V = 75{\cdot}8$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—1·2	—0·032	0·0133	—0·0078	0·009
—0·1_5	+0·035	0·0117	—0·0032	0·341
+2·0	0·186	0·0142	—0·0004	0·252
4·0_5	0·376	0·0224	—0·0107	0·278
7·1_5	0·612	0·0356	—0·0126	0·270
10·1_5	0·804	0·0534	—0·0050	0·256
12·2	0·898	0·0734	+0·0018	0·248
13·2	0·928	0·0856	0·0056	0·244
14·3	0·950	0·0978	0·0060	0·244
15·3_5	0·960	0·109	0·0055	0·244
16·4	0·974	0·116	+0·0018	0·248
17·4_5	0·980	0·126	—0·0044	0·254
—	0·868	0·180	—0·0400	0·295
18·5_5	0·976	0·146	—0·0126	0·263
—	0·732	0·222	—0·0504	0·316
19·7	0·790	0·235	—0·0594	0·323
22·9_5	0·630	0·306	—0·0788	0·363
26·2	0·624	0·349	—0·0810	0·363
29·4_5	0·666	0·428	—0·0972	0·373

$R = 1{\cdot}263 \times 10^6$. $P = 4{\cdot}5_5$ atmos. $\rho V^2 = 50{\cdot}5$. $V = 69{\cdot}7$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—1·2	—0·037	0·0100	—0·0064	0·078
—0·1_5	+0·038	0·0098	—0·0050	0·380
+2·0	0·199	0·0116	—0·0023	0·261
4·1	0·344	0·0164	—0·0001	0·250
7·2	0·570	0·0298	+0·0022	0·246
10·2_5	0·780	0·0494	0·0045	0·244
12·4	0·904	0·0654	0·0055	0·244
13·3_5	0·958	—	—	—
14·4	1·000	0·0858	+0·0023	0·248
15·4_5	1·014	0·106	—0·0079	0·258
16·5	1·020	—	—	—
17·5_5	1·000	0·148	—0·0262	0·276
19·6_5	0·996	0·199	—0·0504	0·300
22·8_5	0·964	0·284	—0·0582	0·308
26·1_5	0·822	0·374	—0·0822	0·341
29·4_5	0·786	0·421	—0·0984	0·369

TABLE 9 (*contd.*)

R.A.F. 34, *all roughened FF carborundum* (0·001 in. *grains*)

$R = 2{\cdot}62_5 \times 10^6$. $P = 9{\cdot}78$ atmos. $\varrho V^2 = 101{\cdot}3$. $V = 67{\cdot}3$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
−1·2	0·005	0·0113	−0·0065	−1·0
−0·1_5	0·039	0·0112	−0·0049	+0·380
+2·0_5	0·196	0·0133	−0·0021	0·261
4·2	0·344	0·0184	+0·0003	0·249
7·4	0·578	0·0318	0·0024	0·246
10·4	0·798	0·0520	0·0039	0·245
12·4_5	0·934	0·0686	0·0048	0·245
13·5	0·988	0·0780	0·0052	0·245
14·6	1·024	0·110	+0·0032	0·247
15·6_5	0·998	0·115	−0·0114	0·261
17·7	0·950	0·161	−0·0311	0·283
19·8_5	0·908	0·234	−0·0690	0·324
23·0	0·760	0·303	−0·0820	0·351
26·2_5	0·684	0·352	−0·0880	0·365
29·5	0·730	0·424	−0·101	0·370

$R = 5{\cdot}05_6 \times 10^6$. $P = 16{\cdot}0$ atmos. $\varrho V^2 = 237{\cdot}5$. $V = 82{\cdot}6$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
−0·1	0·043	0·0122	−0·0056	0·380
+2·1_5	0·214	0·0146	−0·0027	0·263
4·4	0·368	0·0204	−0·0002	0·250
7·6_5	0·610	0·0352	+0·0018	0·247
10·8	0·840	0·0570	0·0030	0·246
12·9_5	0·970	0·0742	0·0040	0·246
14·0	1·024	0·0836	0·0042	0·246
15·1	1·046	0·0968	+0·0009	0·249
16·1	1·030	0·120	−0·0119	0·263
17·1_5	1·010	0·140	−0·0184	0·268
19·1	0·936	0·182_5	−0·0562	0·310
21·1_5	0·766	0·270	−0·0754	0·343
23·2	0·700	0·311	−0·0828	0·358
26·4	0·670	0·364	−0·0894	0·367
29·6_5	0·728	0·446	−0·101	0·368

TABLE 9 (*contd.*)

R.A.F. 34, *all roughened FF carborundum* (0·001 in. *grains*)

$R = 7{\cdot}14 \times 10^6$. $P = 24{\cdot}35$. $\varrho V^2 = 316{\cdot}4$. $V = 76{\cdot}0$ f./s.

$\alpha°$	C_L	C_D	C_m	C.P.
—0·1	0·037	0·0123	—0·0054	0·396
$+1{\cdot}0_5$	0·126	0·0132	—0·0039	0·281
2·2	0·212	0·0149	—0·0026	0·262
4·5	0·382	0·0209	0	0·250
$7{\cdot}8_5$	0·626	0·0402	+0·0022	0·247
$11{\cdot}0_5$	0·858	0·0658	0·0032	0·246
$13{\cdot}2_5$	0·996	0·0862	0·0041	0·246
14·3	1·030	0·0978	+0·0041	0·246
$15{\cdot}3_5$	1·046	0·107	—0·0060	0·256
16·4	1·046	—	—	—
$17{\cdot}4_5$	1·046	0·144	—0·0193	0·268
$19{\cdot}3_5$	0·946	0·218	—0·0516	0·303
$21{\cdot}2_5$	0·750	0·278	—0·0770	0·346
23·3	0·686	0·315	—0·0826	0·360
$26{\cdot}4_5$	0·672	0·362	—0·0904	0·369
29·7	0·746	0·450	—0·106	0·372

TABLE 10

Minimum Drag

N.A.C.A. 0012, *hand finished surface*

P atmos.	$R \times 10^{-6}$	V f./s.	ϱV^2	C_D min.
2·2	0·20	22·8	2·64	0·0115
	0·35	39·6	7·91	0·0101
	0·49	56·2	15·9	0·0088
	0·64	73·4	27·2	0·0077
	0·79	90·4	41·3	0·0073
3·6	0·33	23·3	4·47	0·0108
	0·57	39·4	12·8	0·0085
	0·81	56·4	26·3	0·0072
	1·05	73·4	44·5	0·0067
	1·30	90·4	67·5	0·0063
7·7	0·50	16·5	4·81	0·0095
	1·02	33·5	19·8	0·0066
	1·54	44·9	44·9	0·0062
	2·07	67·8	81·0	0·0065
	2·58	84·2	125·0	0·0062
14·4	0·91	16·5	8·81	0·0072
	1·86	33·7	36·7	0·0065
	2·80	50·7	83·1	0·0068
	3·79	68·5	151·0	0·0073
	4·70	84·9	233·0	0·0076
18·2	1·17	16·8	11·6	0·0032
	2·39	34·4	48·3	0·0070
	3·57	51·2	107·0	0·0075
	4·75	68·3	191·0	0·0076
	5·92	85·1	295·0	0·0075
24·5	1·55	16·4	14·9	0·0072
	3·23	34·2	64·4	0·0071
	4·77	50·5	140·0	0·0078
	6·46	68·4	258·0	0·0076
	8·10	85·6	405·0	0·0075

TABLE 11

Minimum Drag

N.A.C.A. 0012, *roughened FFF carborundum* (0·0004 in. *grains*)

P atmos.	$R \times 10^{-6}$	V f./s.	ρV^2	C_D min.
1·0	0·19	43·4	5·98	0·0122
	0·28	66·3	10·5	0·0094
	0·35	83·0	16·4	0·0108
4·0	0·27	16·4	2·50	0·0102
	0·54	32·5	9·88	0·0093
	0·83	50·2	23·6	0·0074
	1·10	66·4	41·2	0·0070
	1·37	82·8	64·0	0·0069
8·4	2·08	61·9	73·6	0·0074
11·7	3·19	68·1	120·0	0·0086
18·3	1·26	17·0	12·3	0·0066
	2·50	33·7	48·2	0·0075
	3·74	50·4	108·0	0·0073
	5·04	68·1	197·0	0·0098
	6·31	85·2	308·0	0·0097

TABLE 12

Minimum Drag

N.A.C.A. 0012, *roughened FF carborundum* (0·001 in. *grains*)

P atmos.	$R \times 10^{-6}$	V f./s.	ρV^2	C_D min.
1·0	0·13	33·2	2·54	0·0168
	0·18	46·0	4·85	0·0166
	0·26	66·3	10·1	0·0106
	0·33	82·9	15·8	0·0098
4·0	0·35	22·0	4·38	0·0109
	0 61	38·7	13·7	0·0081
	0·89	55·8	28·4	0·0075
	1·15	72·4	47·8	0·0075
	1·41	88·6	72·6	0·0082
7·9	2·02	63·6	73·6	0·0099
11·6	3·09	67·3	120·0	0·0116
17·8	1·19	16·7	11·6	0·0081
	2·45	34·3	48·9	0·0107
	3·66	51·2	109·0	0·0118
	4·93	69·0	198·0	0·0124
	6·13	85·8	307·0	0·0136

TABLE 13

Minimum Drag

N.A.C.A. 0012, chromium plated

P atmos.	$R \times 10^{-6}$	V f./s.	ρV^2	C_D min.
2·3	0·36	38·9	7·91	0·0097
	0·51	55·2	15·9	0·0081
	0·66	72·1	27·2	0·0078
	0·82	88·9	41·3	0·0071
3·4	0·55	40·4	12·8	0·0079
	0·79	57·9	26·3	0·0071
	1·03	75·2	44·5	0·0067
	1·21	88·8	62·0	0·0066
7·8	1·02	33·5	19·8	0·0070
	1·54	50·4	44·9	0·0066
	2·07	67·6	80·8	0·0068
	2·58	84·2	125·0	0·0067
14·6	1·87	33·7	36·7	0·0067
	2·82	50·7	83·1	0·0071
	3·81	68·5	152·0	0·0071
	4·72	84·9	233·0	0·0072
23·8	3·08	33·7	64·4	0·0066
	4·69	51·2	141·0	0·0070
	6·35	69·5	259·0	0·0075
	7·95	87·0	405·0	0·0077

TABLE 14

Minimum Drag

R.A.F. 34, *hand finished surface*

P atmos.	$R \times 10^{-6}$	V f./s.	ϱV^2	C_D min.
1·0	0·21	49·5	5·78	0·0127
	0·28	66·2	10·3	0·0116
	0·34	82·2	15·9	0·0107
4·2	0·39	22·3	4·93	0·0104
	0·68	39·0	15·0	0·0087
	0·97	55·4	30·4	0·0084
	1·25	71·9	51·2	0·0076
	1·46	83·6	69·0	0·0076
9·5	0·77	23·5	12·1	0·0093
	1·48	39·1	33·5	0·0076
	2·11	55·7	67·9	0·0074
	2·75	72·6	116·0	0·0075
	3·18	84·0	154·0	0·0074
16·0	1·44	22·9	19·0	0·0072
	2·51	40·0	57·9	0·0068
	3·56	56·7	117·0	0·0076
	4·65	74·1	199·0	0·0079
	5·34	85·0	269·0	0·0079
24·5	2·15	22·6	28·2	0·0068
	3·76	39·7	86·7	0·0074
	5·42	57·1	108·0	0·0078
	7·10	74·7	308·0	0·0080
	8·10	85·3	401·0	0·0082

TABLE 15

Minimum Drag

R.A.F. 34, *back-half roughened FF carborundum* (0·001 in. *grains*)

P atmos.	$\bar{R} \times 10^{-6}$	V f./s.	ρV^2	C_D min.
1·0	0·13	33·3	2·56	0·0148
	0·20	50·0	5·74	0·0121
	0·27	66·8	10·2	0·0102
	0·33	83·0	15·8	0·0095
4·6	0·63	33·7	11·9	0·0085
	0·90	49·3	25·5	0·0075
	1·24	66·6	46·5	0·0074
	1·55	83·2	72·7	0·0075
9·6	1·43	33·4	24·7	0·0076
	2·14	50·1	55·6	0·0076
	2·88	67·[illegible]	101·0	0·0082
	3·59	84·0	156·0	0·0090
16·2	2·08	34·3	42·1	0·0075
	3·08	50·8	92·0	0·0083
	4·13	68·1	165·0	0·0087
	5·14	84·7	256·0	0·0091
24·3	2·08	22·2	26·8	0·0073
	3·74	39·9	87·0	0·0094
	5·34	57·0	177·0	0·0096
	6·91	73·7	296·0	0·0097
	7·98	85·0	395·0	0·0096

TABLE 16

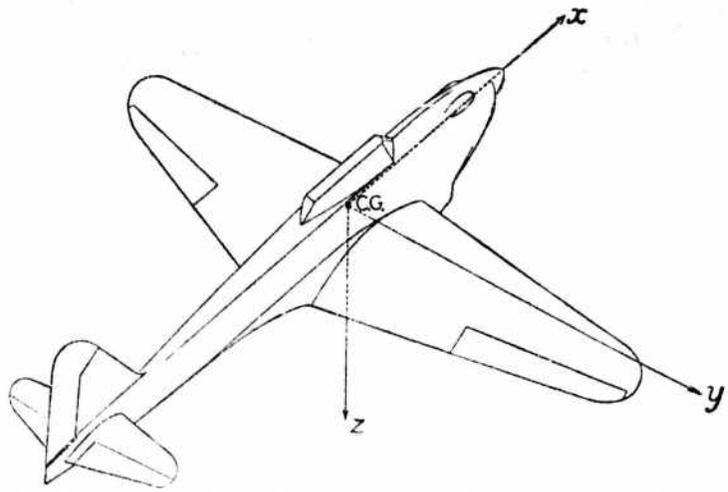
Minimum Drag

R.A.F. 34, *all roughened FF carborundum* (0·001 in. *grains*)

P atmos.	$R \times 10^{-6}$	V f./s.	ϱV^2	C_D min.
1·0	0·19	44·7	4·65	0·0130
	0·23	55·2	7·08	0·0117
	0·30	71·9	12·0	0·0105
	0·35	82·5	15·8	0·0101
4·5	0·40	22·1	5·04	0·0112
	0·69	38·4	15·1	0·0092
	0·99	55·6	31·8	0·0086
	1·29	72·1	53·5	0·0093
	1·49	83·2	71·3	0·0096
9·8	0·91	23·5	12·3	0·0078
	1·50	38·7	33·5	0·0099
	2·18	56·3	70·7	0·0107
	2·85	73·5	121·0	0·0112
	3·26	84·1	158·0	0·0114
15·9	1·42	22·4	18·2	0·0091
	2·51	39·4	56·6	0·0106
	3·60	56·7	117·0	0·0114
	4·74	74·5	202·0	0·0120
	5·40	84·8	262·0	0·0120
24·2	2·19	22·7	28·6	0·0112
	3·66	38·0	88·0	0·0117
	5·48	56·8	179·0	0·0124
	7·12	73·9	303·0	0·0124
	8·19	85·0	400·0	0·0123

(33010) Wt. 1505/137/6024 500 12/56 Hw. G 377/1

SYSTEM OF AXES



Axes	Symbol Designation Positive direction	x longitudinal forward	y lateral starboard	z normal downward
Force	Symbol	X	Y	Z
Moment	Symbol Designation	L rolling	M pitching	N yawing
Angle of Rotation	Symbol	ϕ	θ	ψ
Velocity	Linear Angular	u p	v q	w r
Moment of Inertia		A	B	C

Components of linear velocity and force are positive in the positive direction of the corresponding axis.
Components of angular velocity and moment are positive in the cyclic order y to z about the axis of x, z to x about the axis of y, and x to y about the axis of z.

The angular movement of a control surface (elevator or rudder) is governed by the same convention, the elevator angle being positive downwards and the rudder angle positive to port. The aileron angle is positive when the starboard aileron is down and the port aileron is up. A positive control angle normally gives rise to a negative moment about the corresponding axis.
The symbols for the control angles are :-

ξ aileron angle
η elevator angle
η_T tail setting angle
ζ rudder angle

Publications of the Aeronautical Research Committee

TECHNICAL REPORTS OF THE AERONAUTICAL RESEARCH COMMITTEE—

1933-34	Vol. I.	Aerodynamics. £1 5*s.*
	Vol. II.	Structures, Engines, Instruments, etc. £1 10*s.*
1934-35	Vol. I.	Aerodynamics. £2.
	Vol. II.	Seaplanes, Structures, Engines, Materials, etc. £2.

ANNUAL REPORTS OF THE AERONAUTICAL RESEARCH COMMITTEE—

1933-34	1*s.* 6*d.*
1934-35	1*s.* 6*d.*

INDEX TO THE TECHNICAL REPORTS OF THE ADVISORY COMMITTEE ON AERONAUTICS—

1909-1919 Reports and Memoranda No. 1600. 8*s.*

NUMERICAL LISTS OF REPORTS AND MEMORANDA published between 1909 and 1935—

Reports and Memoranda Nos. 650 (9*d.*), 750 (6*d.*), 850 (1*d.*), 950 (4*d.*), 1050 (4*d.*), 1150 (4*d.*), 1250 (6*d.*), 1350 (6*d.*), 1450 (6*d.*), 1550 (6*d.*), 1650 (6*d.*)

LIST OF PUBLICATIONS ON AERONAUTICS—

(1) Air Ministry Publications.

(2) Aeronautical Research Committee Publications (classified under subjects). Post free on application.

Prices are net and postage extra.

His Majesty's Stationery Office

London W.C.2 : Adastral House, Kingsway

Edinburgh 2 : 120 George Street — Manchester 1 : 26 York Street

Cardiff : 1 St. Andrew's Crescent — Belfast : 80 Chichester Street

or through any bookseller.

S.O. Code No. 23-1708