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Calculated Leading-Edge Laminar Separations from some RAE Aerofoils.

By

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of the Aerodynamics Division N.P.L.

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Calculated Leading-Edge Laminar Separations from some RAE Aerofoils

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SUMMARY

When separation occurs at the leading edge of a thin aerofoil, the Reynolds number at separation largely indicates whether a long or short separation bubble is formed. This Reynolds number depends upon the boundary-layer development, which is governed in turn by such parameters as the lift coefficient and the ratio r/c of the nose radius to the aerofoil chord. In this paper calculations have been carried out to determine separation conditions, when these parameters are varied, for the RAE 100-104 family of aerofoils.

Notation

c	chord of aerofoil
t	maximum thickness of aerofoil
r	leading-edge radius of curvature
C_L	lift coefficient
U_∞	velocity upstream of aerofoil
U	local free-stream velocity
U_m	maximum value of U
x	distance from nose of aerofoil, measured along chord
s	distance from nose of aerofoil, measured along surface
y	normal distance from chord line to surface of aerofoil
s_{st}	value of s at stagnation point
s_0	$s - s_{st}$
R	Reynolds number $U_\infty c/\nu$
ν	kinematic viscosity of the fluid

δ_1/

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δ_1	displacement thickness of the boundary layer
R_{δ_1}	$U_s(\delta_1)_s/\nu$
k	$R_{\delta_1}/R^{\frac{1}{2}}$.

Suffices

m	suffix denoting value at position where $U = U_m$
s	suffix denoting value at separation.

1. Introduction

Laminar boundary-layer separation from the leading edge of a thin aerofoil at incidence is a subject which has aroused new interest during the last five years or so. It is found experimentally that the flow often becomes reattached to the surface some distance downstream, a "bubble" of separated flow being formed. It has been suggested (Owen and Klanfer[1], 1953) that the length of the bubble depends primarily on the Reynolds number based on the displacement thickness of the separating boundary layer. If this Reynolds number R_{δ_1} is low enough, the separated flow is stable and at first remains laminar. It is only at some distance downstream, when the profile has been sufficiently distorted, that instability occurs, followed further downstream by transition and reattachment. Such a bubble, termed long, is found to be of order $10^4\,\delta_1$ in length, and to have appreciable upstream influence on the pressure distribution. On the other hand, if R_{δ_1} at separation is great enough, the initial separated flow is unstable, and it becomes turbulent almost at once with immediate reattachment. The bubble in this case is termed short, having a length of order $10^2\,\delta_1$.

Owen and Klanfer suggested that, if R_{δ_1} is calculated from the observed pressure distribution, a critical value of between 400 and 500 determines whether a long or short bubble is formed. Crabtree[2] (1954), in tests on a different section, later confirmed this result, and deduced 400 to 450 as the critical range. He further suggested tentatively that if R_{δ_1} is calculated from the theoretical pressure distribution, its critical range is about 450 to 550. This range, however, is extremely tentative, for an unpublished N.P.L. experimental result, for a 10% thick RAE 102 aerofoil, due to Garner and Batson, indicates a theoretical critical R_{δ_1} of 375. Further confirmation of Owen's experimental criterion was given later by Crabtree[4] (1957), in a paper which indicates that, although there is not a universal value of R_{δ_1} for the breakdown of the short bubble, the range of experimental R_{δ_1}, $400 < R_{\delta_1} < 450$, should cover many practical cases.

It is clear that the stalling characteristics of a given section depend considerably upon R_{δ_1}, and therefore upon the detailed boundary-layer development. Now on a lifting thin aerofoil the velocity outside the upper-surface boundary layer consists, very crudely, of a linear region, where the flow accelerates from the stagnation point to a speed U_m at a position x_m, which is followed by a decelerated region. From this idea Owen and Klanfer suggest that R_{δ_1} is a function only of U_m and x_m, which in turn are determined principally by the oncoming stream velocity U_∞, the radius of curvature r of the nose, the chord c of the model, and the incidence or lift. Thus R_{δ_1} is a function mainly of $R = \frac{U_\infty c}{\nu}$, r/c and the lift coefficient C_L.

The/

The purpose of this paper is to consider systematically the laminar boundary layers on some aerofoils of the RAE series for a range of C_L. Seven aerofoils are considered, namely the 10% thick RAE 100-104 and the 6% thick RAE 102 and 104. These are convenient since the theoretical pressure distributions have been extensively tabulated. Further, the results for these aerofoils will be particularly useful, as they are often tested experimentally.

Details of the computations are given in Section 2. The data used, namely the pressure distributions for the various aerofoils and their slopes and ordinates, appear in Refs. 5-8. Two methods were used for calculating the boundary-layer development, namely the modified forms (Curle and Skan[9], 1957) of the methods of Thwaites[10] (1949) and Stratford[11] (1954). The results are described in Section 3 and discussed in Section 4.

2. Computational Procedure

Since various numerical difficulties were encountered, a detailed description of the scheme of computation will be given.

Values of the velocity U are known[5,6] for values of x measured along the chord of the aerofoil. We require values of U at known values of s measured along the surface of the aerofoil, and therefore determine the values of

$$s(x) = \int_0^x \left\{ 1 + \left(\frac{dy}{dx} \right)^2 \right\}^{\frac{1}{2}} dx$$

corresponding to the given values of x. The surface slopes dy/dx are given for the 10% thick aerofoils[7,8]; since dy/dx is proportional to thickness, they are also known for the 6% thick aerofoils. Since the slope is infinite at $x = 0$ the process of numerical integration must start from a small positive value of x; values of s very near to the leading edge are obtained from a knowledge of the leading-edge radius[5]. Values of s/c for the range of x/c used in determining the separation points are given in Table 1.

From a knowledge of U as a function of s it was possible to obtain the exact position of the stagnation point s_{st} by plotting, or more accurately by numerical interpolation. Values of s_{st} are given against C_L in Tables 2 to 8 for the seven aerofoils investigated. Since distances must be measured along the surface of the aerofoil from the stagnation point, we need values of $s_0 = s - s_{st}$. These values of s_0 are of course not evenly spaced, and the estimation of U and $U' = \frac{dU}{ds}$ for convenient evenly spaced values of s_0 constitutes the most uncertain and laborious part of the calculation. A general idea of the procedure adopted is given here.

The velocity U was first plotted against s_0. Where the velocity is increasing, the procedure was to read off values of U since very great accuracy is not necessary here. The main difficulty arises beyond the point of maximum velocity, in the region where separation is expected to take place, and where a knowledge of U' is required. The curve here is much flatter, and it was decided to use a series of overlapping quadratic approximations to determine the values of U at closely spaced values of s_0. The interval was made smaller the

closer/

closer the point of separation to the point of maximum velocity. In this way two or more estimates of U were obtained for each required value of s_0. The agreement between these indicated that the final values of the velocity are probably correct to four significant figures.

It was not possible to determine U' with the same degree of accuracy. Since each quadratic gives a linear variation of U' over the range covered, we obtain a series of intersecting straight lines through which it is possible to trace a curve. Values of U' were read off this curve, and compared with the actual numerical values of U' given by the two linear approximations. A series of values of U' with as smooth a variation as possible was thus obtained.

No particular difficulty was experienced in applying this procedure to the 10% thick aerofoils for values of C_L less than 1·0. At C_L = 1·0, where the adverse velocity gradient is steepest and separation takes place early, it was less easy to define the peak region accurately. It was difficult also to obtain a sufficient number of values of U' round the point of separation. Extra values of U were therefore determined, so that the velocity curves could be very well defined in the vicinity of the peak. The results for the 10% thick aerofoils RAE 102 (C_L = 1·0, 1·2) and RAE 104 (C_L = 1·0), and for the 6% thick aerofoils RAE 102 and RAE 104 (C_L = 0·6, 0·8, 1·0) are given in Ref. 6 to four places of decimals.

With these very closely spaced values it was possible to use the quadratic approximation corresponding to the three values of U distributed round the peak to give values of U_m and s_{om} which should be very accurate. It was also much easier, of course, to determine U'.

As the boundary-layer development was to be calculated by an approximate method it was desirable to obtain some indication as to how far the results were significant in the rather sensitive situation when the position of separation moves quickly back with decrease of C_L. Accordingly, separation positions were estimated by the methods of both Thwaites[10] and Stratford[11] in the modified forms given by Curle and Skan[9]. The values of x_s corresponding to the values of s_s at separation were then determined from Table 1 by inverse interpolation.

3. Results

Tables 2 to 8 give the results for the five 10% thick aerofoils and the two 6% thick aerofoils, arranged in order of decreasing leading-edge radius. The position of the stagnation point, the maximum velocity and the position of maximum velocity are given first.

The mean is taken of the values of x_s obtained by the two methods of Thwaites and Stratford, and the final result is expressed in terms of the reciprocal of this mean value, which is plotted against C_L in Fig. 1. It will be seen that the points for each aerofoil lie roughly on a straight line. In order to define the shapes of the curves as they approach the C_L axis further calculations were carried out for the 10% thick aerofoils RAE 102 and RAE 103 at C_L = 0·5 and for the 6% thick aerofoil RAE 102 at C_L = 0·3. The velocity distributions for these cases are given in Ref. 6. The calculation for the 10% RAE 102 at C_L = 0·5 did not give separation, but it indicated that separation

would/

would occur at a value of C_L just above 0·5. Thwaites' method gave separation for the 10% RAE 103 at $C_L = 0·5$, with a value of c/x of about 61, but Stratford's method just failed to give separation, which indicates that the critical C_L must be very close to 0·5. Likewise for the 6% RAE 102, it was concluded that the minimum value of C_L to give separation would be very close to 0·3, and probably just below it.

The curves having been defined for these three cases,* the other four curves were drawn to conform in shape. It was thus possible to obtain reasonably good estimates of the minimum values of C_L for which leading-edge separation would take place. These values are given in Tables 2 to 8 and are plotted in Fig. 2.

Finally, values of U_s and U_s' corresponding to the mean values of x_s were obtained, and these were used to calculate

$$k = R_{\delta_1}/R^{\frac{1}{2}} = 1·065\, U_s(-U_s'\, U_\infty)^{-\frac{1}{2}}.$$

Calculations by Garner[3] for the 10% thick aerofoil RAE 102 suggest that the curve of k against C_L has a minimum at $C_L \sim 0·8$, and is rather flat for higher values of C_L. In order to establish this fact, the point of separation was determined for this aerofoil at $C_L = 1·2$, the refined scheme of calculation being used. From the curves of Fig. 3 it was possible to estimate the minimum values of k with reasonable accuracy. The position of minimum k was more difficult to determine, however, and the values given in Tables 2 to 8 are very approximate. The results are plotted in Figs. 4 and 5.

4. Discussion of Results

The results have been analysed in various ways. In Fig. 1 the values of c/x_s have been plotted against C_L. The value for any intermediate value of C_L, or for any other aerofoil of this family, can be obtained by interpolation. In particular, there is a limiting value of C_L below which leading-edge separation does not take place, and this is shown, plotted against r/c, in Fig. 2. The true limiting value of C_L is a matter of some uncertainty, as it is not at all clear that the position of separation will move back continuously as C_L is decreased towards the limit. For example, calculations by both Thwaites' method and Stratford's method indicate that in such circumstances separation would either occur very near the leading edge or only far back. This, however, may well be a property of the approximate methods used, which can only be decided by several lengthy exact integrations of the boundary-layer equations. Accordingly, the curves in Fig. 1 may well stop before reaching the axis; even if this is not the case, it would appear that there is a marked bending towards the C_L axis as c/x decreases. For example, for the 10% RAE 102 section there are four points, at $C_L = 1·2, 1·0, 0·8, 0·6$, lying roughly on a straight line cutting the axis at $C_L \sim 0·48$. In addition, however, we know that separation just fails to occur at

C_L/

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*A further discussion will be given in Section 4.

$C_L \sim 0{\cdot}50$. The curve is drawn, therefore, as a straight line to $C_L = 0{\cdot}53$, when it bends down rather sharply to cut the axis at a value of C_L just above $0{\cdot}50$; the curves for the other sections are made to follow a similar pattern. The relative smoothness of the curve of limiting C_L against r/c in Fig. 2 gives one some confidence that it may be correct to $\pm 0{\cdot}01$ in C_L. We note that the smaller the value of r/c, that is the sharper the nose, the lower the value of C_L at which leading-edge separation occurs, a result which would be expected on physical grounds.

It was shown in Section 3 that the value of R_{δ_1} at separation may be expressed as

$$R_{\delta_1} = k\,R^{\frac{1}{2}},$$

where k depends upon the aerofoil and upon C_L. In Fig. 3 the values of k are plotted against C_L for each of the seven aerofoils considered. In each case it will be seen that the value of k drops fairly sharply to a minimum as C_L increases; it then increases very slowly with a further increase in C_L. The minimum values of k and the corresponding values of C_L have been estimated from these curves and are plotted in Figs. 4 and 5 respectively.

This minimum value of k is quite important. As C_L increases beyond the lower critical value (Fig. 2) leading-edge separation will occur. If the value of k is large enough the separation bubble will be short. As C_L increases, however, k decreases, and if it decreases sufficiently the short bubble may burst. This, of course, would appear most likely to happen when k has reached the minimum value shown in Fig. 4, and, if it has not occurred then, a further increase in C_L should not cause the bubble to burst. For example, for the 10% thick RAE 102 aerofoil, the curve of k against C_L is fairly flat in the range $0{\cdot}8 < C_L < 1{\cdot}2$, and the minimum k occurs at $C_L \sim 0{\cdot}96$. In the experiment cited in Section 1 it was found that as C_L increased the short bubble burst when $C_L \sim 0{\cdot}90$.

It will be noted that the minimum possible value of k increases with r/c; thus, at a given flow Reynolds number R, a long bubble is less likely with a blunt-nosed section than with a sharp-nosed one. In fact, since the curves of Fig. 3 do not cross, the same is true for an arbitrary fixed value of C_L.

Acknowledgement

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References/

Table 8

RAE 104 Aerofoil Section: t/c = 0·06
r/c = 0·002134

C_L		1·0	0·8	0·6	0·4	0·2
Stagnation point :	s_{st}/c	−0·02622	−0·01804	−0·01065	−0·00561	−0·00227
Maximum velocity :	U_m/U_∞	5·030	4·081	3·144	2·322	1·454
Point of max. velocity:	s_m/c	0·00050	0·00062	0·00077	0·00087	0·00250
x_s/c: Thwaites		0·000307	0·000379	0·000609	0·00130	
x_s/c: Stratford		0·000351	0·000431	0·000678	0·00136	
Mean x_s/c		0·000329	0·000405	$0{\cdot}000643_5$	0·00133	
[mean $x_s/c]^{-1}$		3040	2469	1554	752	
U_s/U_∞ for mean x_s/c		$4{\cdot}822_6$	$3{\cdot}914_7$	$2{\cdot}989_8$	$2{\cdot}111_1$	
cU'_s/U_∞ for mean x_s/c		$-458{\cdot}_1$	$-339{\cdot}_8$	$-224{\cdot}_8$	$-104{\cdot}_5$	
k		$0{\cdot}23_9$	$0{\cdot}22_6$	$0{\cdot}21_2$	$0{\cdot}22_0$	

Estimated limiting value of C_L for separation = 0·25.

Minimum value of k is $0{\cdot}21_1$ at C_L = 0·55.

ES

Table 1

Values of s/c

x/c	t/c = 0·10					t/c = 0·06	
	RAE 100	RAE 101	RAE 102	RAE 103	RAE 104	RAE 102	RAE 104
0	0	0	0	0	0	0	0
0·0001			0·001009		0·000976	0·000636	0·000630
0·0002	0·002108	0·001762	0·001672	0·001607	0·001557	0·001019	0·000951
0·0003			0·002058		0·001920	0·001265	0·001183
0·0004			0·002392		0·002231	0·001480	0·001386
0·0005			0·002682		0·002503	0·001672	0·001568
0·0006			0·002953		0·002757	0·001853	0·001740
0·0007			0·003201		0·002994	0·002023	0·001903
0·0008			0·003442		0·003218	0·002187	0·002060
0·0009			0·003666		0·003429	0·002343	0·002210
0·001	0·004824	0·004073	0·003878	0·003738	0·003630	0·002494	0·002554
0·002	0·007014	0·005986	0·005720	0·005529	0·005332	0·003860	0·003677
0·003	0·008791	0·007571	0·007256	0·007031	0·006858	0·005080	0·004869
0·004	0·010389	0·009019	0·008666	0·008414	0·008219	0·006245	0·006014
0·005	0·011859	0·010368	0·009986	0·009710	0·009500	0·007369	0·007122
0·006	0·013265	0·011669	0·011256	0·010967	0·010741	0·008477	0·008216
0·007	0·014599	0·012917	0·012484	0·012176	0·011939	0·009562	0·009291
0·0075	0·015252	0·013531	0·013090	0·012773	0·012535	0·010102	0·009826
0·008	0·015905	0·014139	0·013688	0·013370	0·013121	0·010639	0·010360
0·009	0·017164	0·015336	0·014865	0·014530	0·014273	0·011708	0·011417
0·01	0·018409	0·016513	0·016028	0·015686	0·015419	0·012768	0·012472
0·012	0·020822	0·018821	0·018307	0·017946	0·017664	0·014873	0·014564
0·0125	0·021412	0·019391	0·018870	0·018500	0·018219	0·015396	0·015083
0·014	0·023171	0·021081	0·020544	0·020166	0·019871	0·016961	0·016640
0·016	0·025470	0·023306	0·022748	0·022356	0·022051	0·019037	0·018706
0·018	0·027733	0·025505	0·024929	0·024524	0·024208	0·021104	0·020765
0·020	0·029964	0·027681	0·027089	0·026673	0·026350	0·023163	0·022816
0·025	0·035451	0·033062	0·032430	0·031995	0·031654	0·028294	0·027927
0·05	0·061803						
0·075	0·087438						
0·1	0·112766						

Table 2/

Table 2

RAE 100 Aerofoil Section: $t/c = 0{\cdot}10$
$r/c = 0{\cdot}01098$

C_L		1·0	0·3	0·6
Stagnation point :	s_{st}/c	−0·03016	−0·02106	−0·01446
Maximum velocity :	U_m/U_∞	2·600	2·201	1·841
Point of max. velocity:	s_m/c	0·00591	0·00769	0·01079
x_s/c : Thwaites		0·00692	0·01260	
x_s/c : Stratford		0·00742	0·01334	
Mean x_s/c		0·00717	0·01297	
$[\text{mean } x_s/c]^{-1}$		139	77	
U_s/U_∞ for mean x_s/c		2·419	2·016	
cU_s'/U_∞ for mean x_s/c		−24·60	−14·00	
k		$0{\cdot}51_9$	$0{\cdot}57_4$	

Estimated limiting value of C_L for separation $= 0{\cdot}67$.

Minimum value of k is $0{\cdot}51_7$ at $C_L = 1{\cdot}05$.

Table 3/

Table 3

RAE 101 Aerofoil Section: $t/c = 0{\cdot}10$
$r/c = 0{\cdot}007634$

C_L		1·0	0·8	0·6
Stagnation point	s_{st}/c	-0·02920	-0·02017	-0·01331
Maximum velocity	U_m/U_∞	2·901	2·422	1·968
Point of max. velocity:	s_m/c	0·00316	0·00416	0·00611
x_s/c: Thwaites		0·00292	0·00502	0·01271
x_s/c: Stratford		0·00320	0·00537	0·01386
Mean x_s/c		0·00306	$0{\cdot}00519_5$	$0{\cdot}01328_5$
$[\text{mean } x_s/c]^{-1}$		327	192	75
U_s/U_∞ for mean x_s/c		2·746	2·256	1·765
cU'_s/U_∞ for mean x_s/c		-52·0	-32·08	-12·67
k		$0{\cdot}40_6$	$0{\cdot}42_4$	$0{\cdot}52_8$

Estimated limiting value of C_L for separation $= 0{\cdot}53_5$.

Minimum value of k is $0{\cdot}40_6$ at $C_L = 1{\cdot}0$.

Table 4/

Table 4

RAE 102 Aerofoil Section: $t/c = 0{\cdot}10$
$r/c = 0{\cdot}006860$

C_L		1·2	1·0	0·8	0·6	0·5	0·4
Stagnation point	: s_{st}/c	−0·03720	−0·02886	−0·01990	−0·01297	−0·01018	−0·00771
Maximum velocity	: U_m/U_∞	3·537	3·014	2·505	2·024	1·801	1·594
Point of max. velocity:	s_m/c	0·00236	0·00284	0·00399	0·00503	0·00605	0·00838
x_s/c: Thwaites		$0{\cdot}00168_2$	0·00240	0·00390	0·00966		
x_s/c: Stratford		$0{\cdot}00136_3$	0·00264	0·00423	0·01028		
Mean x_s/c		$0{\cdot}00177_4$	0·00252	$0{\cdot}00406_5$	0·00997		
$[\text{mean } x_s/c]^{-1}$		564	397	246	100		
U_s/U_∞ for mean x_s/c		$3{\cdot}375_6$	2·855	2·344	1·826		
cU'_s/U_∞ for mean x_s/c		−83·45	−61·93	−40·62	−16·90		
k		$0{\cdot}39_4$	$0{\cdot}38_6$	$0{\cdot}39_2$	$0{\cdot}47_3$		

Estimated limiting value of C_L for separation = 0·51

Minimum value of k is $0{\cdot}38_1$ at $C_L = 0{\cdot}95$.

Table 5/

Table 5

RAE 103 Aerofoil Section: $t/c = 0\cdot10$
$r/c = 0\cdot006329$

C_L		1·0	0·8	0·6	0·5
Stagnation point :	s_{st}/c	-0·02860	-0·01972	-0·01272	-0·00996
Maximum velocity :	U_m/U_∞	3·135	2·533	2·070	1·835
Point of max. velocity:	s_m/c	0·00188	0·00278	0·00441	0·00557
x_s/c: Thwaites		0·00202	0·00316	0·00722	0·0165
x_s/c: Stratford		0·00217	0·00343	0·00764	
Mean x_s/c		$0\cdot00209_5$	$0\cdot00329_5$	0·00743	
$[\text{mean } x_s/c]^{-1}$		477	303	135	≈ 61
U_s/U_∞ for mean x_s/c		2·950	2·419	1·889	
cU'_s/U_∞ for mean x_s/c		-71·49	-48·04	22·21	
k		$0\cdot37_2$	$0\cdot37_2$	$0\cdot42_7$	

Estimated limiting value of C_L for separation $= 0\cdot48_7$.

Minimum value of k is $0\cdot36_5$ at $C_L = 0\cdot90$.

Table 6/

Table 6

RAE 104 Aerofoil Section: $t/c = 0{\cdot}10$
$r/c = 0{\cdot}005927$

C_L		1·0	0·8	0·6	0·4
Stagnation point :	s_{st}/c	-0·02838	-0·01956	-0·01252	-0·00735
Maximum velocity :	U_m/U_∞	3·179	2·630	2·108	1·635
Point of max. velocity:	s_m/c	0·00225	0·00310	0·00348	0·00632
x_s/c: Thwaites		0·00182	0·00286	0·00601	
x_s/c: Stratford		0·00197	0·00308	0·00645	
Mean x_s/c		$0{\cdot}00139_5$	0·00297	0·00623	
$[\text{mean } x_s/c]^{-1}$		528	337	161	
U_s/U_∞ for mean x_s/c		3·019	2·471	1·932	
cU'_s/U_∞ for mean x_s/c		-80·07	-54·54	-26·04	
k		$0{\cdot}35_5$	$0{\cdot}35_6$	$0{\cdot}40_5$	

Estimated limiting value of C_L for separation = 0·47.

Minimum value of k is $0{\cdot}35_3$ at $C_L = 0{\cdot}85$.

Table 7/

Table 7

RAE 102 Aerofoil Section: $t/c = 0{\cdot}06$
$r/c = 0{\cdot}002470$

C_L	1·0	0·8	0·6	0·4	0·3	0·2
Stagnation point : s_{st}/c	-0·02642	-0·01818	-0·01087	-0·00580	-0·00387	-0·0023
Maximum velocity : U_m/U_∞	4·724	3·843	2·967	2·154	1·761	1·428
Point of max. velocity: s_m/c	0·00061	0·00074	0·00096	0 00102	0·00198	0·0031
x_s/c: Thwaites	0·000365	0·000495	0·000809	0·00205	≈0·0104	
x_s/c: Stratford	0·000416	0·000556	0·000888	0·00218		
Mean x_s/c	0·000390$_5$	0·000525$_5$	0·000843$_5$	0·00211$_5$		
$[\text{mean } x_s/c]^{-1}$	2561	1903	1179	473	≈ 96	
U_s/U_∞ for mean x_s/c	4·540$_8$	3·674$_1$	2·815$_8$	1·977$_0$		
cU'_s/U_∞ for mean x_s/c	-355·$_{40}$	-265·$_{53}$	-174·$_{35}$	-72·$_6$		
k	0·25$_7$	0·24$_0$	0·22$_7$	0·24$_7$		

Estimated limiting value of C_L for separation = 0·29$_8$.

Minimum value of k is 0·22$_7$ at C_L = 0·56

Table 8/

Table 8

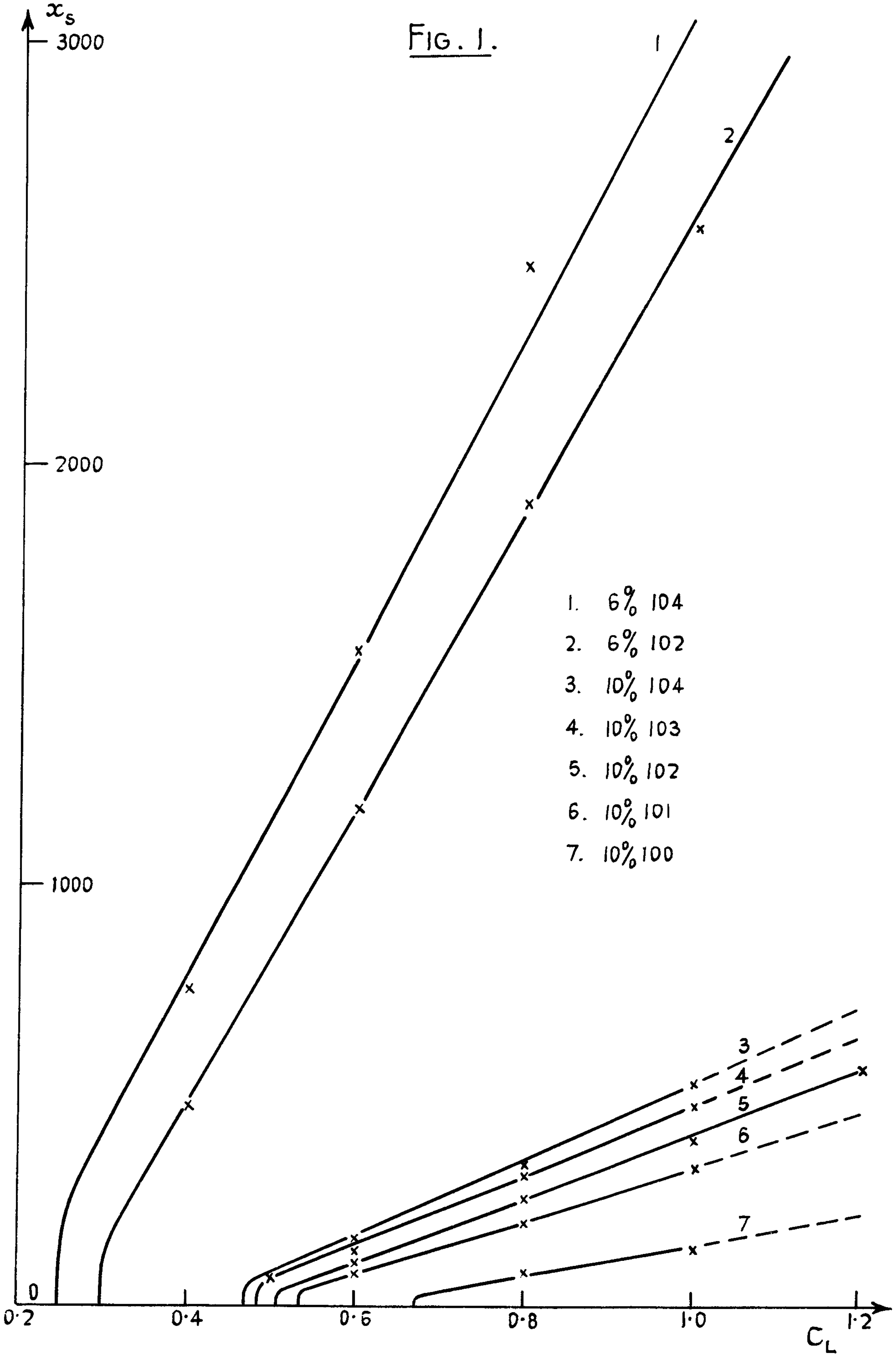
RAE 104 Aerofoil Section: $t/c = 0 \cdot 06$
$r/c = 0 \cdot 002134$

C_L		1·0	0·8	0·6	0·4	0·2
Stagnation point :	s_{st}/c	-0·02622	-0·01804	-0·01065	-0·00561	-0·00227
Maximum velocity :	U_m/U_∞	5·030	4·081	3·144	2·322	1·454
Point of max. velocity:	s_m/c	0·00050	0·00062	0·00077	0·00087	0·00250
x_s/c: Thwaites		0·000307	0·000379	0·000609	0·00130	
x_s/c: Stratford		0·000351	0·000431	0·000678	0·00136	
Mean x_s/c		0·000329	0·000405	0·00064$_5$	0·00133	
$[\text{mean } x_s/c]^{-1}$		3040	2469	1554	752	
U_s/U_∞ for mean x_s/c		4·822$_6$	3·914$_7$	2·989$_8$	2·111$_1$	
cU_s'/U_∞ for mean x_s/c		-458·$_1$	-339·$_8$	-224·$_8$	-104·$_5$	
k		0·23$_9$	0·22$_6$	0·21$_2$	0·22$_0$	

Estimated limiting value of C_L for separation = 0·25.

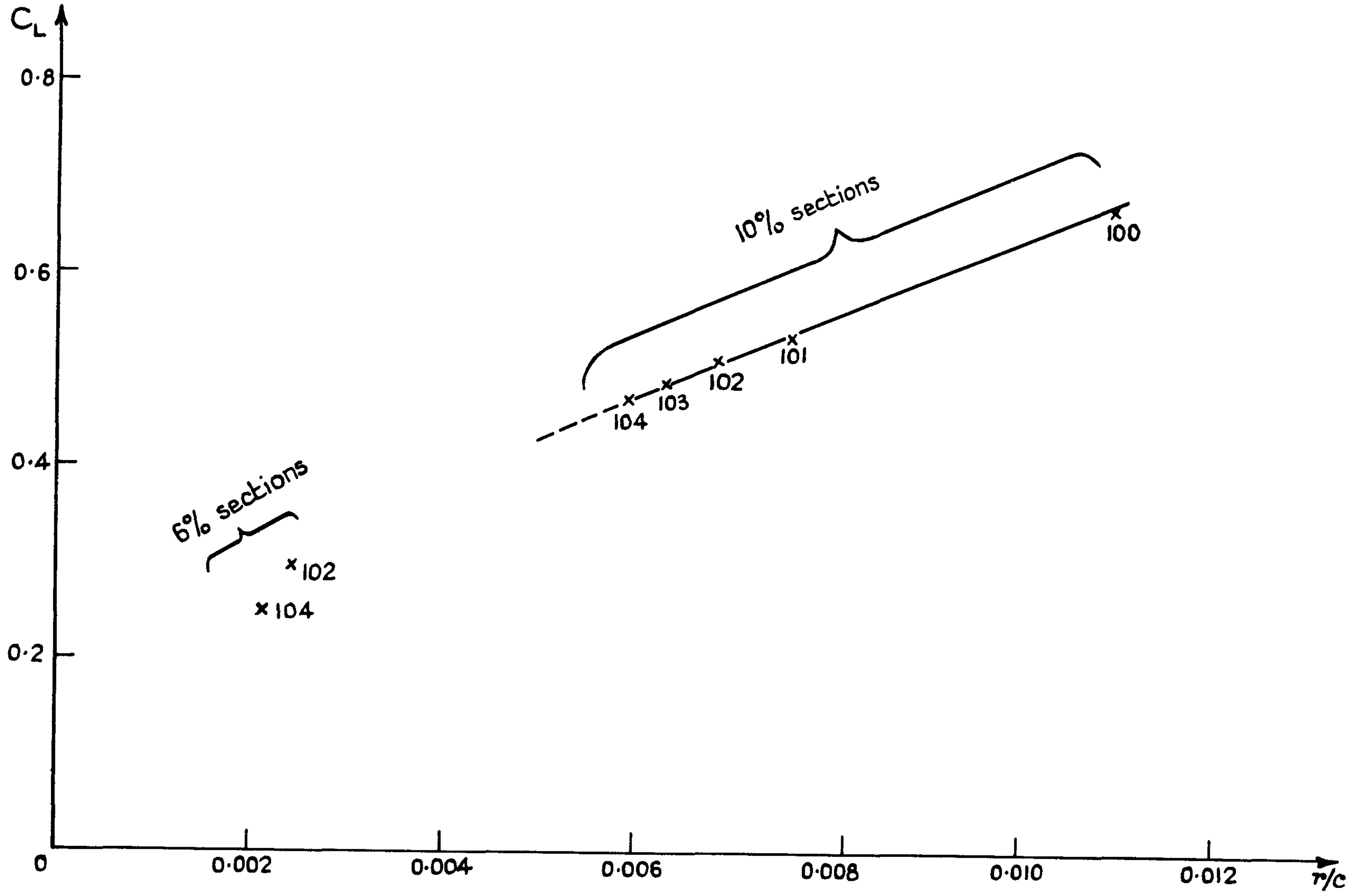
Minimum value of k is 0·21$_1$ at C_L = 0·55.

ES



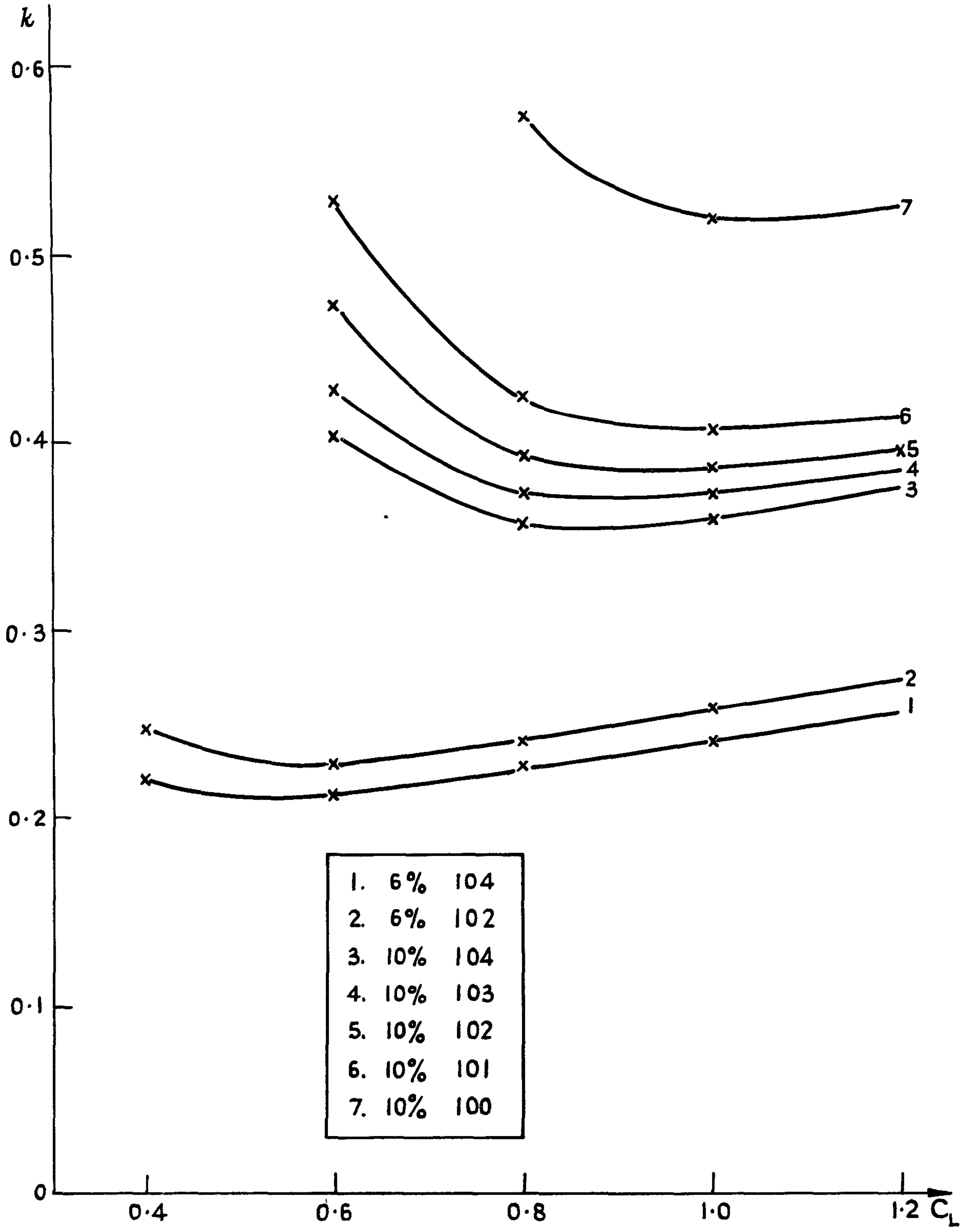
Values of $\frac{c}{x}$ at separation.

FIG. 2.



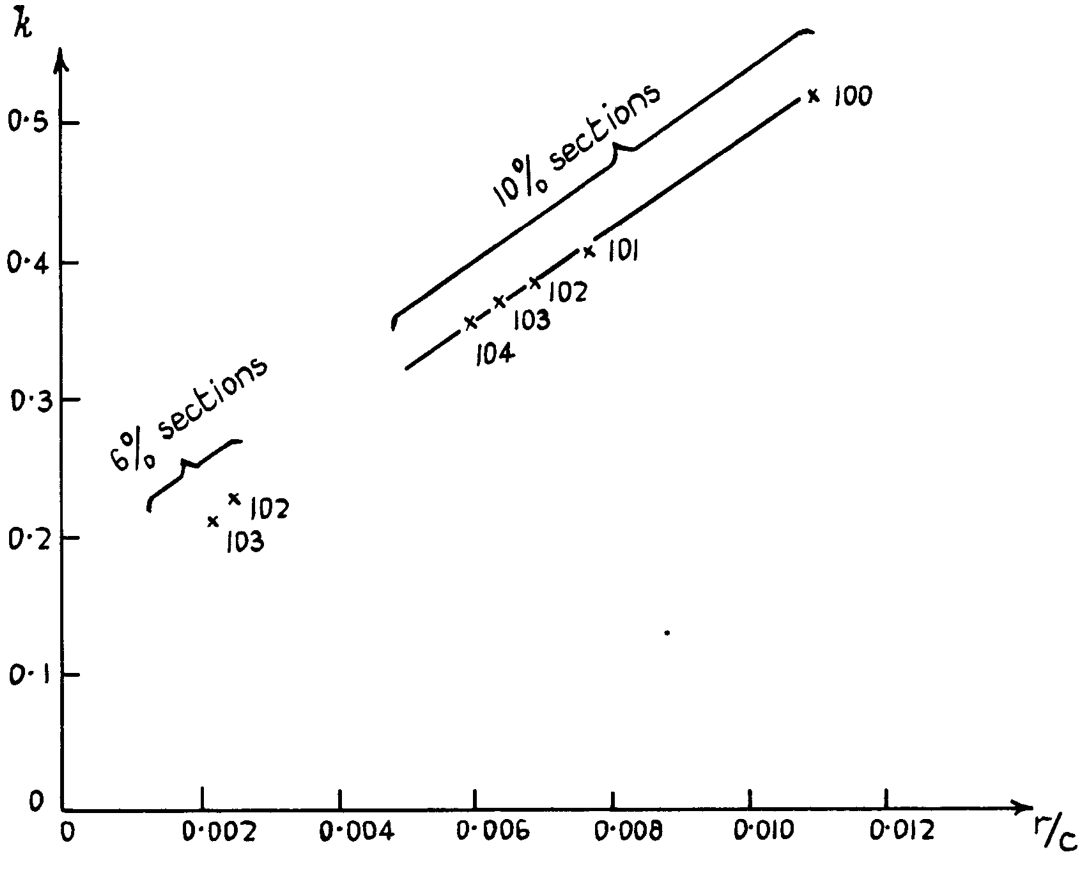
Minimum values of C_L for separation

FIG. 3.



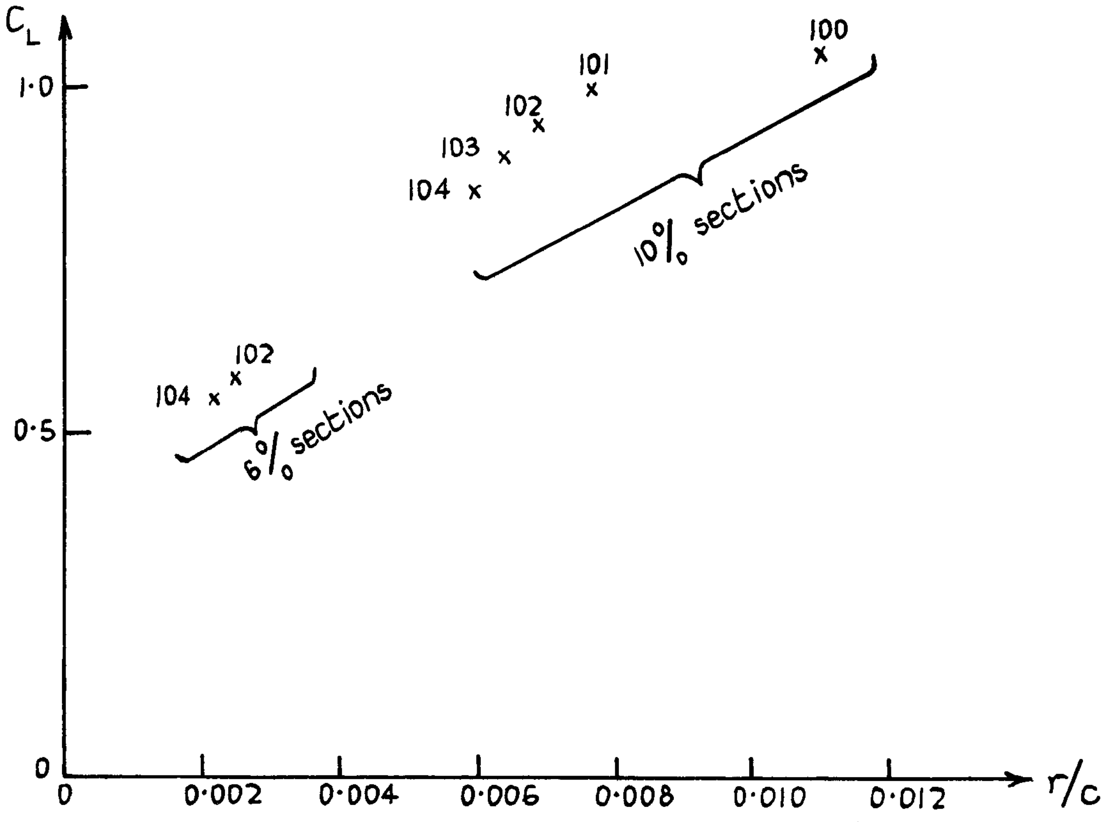
Variation of k with C_L

FIG. 4.



Minimum values of k.

FIG. 5



Values of C_L for minimum k

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