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A Comparison of Three Thick, Symmetrical, Multi-Slot Suction Aerofoils

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1st October, 1948.

Summary.

Two symmetrical thick suction aerofoils with additional small velocity discontinuities over the forward part of the aerofoil are compared with the 30% Griffith aerofoil. For a given transition position, the suction quantities and ideal effective drag coefficients are higher than for the 30% Griffith aerofoil, but more favourable velocity gradients and an increased C_L range are obtained.

The drag and suction quantities are equal to those obtained when the additional suction slots are inserted (in the Griffith aerofoil) without the associated small velocity discontinuities.

In all cases, reductions in drag are achieved with extra slots if extents of otherwise turbulent flow are replaced by laminar flow.

1. Introduction.

This note investigates the possible gains in performance which might be achieved by including additional slots, with and without associated small velocity discontinuities, in the forward part of sections resembling the Griffith 30% suction aerofoil. By sucking away the boundary layer near the nose of the aerofoil, wedges of turbulent flow due to roughness and imperfection of the surface would be absorbed, and laminar flow would therefore be obtained over the rest of the aerofoil where favourable conditions existed. In addition, by designing for velocity discontinuities at the slots, the aerodynamic characteristics of the aerofoil might be further improved: for a given maximum value of the velocity over the aerofoil (U/U_0), much greater favourable velocity gradients might be obtained; for a given maximum thickness, it would be possible to achieve a larger low-drag C_L range.

2. The Aerofoil Designs.

A series of symmetrical aerofoils was designed by the approximate methods of Goldstein and Richards[1,2]. Various combinations of values of the defining parameters were chosen so as to give sections approximately 30% thick. The introduction of small velocity discontinuities in the forward part of the

aerofoils/

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aerofoils gives rise to a characteristic convex-concave or wavy surface in the vicinity of the discontinuity. If the wavy surface leads to boundary-layer transition, this defeats the object of the design, which is to ensure laminar flow to the rear slot.

Two of the aerofoils were regarded as worthy of further consideration, as they appeared to present a reasonable compromise between favourable gradient and concavity of surface. These two aerofoils, Tadpoles IX and XIII, and their velocity distributions (to the first approximation, from which the sections were designed) are compared with the 30% Griffith section in the table below and in Figs.1 and 2. Fig.3 shows the velocity distributions at zero C_L and at the top of the C_L range according to Approximation III. It should be pointed out that the drop in velocity which occurs just in front of the main slot can be avoided by a simple modification to the design method. The final Approximation III would then differ but little from the present Approximation I in the vicinity of the main slot.

Designation of Aerofoil	Tadpole IX	Tadpole XIII	30% Griffith
Chordwise Position of Velocity Discontinuities.	0.15 0.50 0.80	0.15 0.75	0.80
Velocity Gradients up to the Rear Slot, at $C_L = 0$.	0.67 0.43 0.33	1.0 0.25	0.133
Maximum Velocity at $C_L = 0$.	1.45	1.45	1.43
Thickness.	33.4%	30.4%	30.0%
Top of C_L range.	1.1	0.85	0.6

Table I.

With an increasing number of discontinuities, more favourable velocity gradients and greater low-drag C_L ranges have been obtained. The critical Mach numbers of the three sections differ very little. Scaling up the 30% Griffith to have the same maximum velocity as the new aerofoils, the sections in order of thickness appear to be: Tadpole IX, 30% Griffith and Tadpole XIII. Tadpole IX, if scaled down to 30% thickness, must therefore be regarded as slightly better than the Griffith for $M_{crit.}$ and Tadpole XIII as slightly inferior.

To complete the comparison between the three sections, their relative power requirements must be considered. This is done in the following paragraph.

3. Power Requirements.

The slot suction quantity coefficients, the pump drag coefficients and the ideal effective drag coefficients of the three aerofoils at zero lift have been calculated according to the standard methods of references 3,4 at a Reynolds number of 10^7.

The/

The linear velocity distributions of Approximation I, with distances measured along the chord, have been used for simplicity in all three cases. At the forward slots, the whole boundary layer has been assumed to be absorbed. At the rear slots, the suction has been taken to be either that given by Taylor's criterion or (alternatively) the whole boundary layer. The casd has also been considered in which additional slots, at 15 and 50% of the chord, but without discontinuities, c been inserted into the 30% Griffith aerofoil and the whole boundary layer sucked away at each of these two slots.

The calculations were performed for two flow conditions. In the first case, the flow was assumed to be laminar as far as the rear slot (at 0.75 or 0.80 chord), and turbulent from there to the trailing edge, as would be expected from the concavity of the surface. In the second case, the flow was assumed to be turbulent from the front stagnation point to the first slot (as would be caused by flies, roughness etc.), laminar from the first to the last slot, and thereafter turbulent again to the trailing edge.

The calculated coefficients are given in Table II.

Conclusions.

The tabulated results lead to the following conclusions.

If by sucking away a turbulent boundary-layer near the nose, a laminar boundary layer can be restored over more rearward portions of the chord, then large reductions in drag may be obtained, compared with the drag with wholly turbulent flow.

For similar regions of laminar and turbulent flow, the fewer the slots used, the less the drag and the suction quantities.

If the boundary layer is withdrawn at slots in the forward part of the wing, the ideal effective drag coefficient is not affected by the presence or absence of small velocity discontinuities at these slots. But the aerodynamic characteristics of the section (i.e. C_L range, velocity gradients, $M_{crit.}$) may be improved by including the small velocity discontinuities, although at the expense of introducing local waviness of surface. The more favourable velocity gradients should assist in keeping the flow laminar, but the local concavities would tend to have the reverse effect.

Only experiments can decide whether the concavities cause more trouble than the lack of favourable gradients. Such experiments, to decide whether discontinuities are incorporated at forward slots for full scale flight, should be performed at as high a Reynolds number as possible.

References./

References.

No.	Author(s)	Title, etc.
1	S. Goldstein.	A Theory of Aerofoils of Small Thickness. Part I. Velocity Distributions for Symmetrical Aerofoils. A.R.C.5804.
2	S. Goldstein and E. J. Richards.	A Theory of Aerofoils of Small Thickness. Part III. Approximate Designs of Symmetrical Aerofoils for Specified Pressure Distributions. A.R.C.6225.
3	J. H. Preston, N. Gregory and A. G. Rawcliffe.	The Theory of Suction Aerofoils - together with - Theoretical Calculations of Quantity, Profile Drag, and "Pump" Drag for Two Typical Thick Griffith Type Suction Aerofoils. (17th January, 1947), and Errata (2nd August, 1947). (For Supplement see A.R.C.11,610). A.R.C.10,280.
4	N. Gregory.	Further Observations on the Boundary Layer Theory of Suction Aerofoils. (28th June, 1948). Supplement to A.R.C.10,280. A.R.C.11,610.

Table II/

NOTE: Refs. 3 and 4 have been combined and published as A.R.C. R.& M. No. 2577

Table II

Aerofoil	Slot Position and Suction Arrangement	Flow laminar from L.E. to rear slot (0.75 or 0.80c).			Flow turbulent from L.E. to 1st slot and from last slot to T.E. Flow laminar in between.		
		C_{D_e}	C_{D_p}	C_Q	C_{D_e}	C_{D_p}	C_Q
Tadpole IX	.15W .5W .8W	0.001306	0.001058	0.001948	0.002450	0.002202	0.006351
	.15W .5W .8T	0.001286	0.001006	0.001538	0.002430	0.002150	0.005941
	.15W .5T .8T	0.001049	0.000760	0.000920	0.002193	0.001904	0.005323
Tadpole XIII	.15W .75W	0.001197	0.000792	0.001432	0.002403	0.001998	0.005747
	.15W .75T	0.001134	0.000671	0.000851	0.002340	0.00[illegible]377	0.005166
30% Griffith	.8W	0.000842	0.000571	0.001067	0.005767	0.005496	0.018517
	.8T	0.000815	0.000489	0.000447	0.006239	0.003010	0.004248
	.15W .8W	0.001037	0.000766	0.001527	0.002011	0.001740	0.005949
	.15W .8T	0.001012	0.000690	0.000945	0.001935	0.001663	0.005367
	.15W .5W .8W	0.001284	0.001013	0.002054	0.002258	0.001987	0.006476
	.15W .5W .8T	0.001263	0.000956	0.001618	0.002236	0.001929	0.006040

Note: In column 2, the figure gives the chordwise position of the slot,
W denotes suction of the whole boundary layer quantity,
T denotes suction of Taylor's minimum quantity,
underlining indicates presence of a discontinuity.

C_{D_e} = ideal effective drag coefficient, (profile drag + equivalent pump drag)
C_{D_p} = pump drag coefficient, (total for all slots)
C_Q = suction quantity coefficient. (total for all slots)

Power Requirements for a Single Surface of Three Thick Suction Aerofoils. $C_L = 0$, $R = 10^7$.

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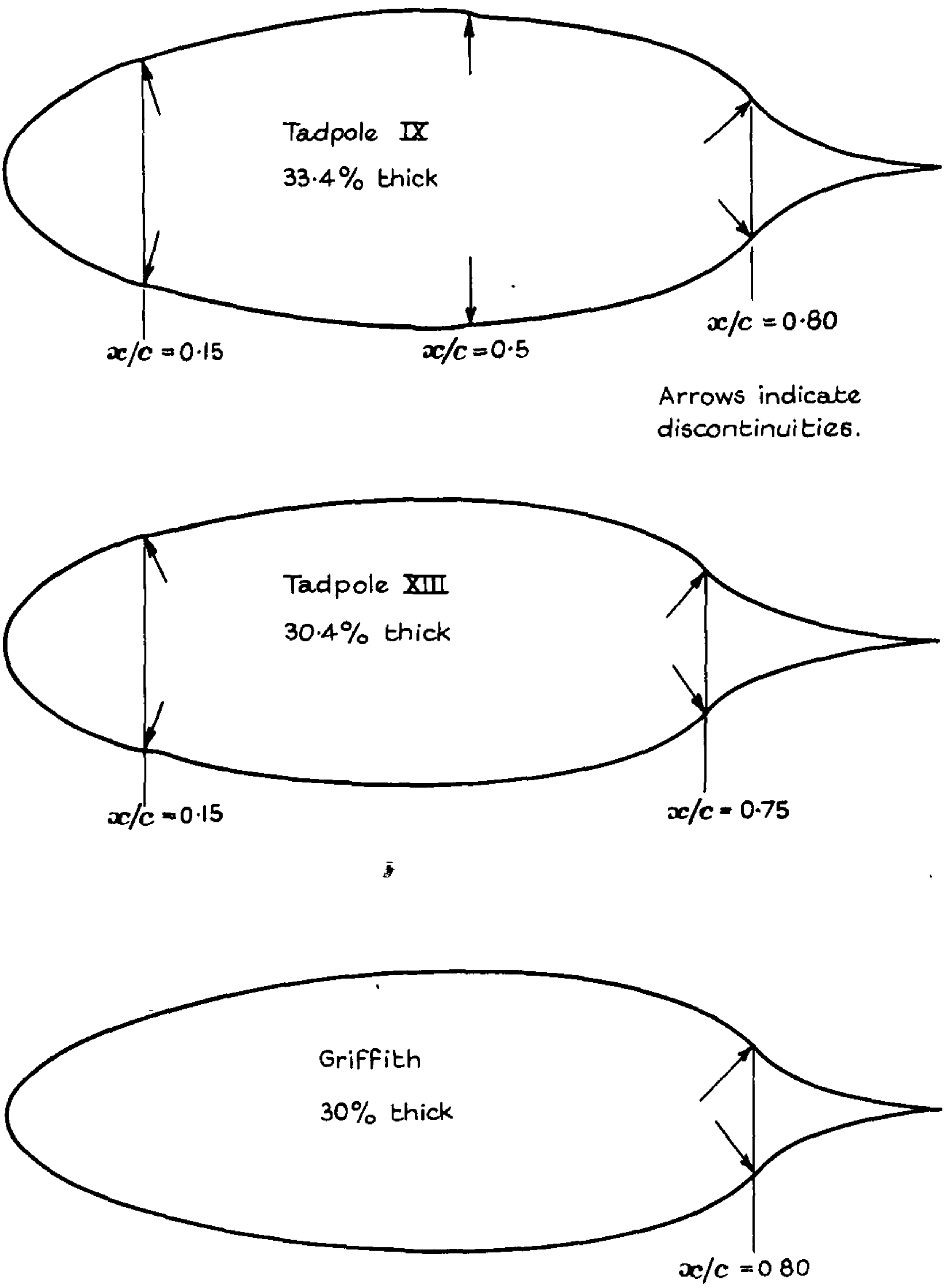
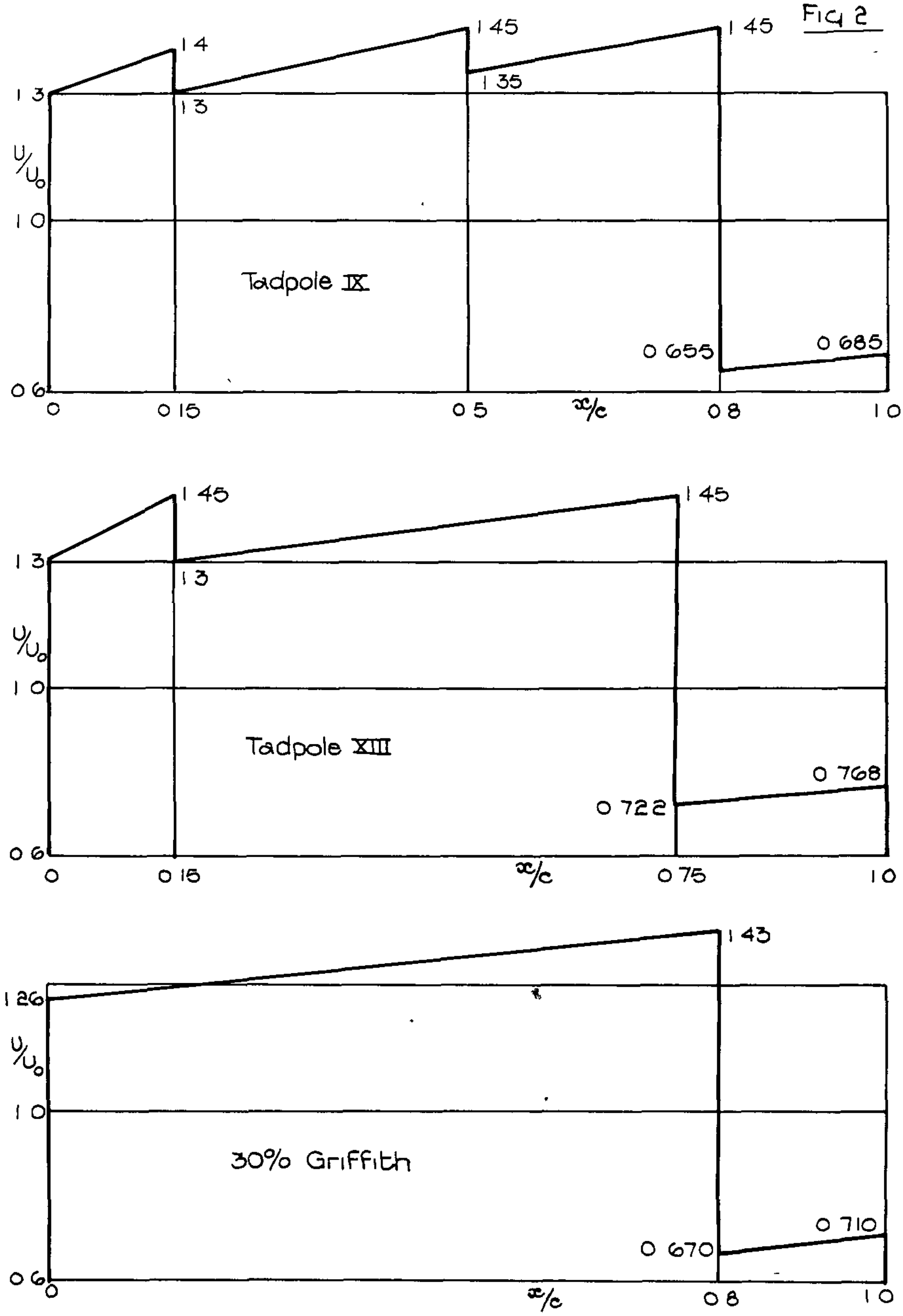


Profiles of 3 Symmetrical Thick Suction Aerofoils.

E.E M.



Velocity Distributions on Approximation I of 3 Suction aerofoils at $C_L = 0$

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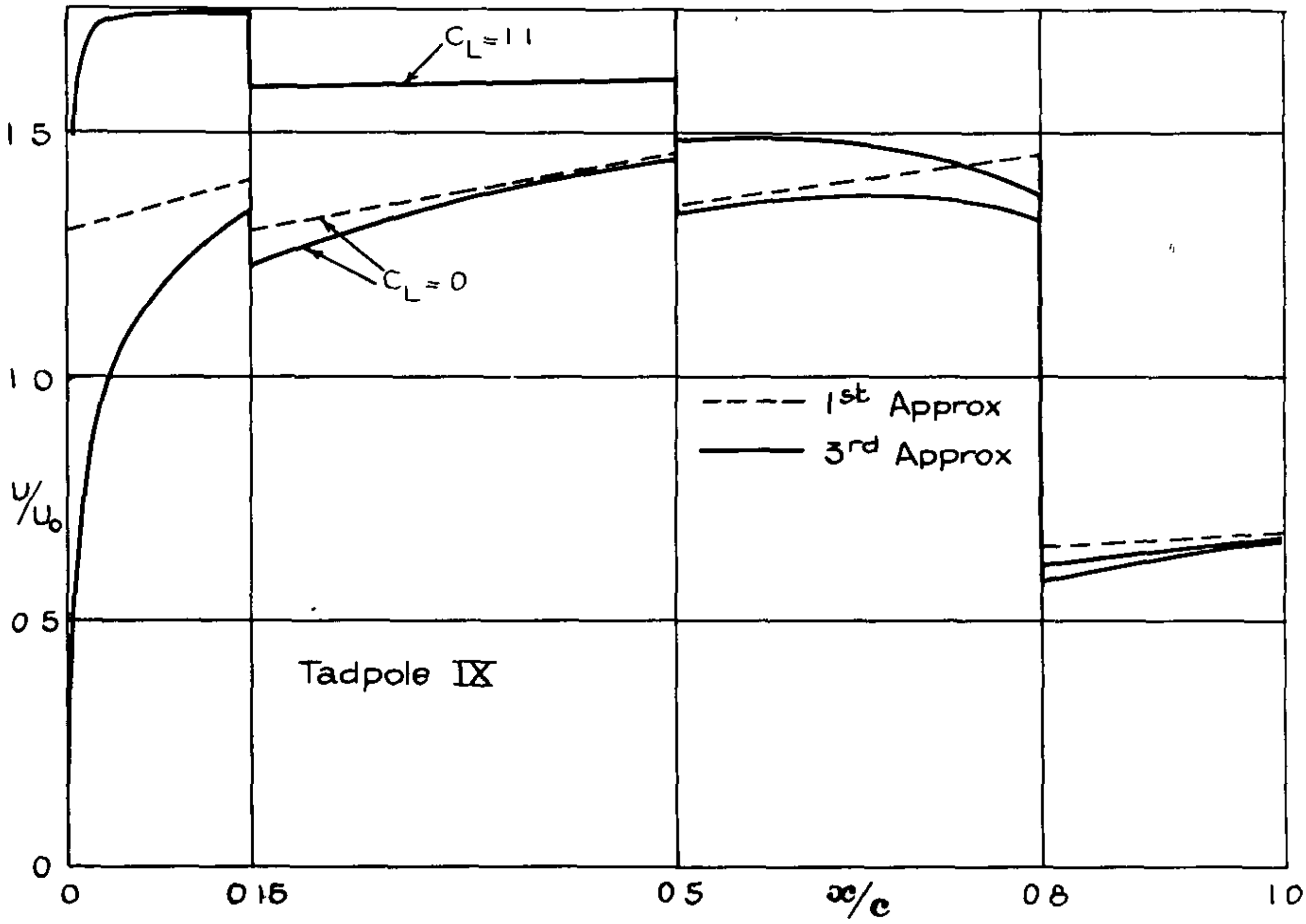
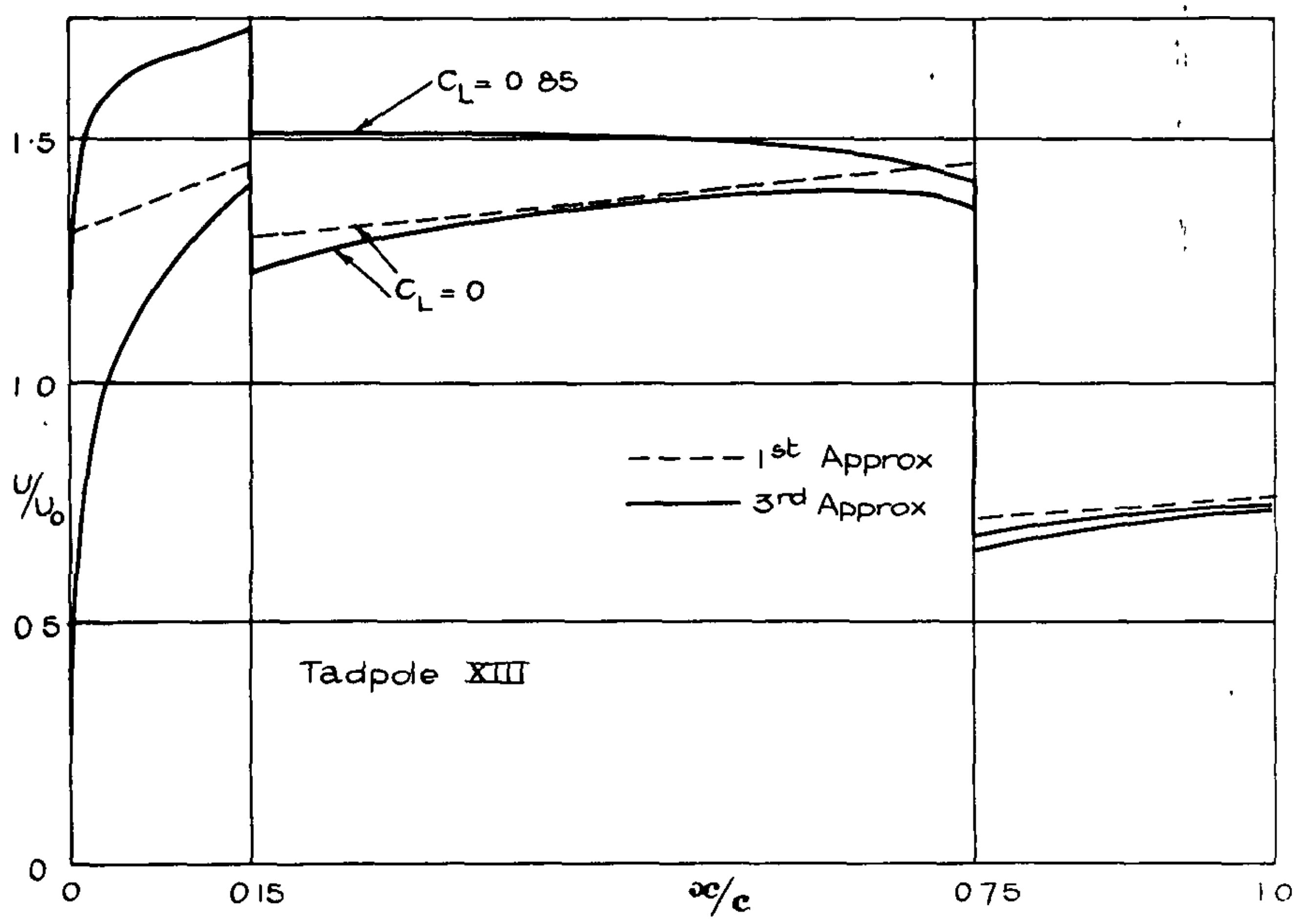
Fig 3a





Velocity Distribution on Approximation III at Zero C_L and at the top of the C_L Range

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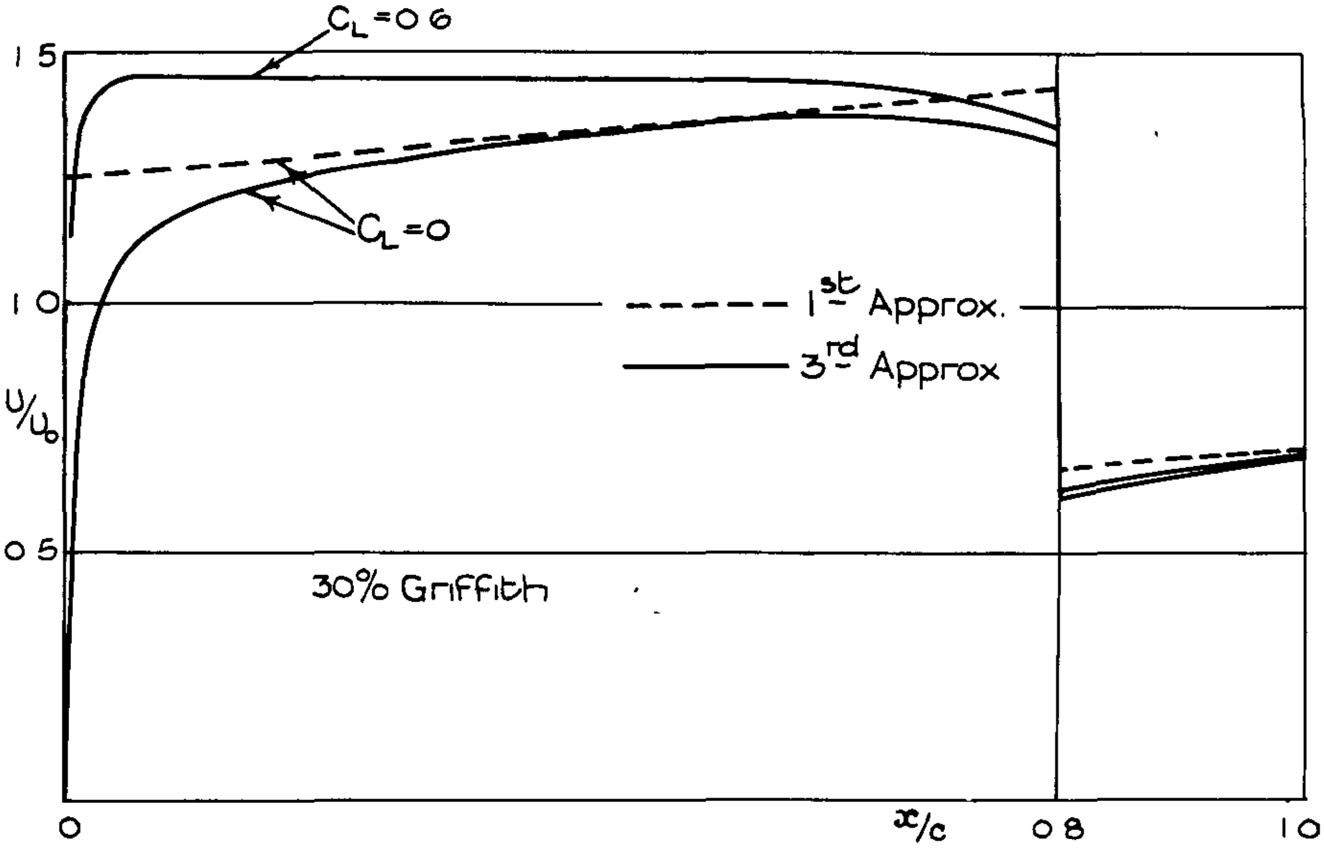

Velocity Distributions on Approximation III at zero C_L and at the top of the C_L range

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