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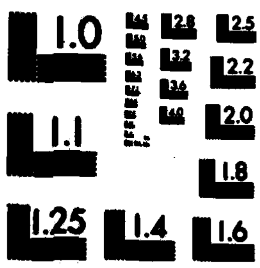

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MELBOURNE, VICTORIA

Aerodynamics Technical Memorandum 388

A NOTE ON THE AERODYNAMIC DESIGN OF THIN PARALLEL-SIDED AEROFOIL SECTIONS (U)

by

N. Pollock

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A NOTE ON THE AERODYNAMIC DESIGN OF THIN PARALLEL-SIDED AEROFOIL-SECTIONS (U)

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SUMMARY

There are many situations where parallel-sided aerofoil sections with leading and trailing edge fairings of limited chordwise extent have advantages over conventional sections. The design of these unconventional sections was investigated using two potential flow plus boundary layer computer programs. Guidelines for the selection of the leading and trailing edge fairing shapes are presented.

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CONTENTS

NOTATION

c	Chord of section
C_D	Drag coefficient = Drag per unit span$/\frac{1}{2}\rho V^2 c$
C_L	Lift coefficient = Lift per unit span$/\frac{1}{2}\rho V^2 c$
C_p	Pressure coefficient = $(P-P_o)/\frac{1}{2}\rho V^2$
P	Local static pressure
P_o	Free stream static pressure
R	Reynolds number based on c
S	Trailing edge curvature parameter - see section 4.2
t	Section thickness
V	Free stream velocity
x	Chordwise coordinate
x_{LE}	Leading edge fairing length
x_{TE}	Trailing edge fairing length
y	Coordinate perpendicular to chord
ρ	Free stream density

1. INTRODUCTION

The familiar families of aerofoil section (see for example Ref.1) pervade all of contemporary aero and hydrodynamic design. They are used for parts of flight or marine systems intended to produce lift with minimum drag. They are also widely used as basically non-lifting fairings for bluff objects where it is desired to minimise drag and flow unsteadiness. However there are many circumstances where a conventional aerofoil section is not necessarily the optimum shape for a fluid swept, approximately two-dimensional, object.

Where design constraints force the use of very thin sections the small leading edge radius on conventional aerofoils produces a number of problems (Refs. 2 & 3). The maximum lift coefficient is limited by an early leading edge separation and the very high velocity peak near the leading edge at incidence will cause early boundary layer transition and increased skin friction drag at some Reynolds numbers. In liquid applications cavitation and ventilation will limit the usable lift. In these situations non-conventional section shapes tending to be parallel sided over a significant portion of their chord could be expected to offer advantages.

Aerofoil sections are a natural choice for fairing bluff objects with large thickness ratio (cross stream dimension/streamwise dimension). The selection of an appropriate aerofoil section is relatively straightforward (Ref.3) since the aerofoil thickness required is almost independent of thickness/chord ratio (Fig.1a). For bluff objects with thickness ratios considerably less than unity the circumscribing aerofoil section thickness is a strong function of the thickness/chord ratio (Fig.1b) and in many real situations the optimisation is difficult. For bluff objects of small thickness it would seem probably that simple leading and trailing edge fairings (Fig.1c) could provide a better compromise than an aerofoil section in some circumstances.

There are some aerodynamic situations where sections with parallel sides over a large portion of their chord are necessary to meet their functional requirements. An example of this is the "ground board" used for reflection plane testing in a low speed wind tunnel (Ref.4). It was this application which motivated the present investigation.

There are also situations where arbitrary rules dictate the use of parallel sided sections where aerofoil sections would otherwise be used. Example of these are centreboards and rudders of some classes of yachts.

The aim of the investigation reported here is to give some guidance as to the selection of suitable *leading and trailing edge fairings for two dimensional flat* plates. The overall thickness/chord ratio range considered is 2% to 6% which covers most of the practical applications. The investigation is limited to incompressible flow in the Reynolds number range 10^5 to 10^7 although the results should be directly applicable to sub-critical compressible conditions.

2. OUTLINE OF METHOD

A series of fairing shapes was investigated using two readily available aerofoil analysis computer programs. The programs were PROFILE (Refs. 6 & 7) and the Improved NASA-Lockheed Multielement Airfoil Analysis Program (Ref.8). Both of these programs were obtained in the form of FORTRAN source code from the NASA Computer Software Management and Information Centre (COSMIC). They were chosen for this investigation due to their availability, adequate accuracy for the present purpose and speed of execution. They are both potential flow programs with a separate boundary layer computation. The NASA program had the capability to iterate between potential and boundary layer solutions and incorporated a representation of the wake.

The programs were used as a "numerical wind tunnel". A series of shapes was tested and, based on an analysis of the results and physical reasoning, further shapes were derived and computed. It would have been possible to specify an optimisation function to be maximised, a series of parameter limits and perform an automated optimisation using the analysis programs inside an optimisation loop. This approach was not adopted since each potential application requires a completely different optimisation function and the procedure does not give any physical insight into the reasons for the identification of the optimum design.

3. ADAPTATION AND VALIDATION OF COMPUTER PROGRAMS

Following modifications necessary to adapt the two programs for operation on the ARL ELXSI-6400 computer system (Appendix) they were applied to a wide variety of problems to gain some insight into their capabilities and limitations. Although both codes had areas where they would not produce solutions, or produced obviously erroneous solutions, they behaved satisfactorily on sections of the type studied in the present investigation (zero camber, thickness chord ratio 2% to 6% and Reynolds number 10^5 to 10^7).

To gain some indication of the accuracy of the codes in this area they were compared with experimental results on two 6% aerofoils, the NACA 0006 and NACA 64A006, from Ref.1. The results of these comparisons are plotted in Figs. 2 & 3. It can be seen that for moderate lift coefficients both codes show a similar and acceptable level of agreement with the experimental results. The largest part of the difference between the two sets of computed results is due to differences in the predicted boundary layer transition points. The more sophisticated boundary layer and wake treatment in the NASA-Lockheed program did not produce significantly better results. The maximum lift coefficient was better predicted by PROFILE than by the NASA-Lockheed code which consistently gave optimistic values.

Since PROFILE gave better results overall and executed considerably faster, it was used for most calculations. However spot checks with the NASA-Lockheed code always showed the same relative performance between different configurations.

All the plotted results presented in this paper were computed using PROFILE. Since PROFILE objected to parallel-sided profiles a very slight divergence was incorporated.

4. RESULTS AND DISCUSSION

4.1 Leading Edges

The semi-ellipse (Fig.5) has been the customary choice for a low speed nose fairing for a parallel-sided two dimensional section. This selection was based on the well behaved pressure distribution produced by this shape (Ref.5) and its known all-round aerodynamically satisfactory behaviour. To investigate the behaviour of semi-elliptic leading edges a series of sections with different fineness ratio fairings were computed. The leading edge shape was given by:

The angles of attack for the onset of gross leading edge separation for the modified and elliptic fairings are presented in Fig.8. For low Reynolds numbers the sharper elliptic fairing gives superior results to the modified fairing for small fairing length. The optimum length for modified fairings at low Reynolds number is large ($x_{LE}/t>5$). This would be expected since it has been known for many years that low Reynolds number aerofoils require sharp leading edges to avoid early laminar separation (Ref.9). At high Reynolds number the modified leading edge has an optimum length of about $x_{LE}/t = 3.5$ where it gives superior results to an optimum elliptic fairing. At intermediate Reynolds numbers the two fairings have similar maximum separation free angle-of-attack ranges, but the modified fairing length required is greater than that for the elliptic fairing.

In situations where cavitation, ventilation or compressibility are significant design considerations the minimum pressure coefficient is an important parameter. The section with the numerically smaller negative pressure peak will have superior characteristics. For all practical parallel-sided sections the lowest pressure occurs near the leading edge at all angles-of-attack. In Fig.9 the variation of minimum pressure coefficient with angle-of-attack and fairing length is plotted for a 4% thick section with both leading edge shapes. The results for 2% and 6% thick sections show very similar trends. For angles-of-attack below 4° the elliptic fairing is superior to the modified one. For angles-of-attack above 4° the modified fairing is superior to the elliptic one. The apparent superiority of the very short elliptic fairing at high angles of attack cannot be realised due to premature separation.

Where a parallel-sided section is to be used as a ground plane or end plate, the minimum deviation from free stream velocity over the greatest possible portion of the chord is the main design requirement. Although these applications involve nominally zero angle-of-attack they will usually experience induced flow angularity and the performance at small angles will be important. At zero incidence the leading edge fairing creates a positive surface velocity increment (i.e. negative pressure coefficient) which dies away as the flow moves aft until the region of influence of the trailing edge fairing is reached. At incidence the additional negative pressure coefficient on the leeward surface will exceed the positive increment on the windward surface. The pressure coefficient near the leading edge (say at 0.1c) on the leeward surface gives a good indication of the departure from free stream conditions over the major part of the section. In Fig.10 this $x/_c = 0.1$ pressure coefficient is plotted against fairing length for both leading edge types and $t/_c = 4\%$. The same trends are observed for 2% and 6% thick sections. It can be seen that the modified leading edge is superior to the elliptic one for all leading edge lengths. The modified leading edge shape would therefore be the normal choice for a ground board or splitter plate in an aerodynamic experiment.

There is little to suggest that leading edge fairing shapes intermediate between the elliptic and zero curvature at tangency types would have significant advantages. However for particularly demanding specific applications they may be worth investigating.

$$y = \pm \frac{t}{2}\sqrt{1 - \frac{(x_{LE} - x)^2}{x_{LE}^2}}$$

where the variables are defined in Fig.4

For the trailing edge a simple quadratic fairing was used (Fig.6). The shape was given by:

with x_{TE}=4.
$$y = \pm \frac{t}{2}\left(1- \frac{(x - c + x_{TE})^2}{x_{TE}^2}\right)$$

Since premature leading edge separation is one of the major problems with thin sections, the effect of section thickness and elliptic leading edge fineness ratio on angle of attack for significant separation was investigated. The results are shown in Fig.7. Boundary layer separation very near the trailing edge was predicted for all angles of attack where the leading edge flow remained attached. However this had no effect on the predictions of leading edge separation since there was no iterative solution of boundary layer and potential flow. The pressure distribution calculated and used in the prediction of leading edge separation was that for an attached trailing edge flow.

The differences between the predicted separation angles of attack for geometrically similar leading edges on different thickness sections are due partly to the differences in Reynolds number based on a characteristic leading edge fairing dimension and partly on the effect of the trailing edge on the leading edge pressure distribution. No attempt to separate these two effects was made. However as would be expected there is a clear trend for the thicker sections to retain attached flow to higher angles of attack.

For most of the cases computed there is a maximum separation free angle of attack for leading edge fairing lengths in the range $2<x_{LE}/t<3$ with earlier separation for longer and shorter fairings. This suggested two different separation mechanisms and an examination of the computations showed that for long fairings the separation occurred on the small radius-of-curvature nose, while for short fairings the separation occurred on the shoulder where the fairing was tangent to the parallel-sided part of the section. The maximum separation angle-of-attack occurred at the transition between these two states. Some of the separations were clearly laminar, some turbulent and some indeterminate. From Fig.7 it is evident that if an elliptic leading edge fairing is used a x_{LE}/t value of 2 will give the largest angle-of-attack range under most conditions.

The elliptic leading edge results suggested the possibility of greater angle-of-attack ranges if one of the separation modes could be suppressed. To explore this possibility a modified leading edge profile with zero curvature at the point of tangency between fairing and section was investigated. The shape (Fig.5) was necessarily blunter than an elliptic one of the same length and was given by:

$$y = \pm \frac{t}{2}\left(\frac{8\sqrt{x}}{3\sqrt{x_{LE}}} - \frac{2x}{x_{LE}} + \frac{x^2}{3x_{LE}^2} \right)$$

4.2 Trailing Edges

As for the leading edge fairing, the first requirement of the trailing edge fairing is the elimination or minimisation of separation. Section drag would probably be the most appropriate parameter to assess the seriousness of trailing edge separation. However neither of the analysis methods used gave a good estimate of drag in the presence of separation so the y coordinate of the separation point divided by the total section thickness was adopted. This gives some indication of the wake thickness.

The variation of separation point coordinate with trailing edge length for a quadratic fairing on a 4% thick section at zero incidence is shown in Fig.11. Similar results are obtained for other thickness ratios and the separation points are relatively insensitive to angle of attack. Separate curves for laminar and turbulent approach boundary layers are presented. For most parallel sided sections at incidence with chord Reynolds numbers less than 10^7 the windward surface boundary layer is laminar at the start of the trailing edge fairing and the leeward surface layer is turbulent. At zero incidence for Reynolds numbers not greatly exceeding 10^6, both boundary layers will be laminar if $x_{LE}/t > 3$ for elliptic leading edge fairings, or $x_{LE}/t > 4$ for modified fairings. It is evident from Fig.11 that trailing edge fairing lengths of around 6t are required to obtain attached flow with a turbulent approach boundary layer and even longer fairings with laminar layers. As would be expected longer fairings always give superior results to shorter ones.

The quadratic fairing shape considered up to this point was selected since it was the simplest that would meet the required conditions of tangency with the basic section and zero trailing edge thickness. To investigate the effect of fairing shape in more detail a cubic expression was used with the slope at the trailing edge as an additional parameter.
The shape was given by:

$$y = \pm \frac{t}{2} \left(1 + (2S-3)\frac{x_1^2}{x_{TE}^2} + 2\,(1-S)\,\frac{x_1^3}{x_{TE}^3} \right)$$

where $x_1 = x - c + x_{TE}$

$$\text{and } S = \frac{\text{Slope at } x = c}{\text{Slope at } x = c \text{ for quadratic fairing of same } x_{TE}}$$

For S = 1 the cubic shape reduces to the earlier quadratic form and for S = 0.75 the special case of zero surface survature at the trailing edge results. For S<0.75 the fairings have concave regions.

In Fig.12 the variation of trailing edge separation y coordinate is plotted against the slope parameter for a 4% thick section with an x_{TE} = 4t cubic fairing. Similar results are obtained for other thicknesses and trailing edge lengths. For a laminar approach boundary layer a minimum in y_{sep} occurs for values of S between 0.75 and 1.0. For a turbulent layer y_{sep} reduced monotonically with reducing S. For general use the zero curvature S = 0.75 shape appears to be a good choice.

As noted previously the major requirement for sections for ground board and splitter plate applications is the minimum deviation from free stream velocity ($c_p = 0$) over the greatest chordwise extent. The fairing required to provide trailing edge closure inherently produces a local flow acceleration which has some upstream influence. The shorter the trailing edge fairing the further downstream this acceleration occurs, but the greater its magnitude. The result of these conflicting effects for a specific trailing edge fairing is shown in Fig.13. Very short fairings show definite superiority in this particular situation and this result appears to be fairly general from the calculations conducted. Short fairings could have significant separation and the truncation of the section to produce a bluff base could give good results in some circumstances.

4.3 Comparison Between Parallel-Sided and Conventional Aerofoils

To provide some insight into their relative performance, a conventional and a parallel-sided section were compared. A thickness/chord ratio of 4% was chosen and a scaled thickness NACA 64006 profile was used as the conventional reference aerofoil. Although in principle NACA 6-series sections can not be simply scaled, the section produced had a satisfactory pressure distribution and was considered to be representative of good modern practice. On the basis of the investigations reported above a parallel-sided section with a 4t long modified leading edge fairing and a 5t long, S = 0.75, cubic trailing edge fairing was selected for comparison. The two section shapes are compared in Fig.14. It can be seen that the parallel-sided section has considerably greater cross section area and would have even greater strength (first moment of area) and stiffness (second moment of area) than the conventional section.

Comparative lift-drag curves are plotted in Fig.15. At a Reynolds number of 10^5 both sections have a similar maximum lift and the conventional section has consistently lower drag. At a Reynolds number of 10^6 the parallel-sided section has approximately double the maximum lift, but higher drag than the conventional section. At a Reynolds number of 10^7 the parallel-sided section has more than double the maximum lift of the conventional section and lower drag at lift coefficients above 0.15. The rise in drag at low lift appears to be a genuine effect associated with the movement of the transition points.

It is clear that conventional section shapes are not necessarily the optimum shape for very thin aerofoils.

5. CONCLUSION

There are many situations in which parallel-sided sections with leading and trailing edge fairings of limited chordwise extent have advantages over conventional sections. A numerical investigation into the design of this type of profile was undertaken using the Improved NASA-Lockheed Multielement Airfoil Analysis Program and the Eppler program PROFILE. A section thickness range of 2% to 6% and a Reynolds number range of 10^5 to 10^7 were covered.

The main conclusions were:

a. For a conventional semi-elliptic leading edge fairing a maximum angle of attack range is realised for a fairing length to thickness ratio of approximately 2.

b. For many applications a leading edge fairing with zero curvature at the point of tangency has advantages over an elliptic fairing.

c. Trailing edge fairings defined by a cubic function with zero curvature at the trailing edge have favourable characteristics.

d. For ground board or splitter plate applications in aerodynamic testing, the shortest practical leading and trailing edge fairings should be used.

The use of relatively simple potential flow and boundary layer programs as a "numerical wind tunnel" was found to be a valuable design technique allowing a wide range of shapes to be investigated at low cost.

REFERENCES

1. I.H. Abbott & A.E.Von Doenhoff — Theory of Wing Sections. Dover Publications N.Y. 1959

2. S.F. Hoerner & H.V. Borst — Fluid-Dynamic Lift. Hoerner Fluid Dynamics N.J. 1975

3. S.F. Hoerner — Fluid-Dynamic Drag Hoerner Fluid Dynamics N.J. 1965.

4. W. Rae & A. Pope — Low Speed Wind Tunnel Testing 2nd Edition. Wiley 1984

5. J.L. Hess & A.M.O. Smith — Calculation of Potential Flow About Arbirtary Bodies. Progress in Aeronautical Sciences Vol. 8. D.Kuchemann Ed. Pergamon Press. 1967.

6. R. Eppler & D.M. Somers — A Computer Program for the Design and Analysis of Low-Speed Airfoils. NASA Tech. Memo. 80210. 1980.

7. R. Eppler & D.M. Somers — Supplement to: A Computer Program for the Design and Analysis of Low-Speed Airfoils. NASA Tech.Memo.81862. 1980

8. G.W. Brune & J.W. Manke — An Improved Version of the NASA-Lockheed Multielement Airfoil Analysis Computer Program. NASA CR-145323. 1978.

9. F.W. Schmitz — Aerodynamics of the Model Airplane, Part 1 - Airfoil Measurements. 1942 Redstone Scientific Information Centre, Translation RSIC-721.

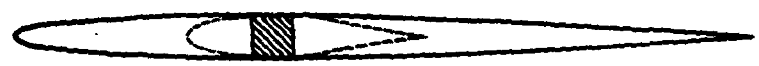
APPENDIX

Modification to Programs for use on ARL ELXSI 6400 computer system

In program PROFILE the 5th parameter in the call to subroutine GAUSS in subroutine PANEL was a constant. Not surprisingly when GAUSS tried to change the value of this parameter an error was generated. The solution adopted was to replace the constant in the call with a dummy variable initialised to the appropriate value (0.) prior to the call. To avoid floating overflows when computing thin sections the +DOUBLE compiler switch (64 bit precision) was used.

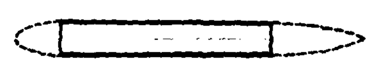
The modifications to the NASA-Lockheed program were more extensive. Due to the effectively unlimited virtual memory size of the ELXSI the overlay structure of the code was removed by treating the overlay calls as subroutine calls. The code used a dynamic storage system which relied on operating system specific capabilities which were not readily simulated on the ELXSI. The solution adopted was to define a large (60 000) one dimensional array and EQUIVALENCE-ing all variables stored in dynamic storage to this array. The function LOCF always returned the value 1. The statement SAVE LOCB, IPA was added to subroutine DYNSET and SAVE THTFIX was added to subroutine BLTRAN. The assembly language matrix manipulation routines VIP and VIPD were replaced with FORTRAN translations. Many other minor changes were made to bring the code up to current FORTRAN standards. After operating the code for some time it was found that although boundary layer transition following laminar separation was correctly predicted, *natural transition never* occurred. The problem was traced to the inconsistent dimensioning of array A in routines BLTRAN, POINT and SLOPE. The effect was to overwrite the local switch variables KON and KCH in BLTRAN. The solution adopted was to DIMENSION array A(4) in BLTRAN. The use of the +DOUBLE compiler switch overcame occasional errors in the boundary layer routines.

The fixed input formats in both codes were converted to free format to simplify the preparation of data files.



a. *High thickness ratio object - NACA 64 series sections*

b. Moderate thickness ratio object
- NACA 64 series sections



c. Moderate thickness ratio object
- simple leading and trailing edge fairings

FIG. I. AERODYNAMIC FAIRINGS FOR BLUFF OBJECTS

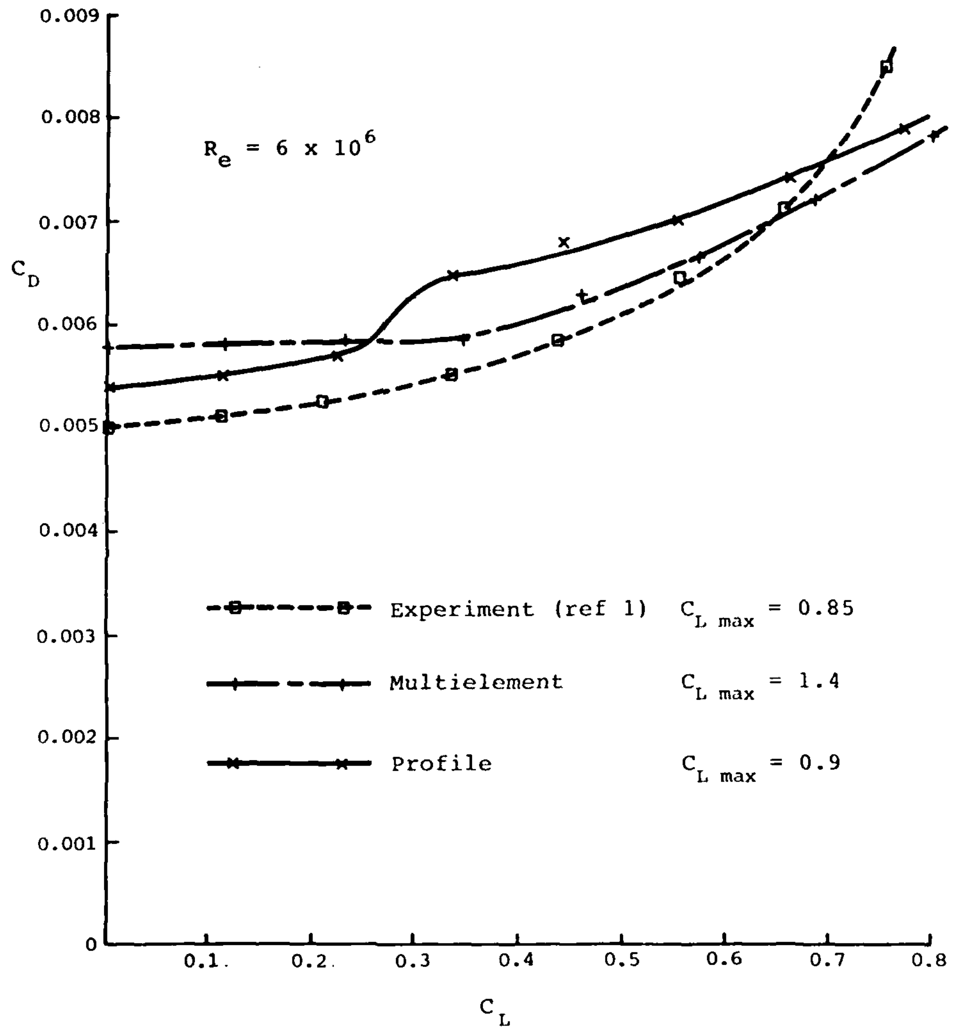


FIG. 2. COMPARISON BETWEEN COMPUTATION AND EXPERIMENT - NACA 0006

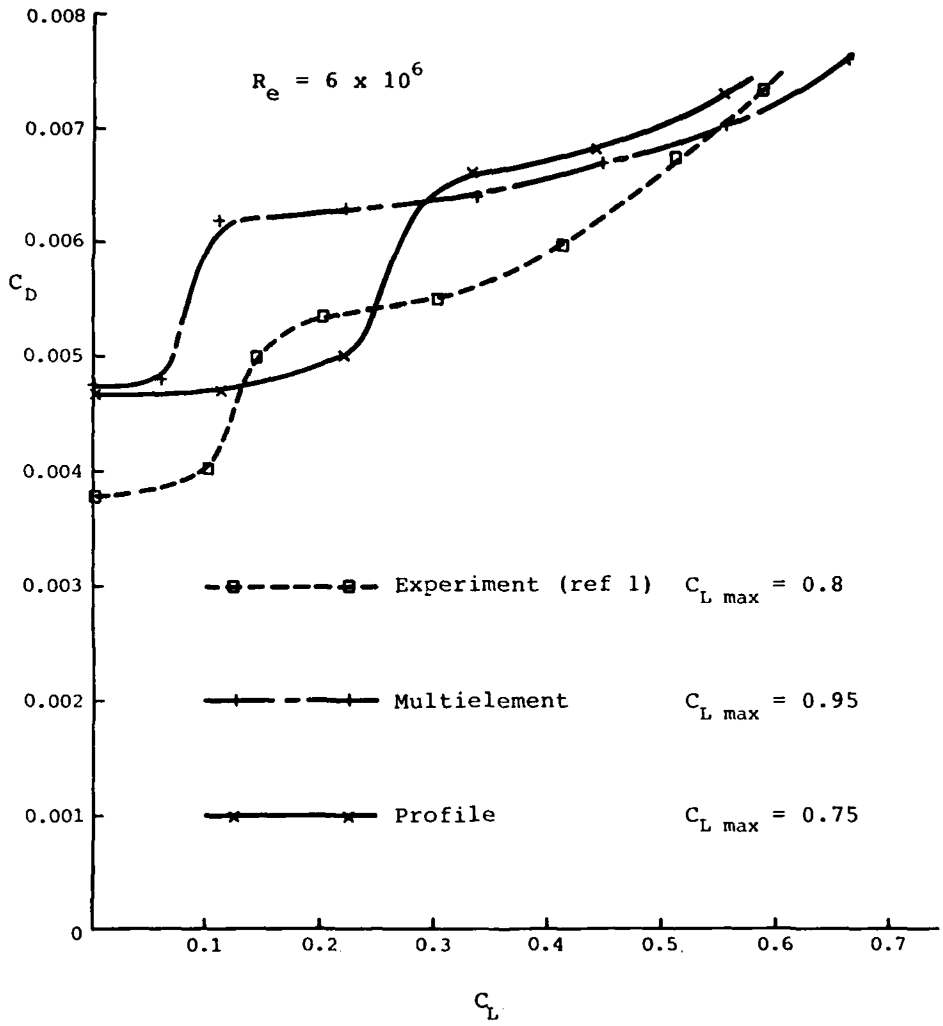


FIG. 3. COMPARISON BETWEEN COMPUTATION AND EXPERIMENT - NACA 64A006

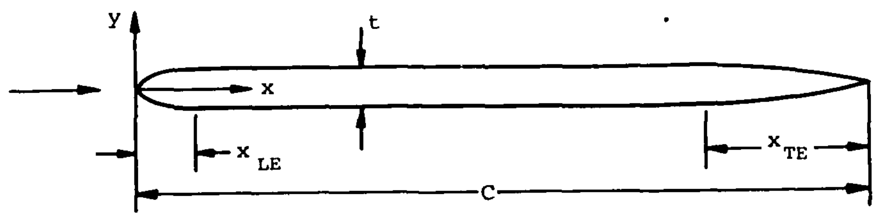


FIG. 4. BASIC DIMENSIONS OF SECTION

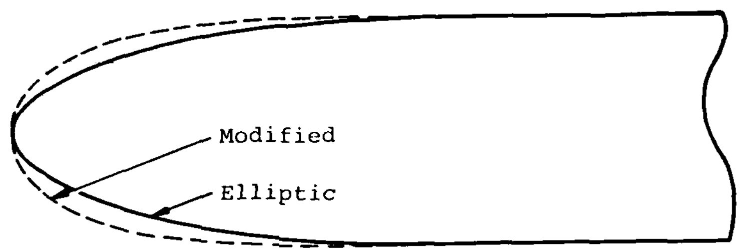


FIG. 5. LEADING EDGE SHAPES $x_{LE}/t = 2.5$

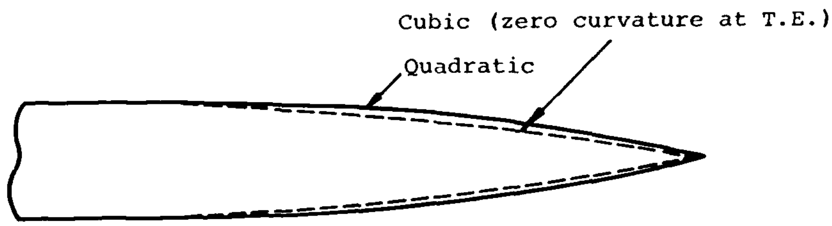


FIG. 6. TRAILING EDGE SHAPES $x_{TE}/t = 5.0$

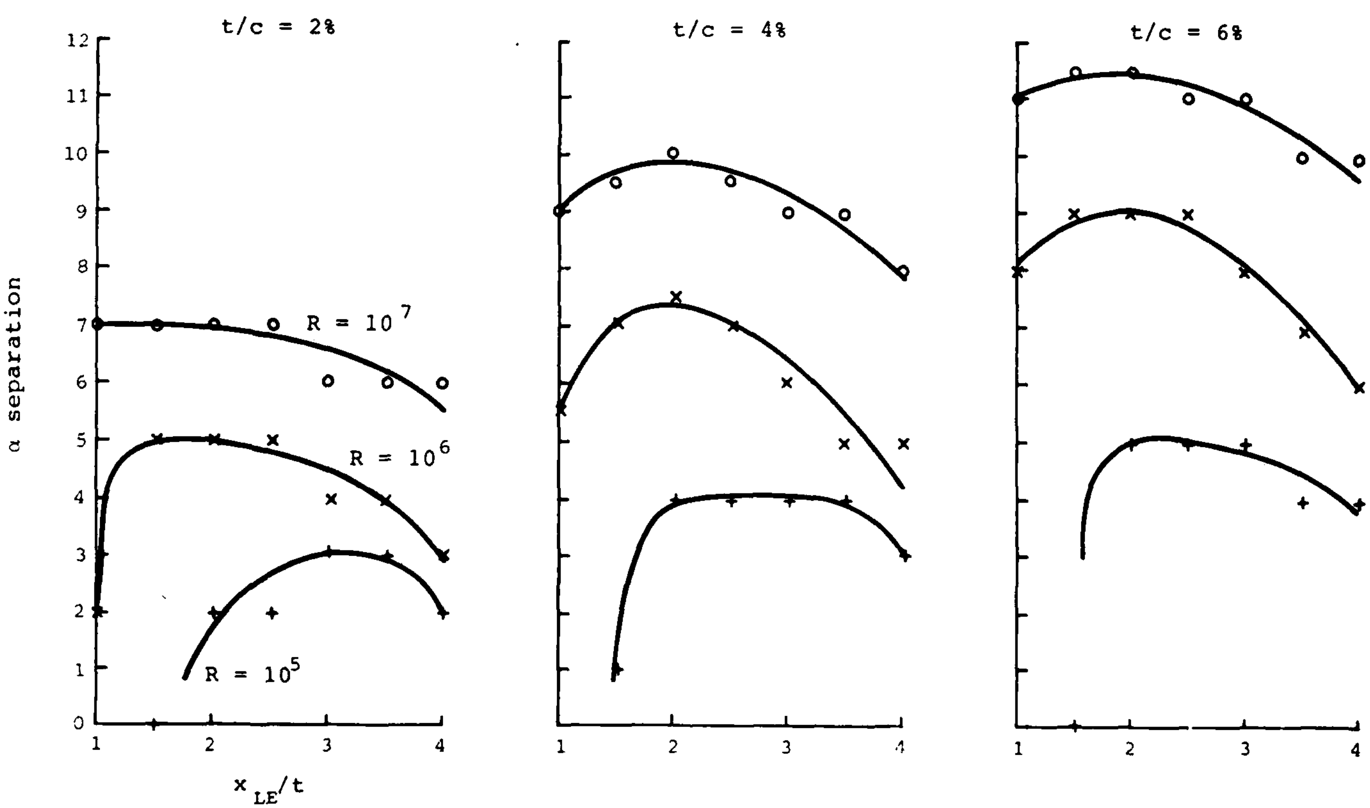


FIG. 7. VARIATION OF ANGLE OF ATTACK FOR GROSS SEPARATION WITH t/c, x_{LE}/t AND R-ELLIPTIC LEADING EDGE

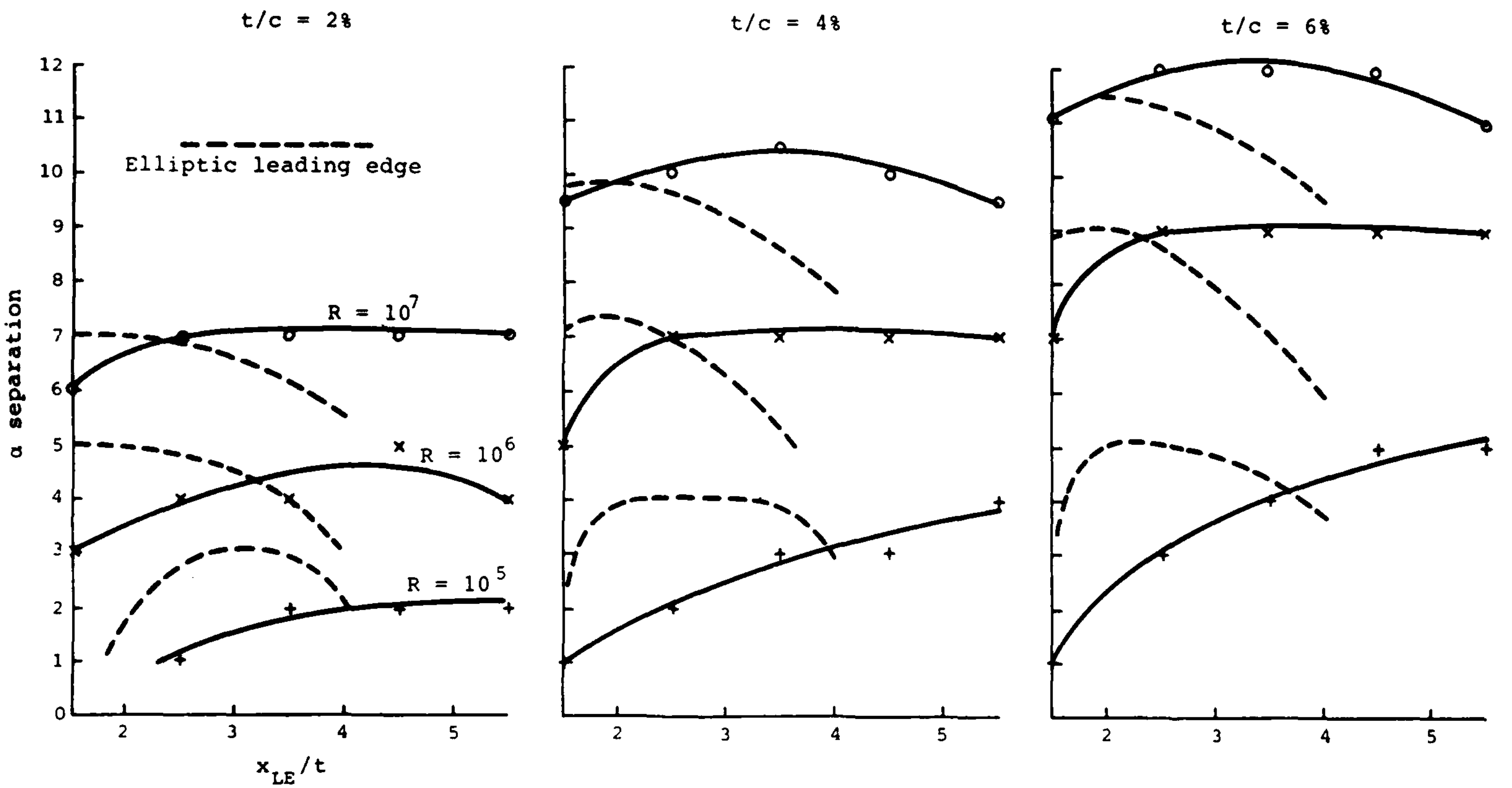


FIG. 8. VARIATION OF ANGLE OF ATTACK FOR GROSS SEPARATION WITH t/c, x_{LE}/t AND R-MODIFIED LEADING EDGE.

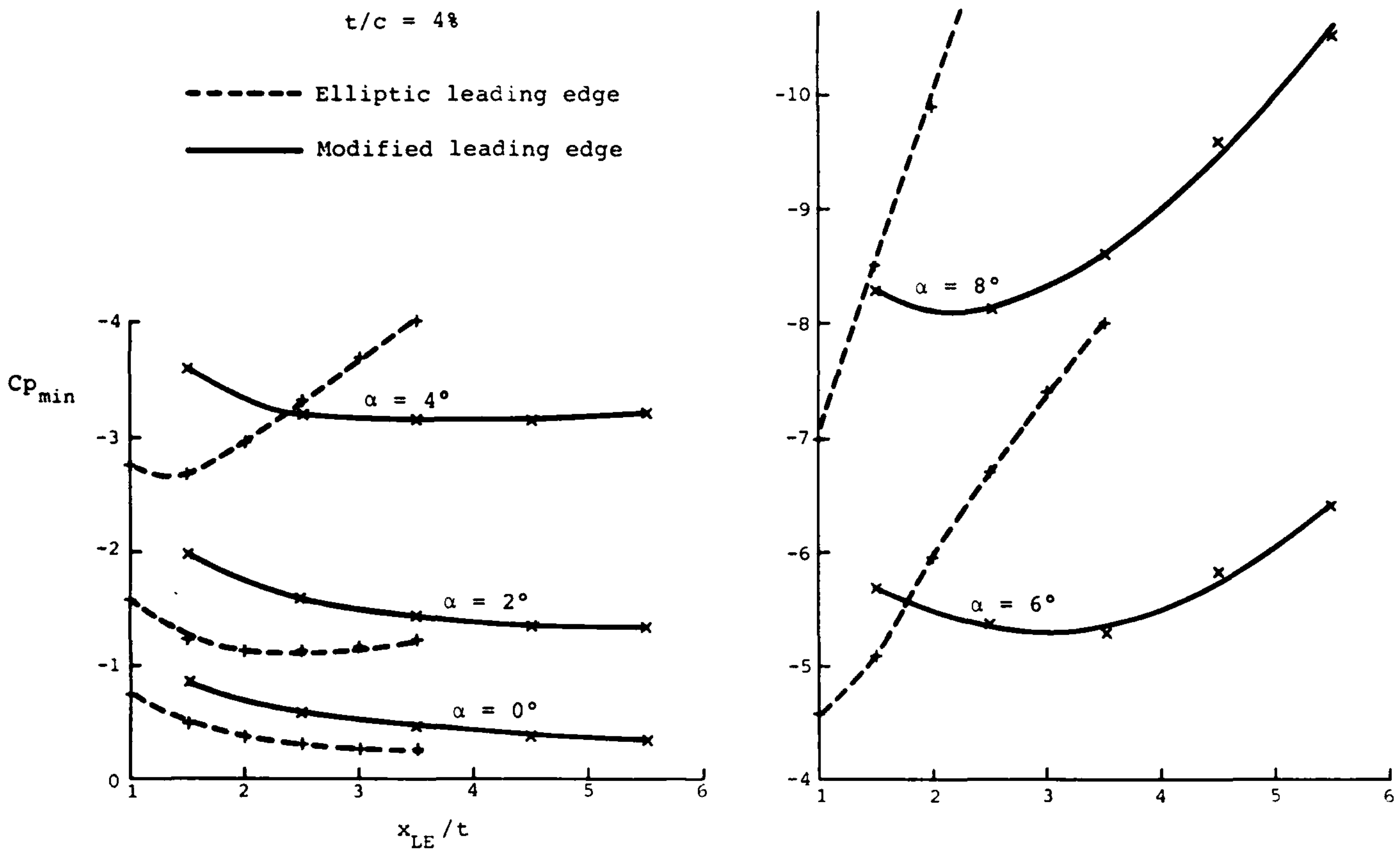


FIG. 9. VARIATION OF MINIMUM PRESSURE COEFFICIENT WITH LEADING
LEADING EDGE SHAPE

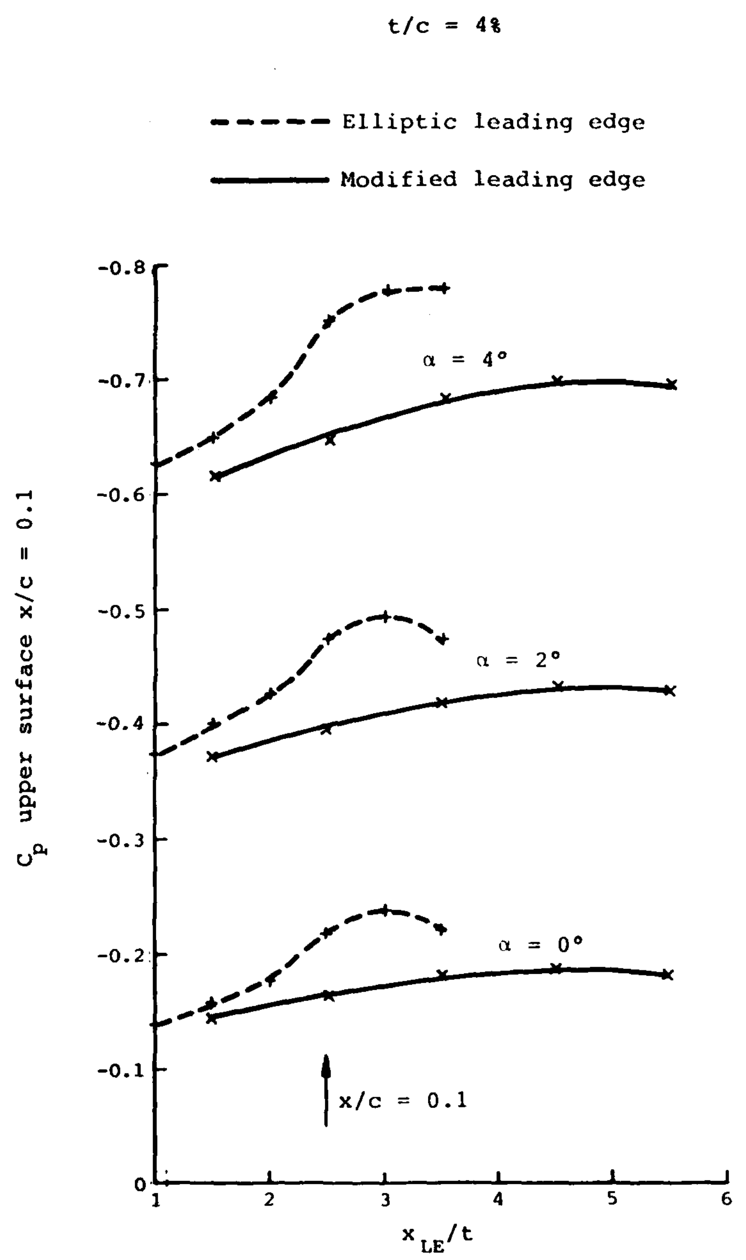


FIG. 10. VARIATION OF PRESSURE COEFFICIENT AT x/c = 0.1 WITH LEADING EDGE SHAPE

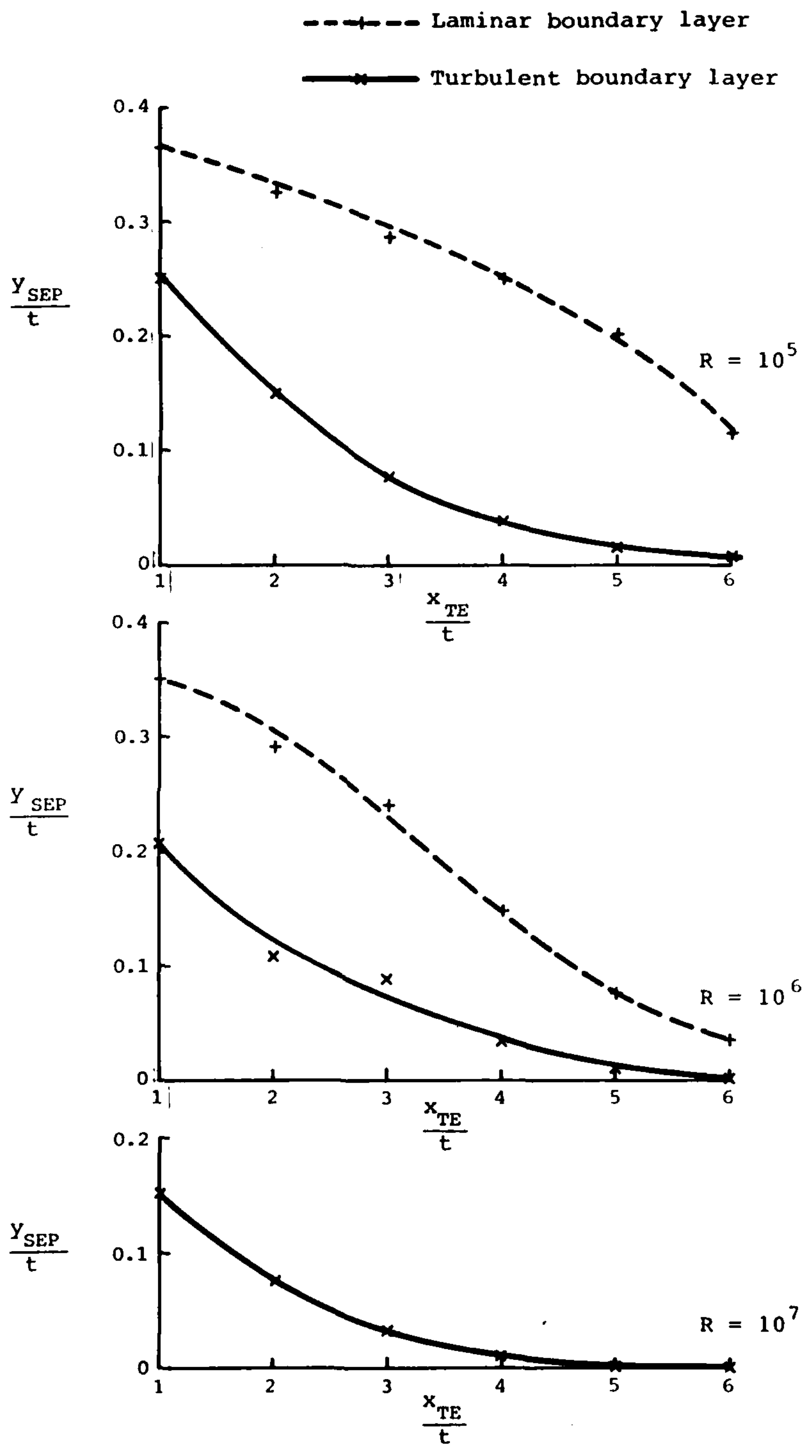


FIG. 11. VARIATION OF Y COORDINATE OF SEPARATION WITH TRAILING EDGE LENGTH - QUADRATIC TRAILING EDGE, t/c = 4%

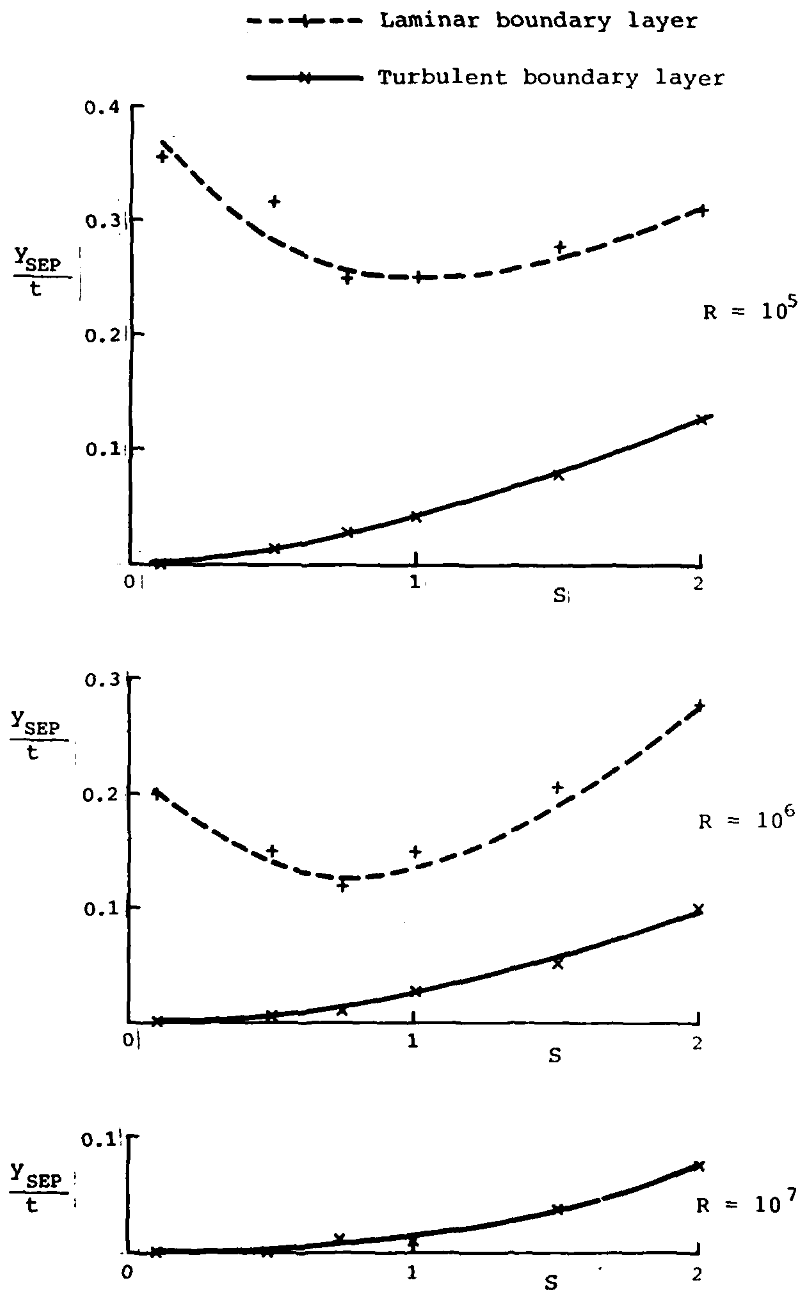


FIG. 12. VARIATION OF y COORDINATE OF SEPARATION WITH TRAILITY EDGE SLOPE PARAMETER S - CUBIC TRAILING EDGE x_{TE} = 4t, t/c = 4%

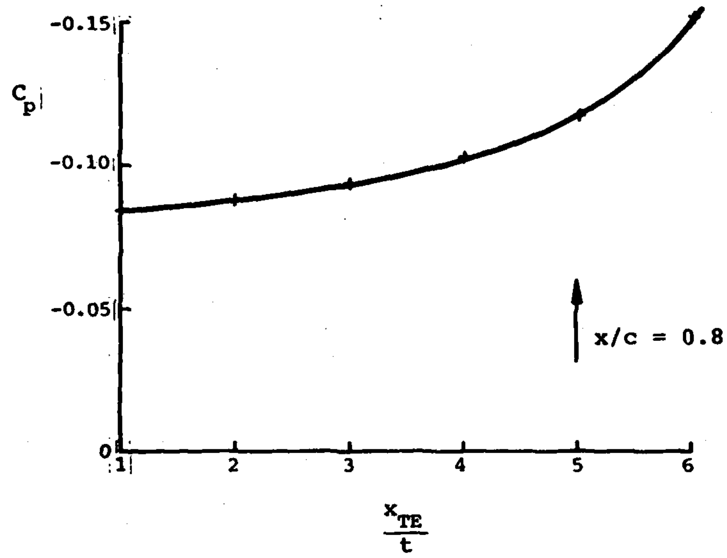
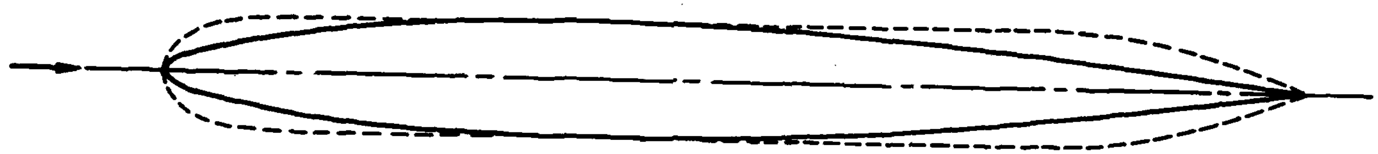


FIG. 13. VARIATION OF PRESSURE COEFFICIENT AT x/c = 0.8 WITH TRAILING EDGE LENGTH - QUADRATIC TRAILING EDGE, t/c = 4%, α = 0°

Scaled NACA 64006 section

Parallel sided section
Modified leading edge $x_{LE} = 4t$

$S = 0.75$ trailing edge $x_{TE} = 5t$



Note: Thickness coordinates multiplied by 2.5

FIG. 14. CONVENTIONAL AND PARALLEL SIDED AEROFOIL SECTIONS, t/c = 4%

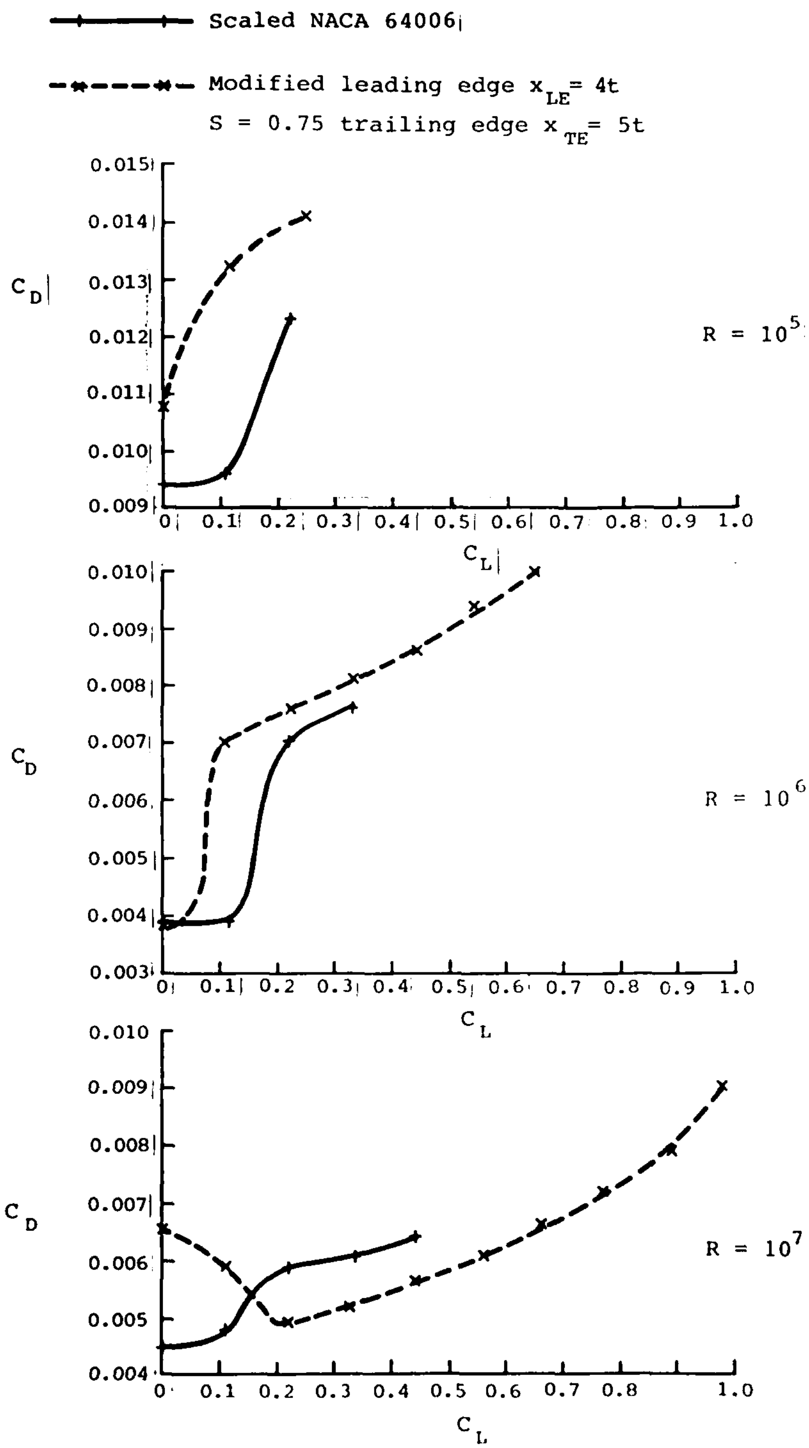


FIG. 15. COMPARISON BETWEEN CONVENTIONAL AND PARALLEL SIDED SECTIONS t/c = 4%

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There are many situations where parallel-sided aerofoil sections with leading and trailing edge fairings of limited chordwise extent have advantages over conventional sections. The design of these unconventional sections was investigated using two potential flow plus boundary layer computer programs. Guidelines for the selection of the leading and trailing edge fairing shapes are presented.

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