NASA-TM-75402 19810007469

NASA TECHNICAL MEMORANDUM

NASA TM-75402

DISCUSSION OF TEST RESULTS IN THE DESIGN OF LAMINAR AIRFOILS FOR COMPETITION GLIDERS

Jerzy Ostrowski, Stanislaw Skrzynski and Mieczyslaw Litwinczyk

Translation of "Omowienie wynikow badan zwiazanych z konstruowaniem profilow laminarnych dla szybowcow wyczynowych", Archiwum Budowy Maszyn, Vol. 25, No. 1, 1978, pp 105-120.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 DECEMBER 1980

STANDARD TITLE PAGE

1. Report No. NASA TM- 75402	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DISCUSSION OF TEST RESULTS IN THE DESIGN OF LAMINAR AIRFOILS FOR COMPETITION GLIDERS		5. Report Date December 1980
		6. Performing Organization Code
7. Author(s) Jerzy Ostrowski, Stanislaw Skrzynski and Mieczyslaw litwinczyk		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No.
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Admin. Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Omowienie wynikow badan zwiazanych z konstruowaniem profilow laminarnych dla szybowcow wyczynowych", Archiwum Budowy Maszyn, Vol. 25, No. 1, 1978, pp 105-120.

16. Abstract The paper discusses some results of an investigation into phenomena of flow influencing in an essential manner the properties of laminar airfoils. The subject of the investigation was the deformation of flow in the boundary layer and local separation of a laminar layer (laminar bubbles) from various airfoils. These phenomena are classified and their influence is discussed. Another subject of discussion are various aerodynamic characteristics and the principles for prescribing pressure distribution to attain a high value of $c_{z\ max}$ with a possibly low drag coefficient.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

DISCUSSION OF TESTS RESULTS IN THE DESIGN OF LAMINAR AIRFOILS FOR COMPETITION GLIDERS

Jerzy Ostrowski, Stanislaw Skrzynski and Mieczyslaw Litwinczyk

Optimization of flight profiles, especially for swift planes, /105* has usually been achieved from the point of view of reducing lag coefficient. The carrying power of such profiles has been augmented by appropriate mechanization of the wing in an attempt to attain coefficients of maximal carrying power considerably higher than those of the basic profile.

In glider construction there is a limit on wing mechanization: either flap and brake (open class) or brake alone (standard class). This is the reason for dissimilarity of standards set for glider profiles, especially in the standard class. Here the criterion of minimal lag is still in force, yet the requirements for the size of $c_{z\ max}$ are on the increase. It is particularly important to achieve high $c_{z\ max}$ values for small (in the scale of aviation applications) Re numbers, starting with values less than one million.

For a long time glider builders used NACA laminar profiles. In the early 1960's profiles of the Fx (Wortman) type appeared with better properties than the NACA. However there was still a need for complete documentation of these profiles as well as of a good deal of information necessary for constructors' estimates of the features of the glider being planned.

This was the situation when during that decade a joint commission came from the Bielsk Glider Factory and the former Aerodynamics Department of the Warsaw Polytechnic to undertake research aimed at securing the missing information in respect to the properties of profiles in the range of small Reynolds numbers and to run tests on the modifications of such profiles for improving their features. For this

* Numbers in the margin indicate pagination in the foreign text.

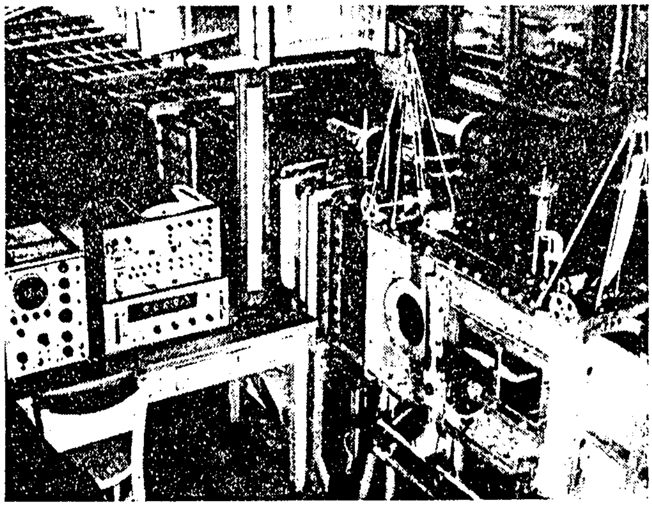


Fig. 1

purpose we built a small laminar tunnel, providing for its regulation, and we planned and set up the instrumentation (Fig. 1). We then carried out preliminary flow characteristic tests, worked out a method of measurements, deter- /106
mined improvements on the tunnel and assessed a number of factors affecting the range and results of measurements.

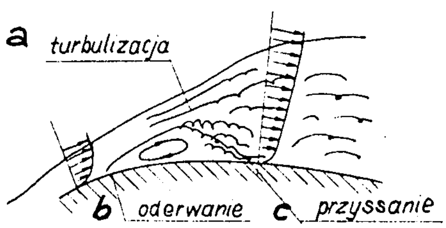


Fig. 2

Key: a. turbulence
b. separation
c. adherence

Analysis of the reflux for various profiles and the existing experimental data (even though at the beginning of the testing these were very scant for small Re numbers) indicated the fairly real influence of certain flow phenomena in the laminar border layer, particularly in the zone of transition between laminar and turbulent flow, the value for $c_{z\ max}$, the course of separation and the plotting of the c_z and c_x curves. These flow phenomena, until now studied without much system, occurred in the shape of fully developed "laminar bubbles".

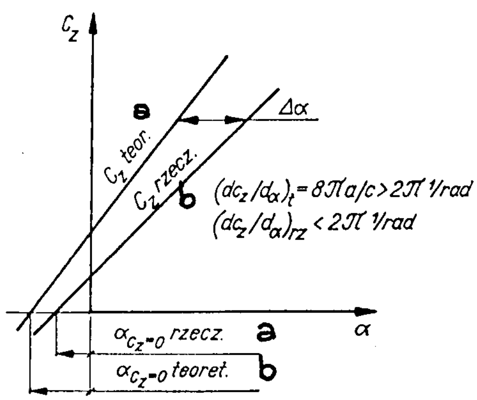


Fig. 3

Key: a. theoretical
b. actual

As a function of profile formation, Re number and surface unevenness these bubbles arise in the area of narrower or wider angles of friction and occasion either changes in the course of the c_z and c_x curves or else a slow or rapid separation process. Fig. 2 shows how a laminar bubble occurs. It is characterized by separation of the laminar border layer and adherence of this layer as a turbulent layer. In its fully

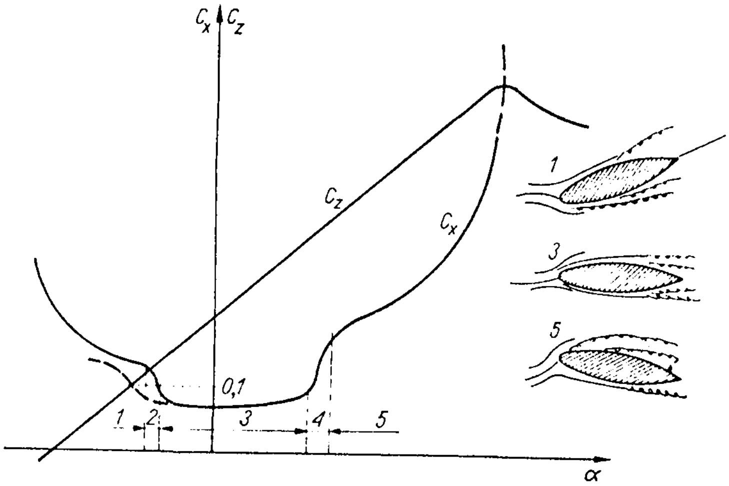


Fig. 4

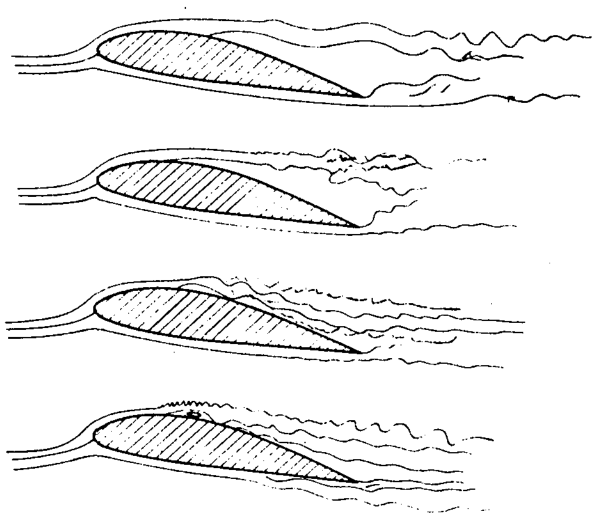


Fig. 5

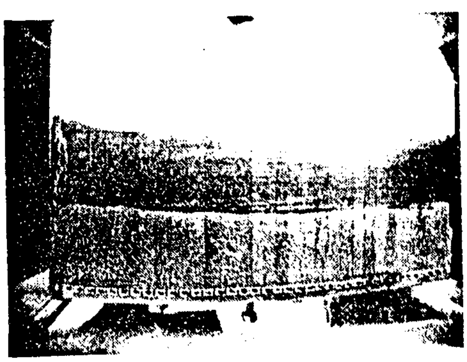


Fig. 6

developed form the bubble becomes a separation area with considerable recirculatory flow.

The term "bubble" does not do justice to the character of the observed phenomena. Although the laminar bubbles form in the area directly preceding separation in all /107 test cases, we observed a number of deformation phenomena in the velocity field without recirculatory flow. In a real way this deformation altered flow structure in the layer, which may be considered as the earliest stage of bubble evolution. Then too the size and shape of the bubbles themselves were different. In measuring test bubbles on profiles from an 0.3 m chord to a 1 m chord we were able to differentiate bubbles several hundredths of a millimeter thick and on the order of 1 mm. Their length varied from several to several hundred mm. The term long bubbles is used if the length is from several dozen to several hundred times their thickness [2]. Short bubbles usually occur near the nose of the profile and represent local separation in miniature, such as

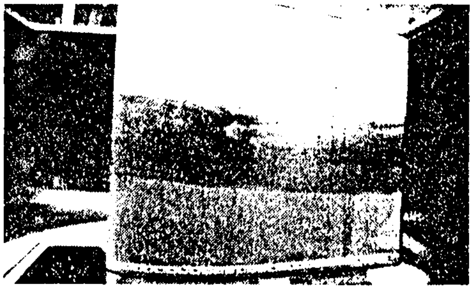


Fig. 7

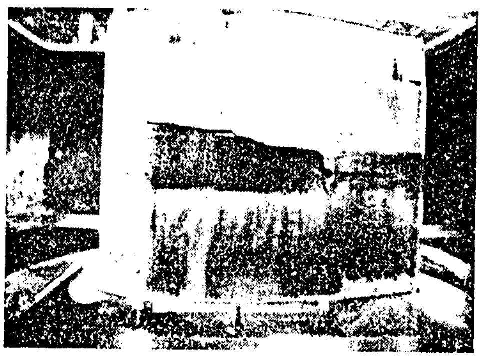


Fig. 8

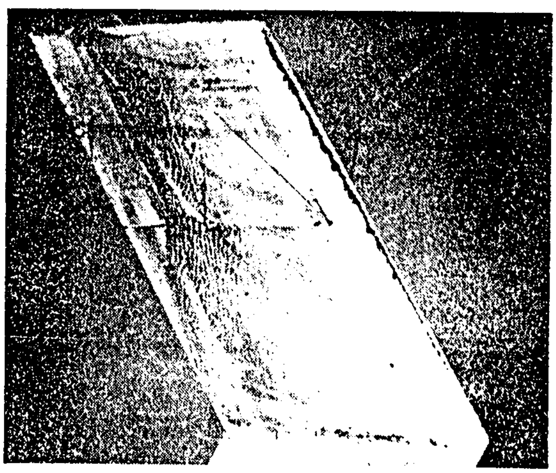


Fig. 9

for example one notices when there is separation in a sharp edge environment. Such separations of a local nature are included in this classification because their thickness is much greater than that of a border layer (often man times thicker).

A particularly large amount of time was devoted to the testing of laminar bubbles, since the elaboration of appropriate forms for laminar airfoils results in the selection of a form where further lamination retards the appearance of bubbles and reduces them in size.

Experimental elaboration was undertaken from the viewpoint of the fact that, despite appearances, there existed a great deal of imperfection in profile theory, which, although it has become the formally correct scheme and the one enshrined in descriptions of flow phenomena according to the classical concept, yields such divergent results in respect to values gotten experimentally, that neither the pressure distribution derived from a theoretical description nor the distribution of tangential stresses may be used as the basis for an assessment of the effect of changes in airfoil contours on their aerodynamic characteristics. Here there is especially a great divergence in the slope of the actual curve c_z and of the theor-

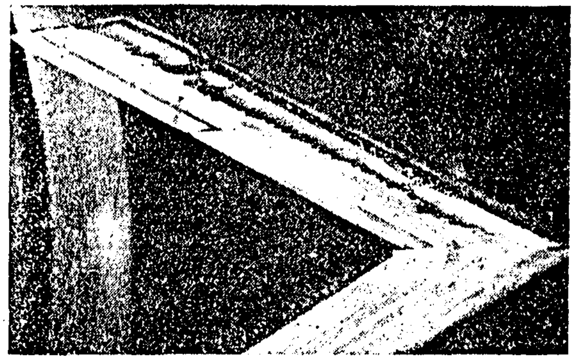


Fig. 10

Fig. 11

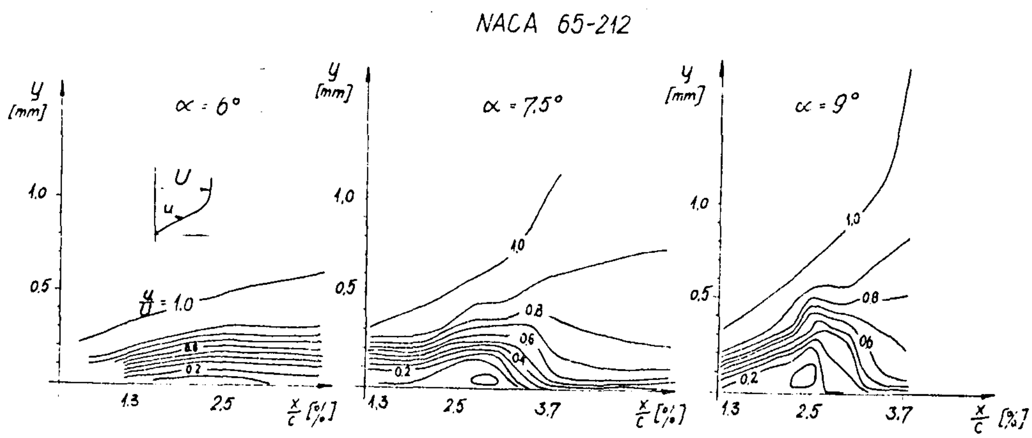


Fig. 12

etical curve (Fig. 3), particularly great for uneven profiles for which the value $dc_z/d\alpha$ obtained theoretically increases greatly with profile uneveness. In actuality this increase is much less and thus there is greater divergence. Further we note a difference in the case of asymmetric profiles between zero angle values when carrying power is $\alpha_{c_z=0}$. For the profile tested in real fluid the zero angle

nr	1	2	3	4	5	6	7	8	9	10	11
x/c %	10	10,3	10,4	10,5	10,6	10,7	10,9	11	11,1	11,2	15

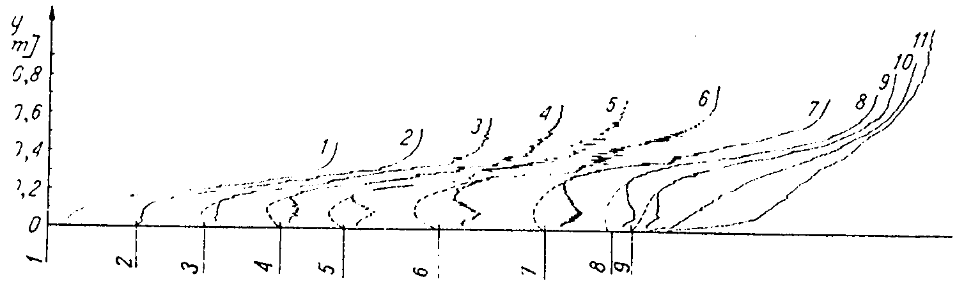


Fig. 13

nr	1	2	3	4	5	6	7	8	9	10	11	12	13
x/c %	38,3	45	51,7	52,3	53,3	55	56,7	58,3	61,7	65	68,3	71,7	75

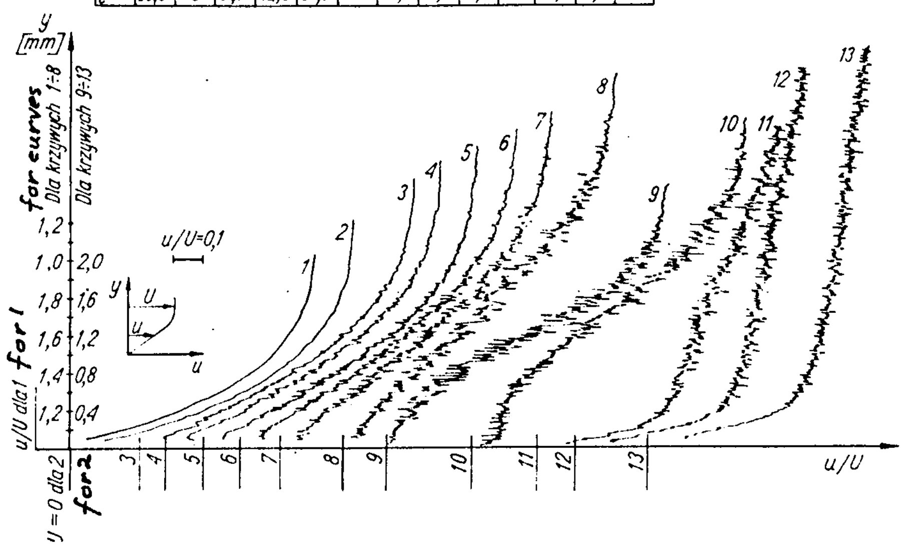


Fig. 14

of the carrying power is less than one would theoretically expect.

Tests for a way out of the impasse by the introduction, as a reference value, of the coefficient c_z in place of the friction angle α [5] and transformation of theoretical calculations to suit real conditions are not justified in view of the divergence found in the results. In the first place, the angle of friction was at the time undefined and in the second place, with such a great difference $\Delta\alpha$ the theoretical velocity field will be quite different from the actual one and cannot be used as the basis for an analysis of flow phenomena in a border layer. In the test area for these phe- /108

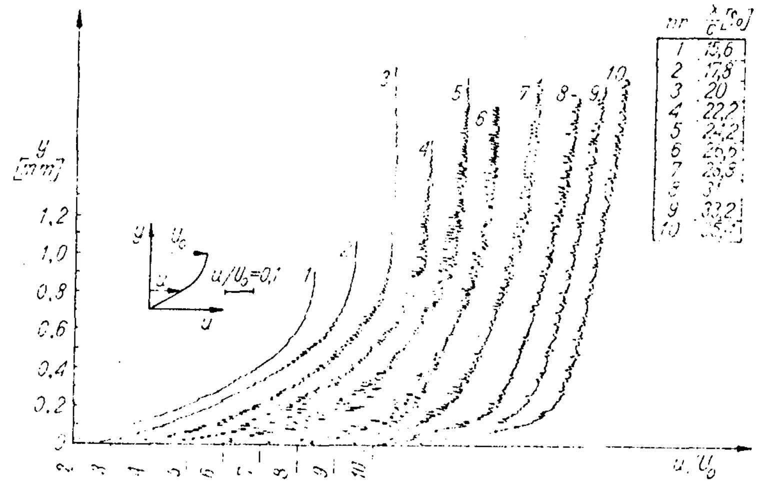


Fig. 15

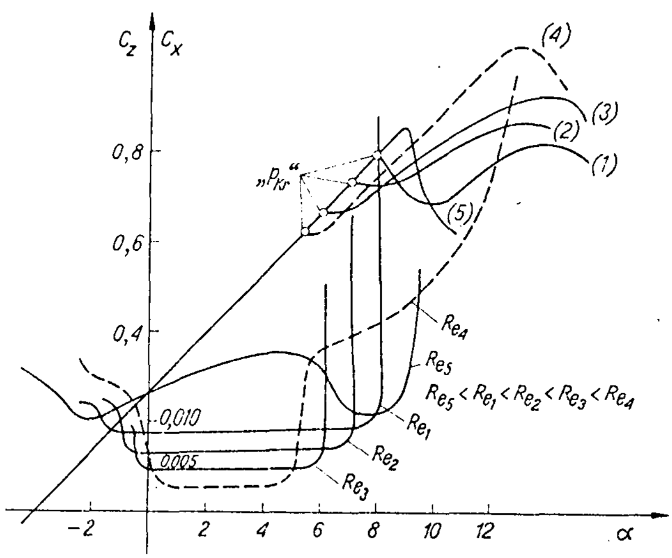


Fig. 16

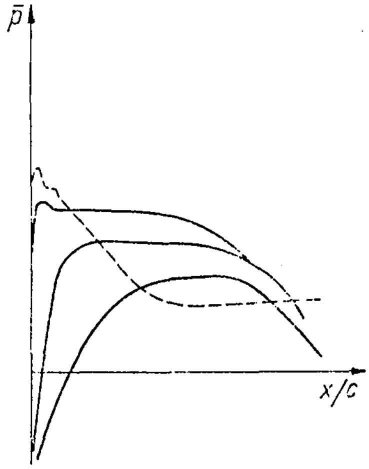


Fig. 17

nomena the theory of the laminar layer then no longer yields any information in view of the assumption of pressure stability in a normal direction and the gaps in the turbulence theory, particularly in the area of processes that occur in the regions where the stability of the laminar layer is lost.

Fig. 4 presents diagrammatically a typical curve for laminar lag. Here one may distinguish five distinct sections characteristic of profile flows. Section 1 corresponds to reflux where a large portion of the upper surface experiences laminar flow in a layer whereas the entire lower surface is marked by turbulent flow; section 3 is where laminar flow occurs over a large part of the upper and lower portions of the profile, while section 5 is the opposite of section 1. In sections 2 and 4 we find more or less rapid changes in the value for the coefficient c_x due to corresponding lamination of flow on the lower surface or flow disturbance on the upper. The size of such sections and the course of the c_x curve in them is a function of the rapidity with which the transition points shift (or more exactly transition zones) with changes in the angle of friction. The shifting process for transition zones is a function of a number of factors, precisely of the kind and formation site of laminar bubbles as well as of velocity field deformation in the border layer. They appear on the lower surface with small and negative c_z values and on the upper portion of the profile when those values are large.

For an understanding of the reasons for the appearance of such phenomena it seems useful to discuss the process of laminar bubble formation. Here we may make use of the scheme presented in [3] il- /109 lustrating the occurrence of a bubble on a circular profile in the area of critical Re numbers. Fig. 5 shows how this scheme is applied to a flight profile. When the Re numbers are small and subcritical, laminar separation occurs near the site of a change in the symbol of the pressure gradient and this change is a function of the shape and arrangement of the profile. The separated stream is subjected to turbulence at a certain distance behind the airfoil. As the Re number increases the turbulent region of the separated stream approaches the surface of the airfoil (Fig. 5b), whereas if it approaches the surface at a correspondingly short distance the flow is shut off (Fig. 5c) as the result of turbulent diffusion and creates the characteristic laminar bubble shown in Fig. 2. With further increase in the Re number, depending on the shape of the airfoil contour (change in pressure gradient) the bubble may disappear with the appearance of a transition zone from laminar to turbulent flow in the border layer without separation. In some cases one may note considerable deformation of the velocity field in the transition zone. In other cases, when pressure gradients are quite small, we observe no velocity field deformation in the layer. There may then exist, depending upon Re number and contour formation, different size bubbles and various more or less obvious deformations in the border layer. From the change in the friction angle of the profile the observed deformations may pass down the contour assuming different forms. In some cases large bubbles may appear at fairly narrow angles of friction and persist over a very wide range of Re numbers; in other cases we may find quite small bubbles among the borders of friction only with large angles of friction. Figures 6, 7 and 8 present bubbles in order: a bubble at the margin of friction, a bubble near the point of maximal thickness (in the diffusion zone) as well as a broad area comprising deformation of the laminar layer. Bubbles are likewise observed on wings with full spread and different contours. Figures 9 and 10 show in succession a short bubble at the margin of friction on a wing tilted to $\gamma = 30°$ and a long bubble on one tilted to $\gamma = 60°$.

Their effect however on separation phenomena is different, less in respect to the tridimensional nature of reflux from a tilted wing.

/111

Fig. 11 gives a schematic representation for two classical cases: a thick profile with a fully developed bubble behind the point of maximal thickness and a slender profile with a small bubble at the nose.

On certain types of profile we may observe, even with narrow angles of friction, flow deformation in the laminar layer comprising removal of the layer from the wall of the profile and the setting up of a very thin sublayer with a small linear velocity gradient. Such deformation does not bring about the loss of layer stability. The layer behind the deformation area still retains a laminar velocity profile. Such a case of deformation may be regarded as the very earliest stage of a laminar bubble, since it may be seen at those sites on the contour where, when the friction angle increases, we observe a laminar bubble or deformation that occasions flow turbulence.

It follows from the above description that over a wide range of changes in the geometry of the profile and Re numbers we may note a variety of laminar bubble forms, both quantitatively and qualitatively, and deformation of the velocity field in the layer. They are illustrated in the Figures presented. Figure 12 shows successively the forms of evolution of a bubble with a change in the angle of friction and illustrated by means of lines of steady velocity. Fig. 12 (left) shows field deformation without local separation (profile NACA 65-212, friction angle $\alpha = 6$). Fig. 12 (middle) presents in turn an already fully developed laminar bubble ($\alpha = 7.5°$) and Fig. 12 (right) the same bubble for a friction angle $\alpha = 9°$.

Fig. 13 illustrates velocity field deformation in the setting of a laminar bubble and likewise involving the transition zone from laminar to turbulent motion; Fig. 14 shows the transition zone in the deformation area (without separation).

Fig. 15 represents a velocity field in the transition zone with /112
no separation resulting from the great changes in pressure gradient.

Bubbles may likewise be visualized by covering the area surface with a matching adhesive fluid. No matter how much the presence of the liquid changes local reflux conditions, the sites of a bubble coming into being may be determined and also its size. However visualization does not permit us to determine whether we are dealing with a developed bubble or with field deformation. In the latter case a considerable reduction in tangential tensions favors accumulation of oil and this may result in border layer separation at the site.

As we see from the phenomena discussed previously, laminar bubble formation constitutes a phenomenon directly preceding separation. Hence the basic question in planning a good profile has been the se- /113
lection of profile shape so as to retard the appearance of such bubbles or to preclude their development.

A good glider profile should have these features: the least possible lag in areas of high velocity (as most of the contour is bathed in a laminar layer); the greatest possible $c_{z\ max}$ and in addition the beginning of the saddle shifted far toward the side of negative angles of friction, so that at very high velocities (small coefficients of carrying power, such as $c_z \sim 0.1$) the lag coefficient c_x is located on the borders of the saddle. Formation of a long laminar layer requires shifting the maximum width of the profile far to the rear and this in turn suggests the necessity of providing a contour of great curvature in the diffusion zone, so much the more since in consideration of the need for obtaining a high $c_{z\ max}$ value the shaft of the profile's skeletal line must be considerable (3-4%). Sharp curves in the contour in the diffusion zone favor the formation of bubbles and these cause partial separation even at relatively narrow angles of friction (small $c_{z\ max}$).

Shifting the position of the saddle toward the smallest possible c_z values makes profile asymmetry difficult ($\alpha_{c_{z=0}} \approx -4$) and this, in the face of the position of the accumulation point above the border of friction in this area of friction angles, creates great difficulty in constraining reflux from the nose without separation or deformation that cause turbulence of the layer on the bottom surface of the contour.

We see from this that all the changes of contour that have a favorable effect on the $c_{x\ min}$ value, the coefficient for the c_m moment and the extreme position of the saddle have an adverse effect on the size of $c_{z\ max}$ and the course of separation.

Reconciliation of these discrepancies in an optimal way would require study of profiles of different shapes and assessment of the effect of geometrical differences for individual portions of the contour on pressure distribution, flow phenomena and actually on its characteristics.

We used here the method of successive changes in the shape of select portions of the contour while retaining unaltered basic geometric parameters of the test profiles. In this way, through a series /114 of modifications, we achieved a profile with definite aerodynamic characteristics. Then, altering step by step the basic geometric parameters (e. g. position of maximum thickness) and the contour, we obtained profiles whose characteristics, along with the results of reflux testing, put us in a position to assess the effect of changes in geometric parameters and the shapes of test profiles on their aerodynamic characteristics. Profiles obtained in the course of such tests and exhibiting certain characteristics in relation to previously tested ones were described and numbered so as to produce a series of profiles NN comprising 10 to 20 and including several resulting from modifications of NACA profiles and those of the F_x series.

As a result of this testing program we obtained information in regard to the possibility of setting up pressure distribution in a manner that would provide stability in the marginal layer over a wide range of friction angles (retardation of occurrence and diminution of occurring deformation of laminar flow).

It appeared that a profile meeting the above requirements had to incorporate -- in contrast to classical hypotheses (contour selection for a required pressure distribution at a given friction angle) -- definite changes in pressure distribution along a chord with a change in the angle of friction.

Without entering into the specifics of individual stages we will discuss below three types of characteristics with corresponding changes in pressure distribution and forms of deformation of the layer that have a bearing on individual characteristic types.

Fig. 16 presents characteristics of the first type. As the Re number goes down separation shifts toward wider friction angles (curves 1, 2 and 3) and even reaches the area of the laminar saddle. There is no displacement here of the transition zone in the border layer toward the front with mounting Re numbers. Deformation of the velocity field, which in this case occurs in the rear portion of the profile behind the point of maximal thickness, changes to a long laminar bubble as the angle of friction widens. The c_z characteristics /115
for this type of profile present two maxima in the range of small Re numbers: the first, when there is separation in the diffusion zone, caused by the bubble discussed above; the second occurring with wide friction angles following the creation of a second (short) bubble at the profile nose. Typical representatives of this type of

profile are the thick profiles NACA of the 65 and 66 series.

If there is nothing altered about the profile shape, so that in the rear portion only a weak bubble is formed, then as the Re number changes there will be a change in the c_z characteristic in the manner shown in the Figure. A second maximum for this characteristic appears and at the corresponding Re number the bubble in the diffusion zone disappears. We then get the c_z characteristic shown in Fig. 16 by the heavy line (shown likewise in Fig. 4). The second maximum for this characteristic enters the area of usable angles of friction. In the area where the bubble appeared we note weak deformation of the laminar velocity field and, for angles corresponding to to inception angle of the bubble at lower Re numbers, a break or leap in the c_z angle. When the Re numbers are very small, $\sim 0.5 \cdot 10^6$, the form of the lag curve deviates from what has been discussed -- we note a second c_x minimum with wide angles of friction. In the region of this minimum there is a large bubble (curve 5).

Fig. 17 shows changes in pressure distribution with an increase in the angle of friction for this type of profile. We see clearly that as this angle widens there is a rapid increase of hypopressure around the nose that creates conditions favoring the appearance of a very long bubble which produces instant separation in the rear part of the profile. This separation results in a reduction of carrying power and therefore also of circulation. There is a change in the position of the point of entry and in wing reflux. In this context flow is sucked against the forepart of the profile. Hypopressure in this area increases with a further increase in the angle of friction, creating a distribution typical of a bubble arising near the margin of friction (typical flattening out behind the point of maximal vacuum). This is shown on the diagram with heavy lines.

Fig. 18 shows the characteristics of profiles where there is no formation of a long bubble of the type discussed. Here we note a /116
gradual increase of lag from the end of the saddle and separation occurs as the result of the bubble formation at the friction border.

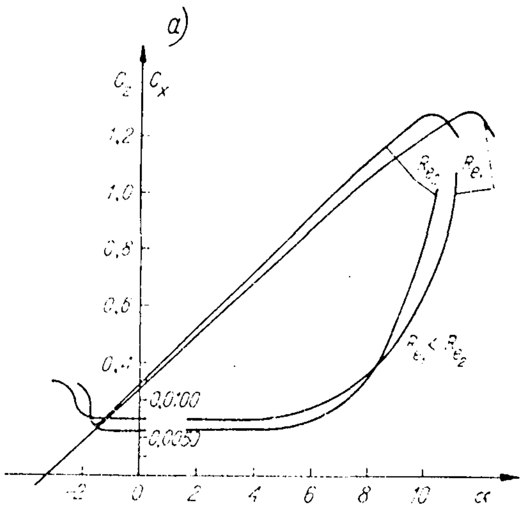


Fig. 18

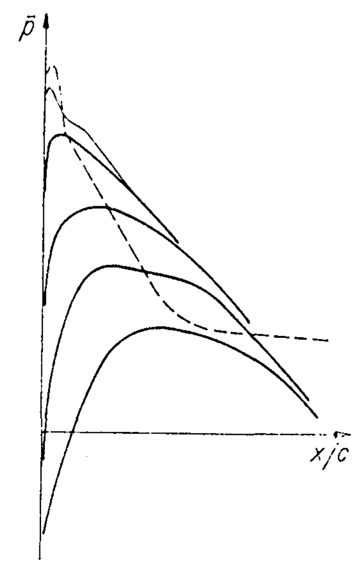


Fig. 19

In the area of friction angles, where we observe increasing lag the transition zone on the upper portion of the profile shifts forward. Here changes in pressure distribution as the angle of friction widens are characterized by a much evener increase of vacuum and a forward shift of the hypopressure maximum of Fig. 19. The bubble forms at considerably greater angles of friction so that $c_{z\ max}$ is much greater. This is the type of characteristic we find in profiles such as F_x61-163, F_x63-167, NN 6 and thick asymmetric NACA profiles of the 64 series.

A third type of characteristics (Fig. 20), the least studied because of the difficulty of measuring very small bubbles that arise near the nose, differs from the preceding in the gradual shift of the hypopressure maximum towards the friction border (compare Figures 17 and 19 with 21). Admittedly this leads to a rapid monotone increase in lag almost from the $c_{x\ min}$ (here there is no typical saddle formation) but formed bubbles do not appear in this case, since changes in pressure gradients are less over a wide range of friction angles than in the previous cases. Here a special feature is likewise constraint in the appearance of a small laminar bubble at the border of friction even in the area of negative pressure gradients. Such a bubble disturbs the layer, making it static and retarding its separation and the latter occurs only when, with an increase in the angles of friction, the bubble shifts toward the side of positive pressure gradients. This phenomenon is accompanied by changes in pressure distribution in the environment of the borders

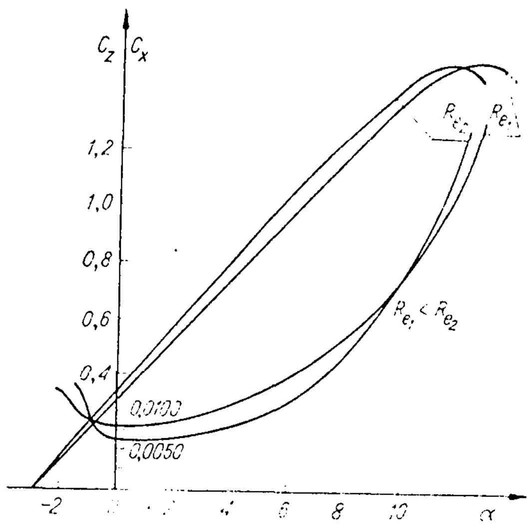


Fig. 20

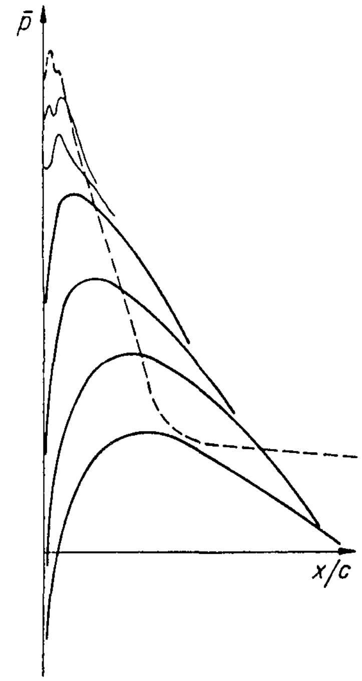
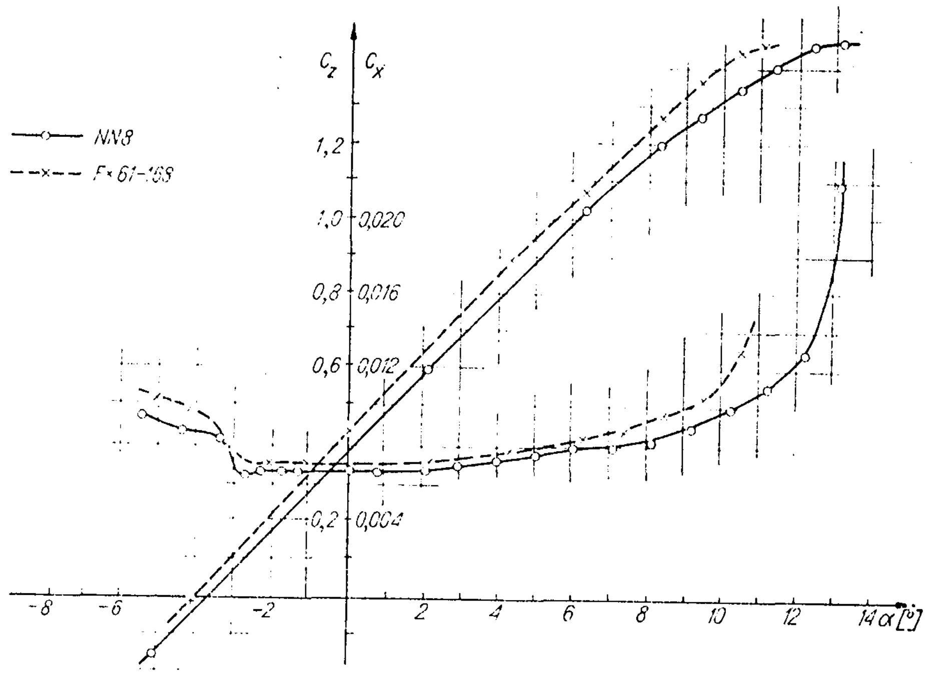


Fig. 21

of the nose as shown in Fig. 21. Both these factors -- constraint of the characteristic changes in pressure distribution with a change in the angle of friction and constraint of the very small bubble referred to in the area of negative pressure gradients -- here are decisive in respect to the large value of $c_{z\ max}$ achieved for this type of profile. The real question in the attainment of correspondingly low lag is the constraint of reflux fulfils /117 the requirements of the above conditions when the maximal thickness of the profile is shifted as far back as possible.

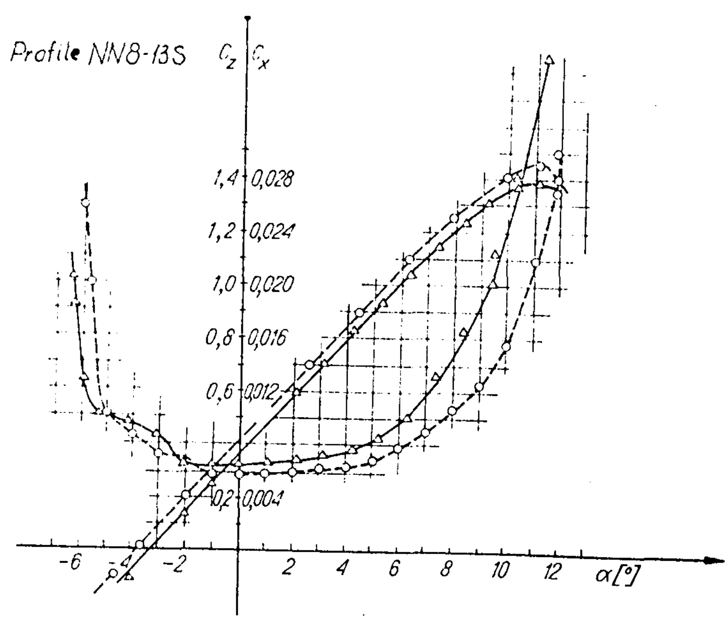
Profiles that are still laminar and possess this sort of characteristic are NN7, NN8 and Wortmann F_x63-168 with a slight modification of the nose in accord with test results (profile NN8 is a modification of F_x63-168 comprising the forepart and the flow portion, due to which we achieved moment reduction by about 30%, better placement of the saddle and a $c_{x\ min}$ less than over 5%). A comparison of characteristics for the last two profiles is given in Fig. 22.

For a general assessment of the aerodynamic properties of profiles representing types of characteristics the following data may be helpful: first type -- profiles optimized



NN8
Fx 61-163
C_z
C_x
1,2
1,0
0,020
0,8
0,016
0,6
0,012
0,2
0,004
-8
-6
-2
2
4
6
8
10
12
14 α[°]

Fig. 22



Profile NN8-13S
C_z
C_x
1,4
0,028
1,2
0,024
1,0
0,020
0,8
0,016
0,6
0,012
0,2
0,004
-6
-4
-2
2
4
6
8
10
12
α[°]

Fig. 23

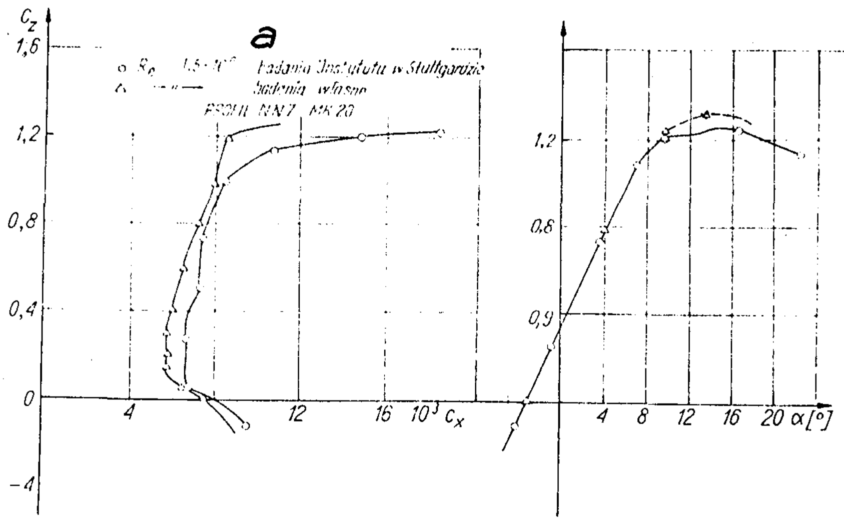


Fig. 24

Key: a. testing by the Stuttgart Institute
testing in Jasien

from the viewpoint of the c_x minimum value, profiles which present at Re ∿ 1.5×10^6: $c_{x\ min}$ ∿ 0.0055 and $c_{z\ max}$ ∿ 0.9; the second type for the same Re number presents: $c_{x\ min}$ ∿ 0.006 and $c_{z\ max}$ ∿ 1.3; the third type $c_{x\ min}$ ∿ 0.0065 and $c_{z\ max}$ ∿ 1.45.

A comparison shows that when there is a relatively small, about 15%, increase in the $c_{x\ min}$ an approximately 60% increase is obtained for $c_{z\ max}$.

Evaluating the results on the basis of practical use we must pay attention to the very high sensitivity of the test profiles in respect to changes of shape in areas where large contour curves appear and in particular the nose and its environs. Very slight inaccuracies in projection of a contour and even an insignificant amount of surface roughness may occasion considerable changes in the formation of the lami- /119
nar saddle as well as an adverse increase in $c_{x\ min}$ (up to 10%) and a lowering of $c_{z\ max}$. Inaccuracies in producing the model are the chief reason for observed differences in measurement results on the model of this very profile. Fig. 23 shows by way of example charts drawn up

for two models of the profile of the 13% NN 8-13. Fig. 24 presents results of testing done on airfoil NN 7MK in the wind tunnel of the Stuttgart Institute on which we have superimposed measurement results of our own for this profile. Here we see clear deterioration of the laminar saddle (it appears in the curves plotted for our own measurements), although on the other hand when we repeated our own measurements we also got the c_x curve without formation of the saddle. One can also note good agreement with measurement results from countries outside Poland, e. g. for the Wortmann F_x61-168, in respect to those obtained in our own wind tunnel. Airfoil sensitivity suggests the need for great precision in determining the geometry of the model and transfering it to a real wing while maintaining very great accuracy.

REFERENCES

1. Moore, T. W. F., A Note on the Causes of Thin Aerofoil Stall, Journal of the Royal Aeronautical Society, December 1959.
2. Crabtree, L. F., The Formation of Regions of Separable Flow on Wing Surfaces, Part I and II, Report and Memoranda No. 3122, 1959.
3. Morkorin, M. V., Flow around a Circular Cylinder - a Kaleidoscope of Challenging Fluid Phenomena, Symposium of Fully Separated Flow, Amer. Soc. Mech. Eng.
4. Owen, P. R. and L. Klanfer, On the Laminar Boundary Layer Separation from the Leading Edge of a Thin Aerofoil, R. A. E. Rep. Aero, 2508, October 1953.
5. Nowak, Z., Obliczenia oporu profilow lotniczych [Calculation of Flight Profile Lag], Reports of the IPTT, 1974.

DO NOT REMOVE SLIP FROM MATERIAL

Delete your name from this slip when returning material to the library.

NAME	DATE	MS
Mark Russell	4/14/92	163

NASA Langley (Rev. Dec. 1991) RIAD N-75