January 2005 • NREL/SR-500-36337

Subcontractor Report

The S829 Airfoil

Period of Performance: 1994 – 1995

D. M. Somers
Airfoils, Inc.
State College, Pennsylvania

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National Renewable Energy Laboratory
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ABSTRACT

A 16-percent-thick, natural-laminar-flow airfoil, the S829, for the tip region of 20- to 40-meter-diameter, stall-regulated, horizontal-axis wind turbines has been designed and analyzed theoretically. The two primary objectives of restrained maximum lift, insensitive to roughness, and low profile drag have been achieved. The constraints on the pitching moment and the airfoil thickness have been satisfied. The airfoil should exhibit a docile stall.

INTRODUCTION

The majority of the airfoils in use on horizontal-axis wind turbines today were originally developed for aircraft. The design requirements for these airfoils, primarily National Advisory Committee for Aeronautics (NACA) and National Aeronautics and Space Administration (NASA) airfoils (refs. 1–6), are significantly different from those for wind-turbine airfoils (ref. 7). Accordingly, several families of airfoils have been designed specifically for horizontal-axis wind-turbine applications, as shown in the following table.

Diameter	Type	Thickness Category	Airfoil			Reference
			Primary	Tip	Root	
2–10 m	Variable speed Variable pitch	Thick		S822	S823	13
10–20 m	Variable speed Variable pitch	Thin	S801	S802 S803	S804	8
	Stall regulated	Thin	S805 S805A	S806 S806A	S807 S808	8
	Stall regulated	Thick	S819	S820	S821	12
20–30 m	Stall regulated	Thick	S809	S810	S811	9
	Stall regulated	Thick	S812	S813	S814 S815	9 and 10
20–40 m	Variable speed Variable pitch	—	S825	S826		14
30–50 m	Stall regulated	Thick	S816	S817	S818	11
40–50 m	Stall regulated	Thick	S827	S828		15

An overview of most of these airfoil families is given in reference 16.

The airfoil designed under the present study is intended for the tip region of 20- to 40-meter-diameter, stall-regulated, horizontal-axis wind turbines. The specifications for the airfoil were outlined by and later refined during discussions with James L. Tangler of the National Renewable Energy Laboratory (NREL).

Because of the limitations of the theoretical methods (refs. 17 and 18) employed in this study, the results presented are in no way guaranteed to be accurate—either in an absolute or in a relative sense. This statement applies to the entire study.

SYMBOLS

C_p	pressure coefficient
c	airfoil chord, m
c_d	section profile-drag coefficient
c_l	section lift coefficient
c_m	section pitching-moment coefficient about quarter-chord point
L.	lower surface
R	Reynolds number based on free-stream conditions and airfoil chord
S.	boundary-layer separation location, $1 - s_{sep}/c$
s_{sep}	arc length along which boundary layer is separated, m
s_{turb}	arc length along which boundary layer is turbulent including s_{sep}, m
T.	boundary-layer transition location, $1 - s_{turb}/c$
U.	upper surface
x	airfoil abscissa, m
y	airfoil ordinate, m
α	angle of attack relative to x-axis, deg

AIRFOIL DESIGN

OBJECTIVES AND CONSTRAINTS

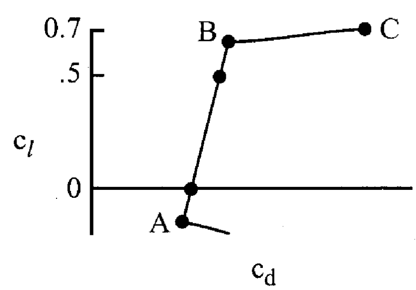
The design specifications for the airfoil are contained in table I. Two primary objectives are evident. The first objective is to restrain the maximum lift coefficient to the very low value of 0.70 for a Reynolds number of 2.0×10^6, which corresponds to the 0.95 blade radial station. A requirement related to this objective is that the maximum lift coefficient not decrease with transition fixed near the leading edge on both surfaces. In addition, the airfoil should exhibit docile stall characteristics. The second objective is to obtain low profile-drag coefficients over the range of lift coefficients from 0 to 0.50 for the same Reynolds number.

Two major constraints were placed on the design of this airfoil. First, the zero-lift pitching-moment coefficient must be no more negative than −0.05. Second, the airfoil thickness must equal 16-percent chord.

The basis for the objectives and constraints, most notably the restrained maximum lift coefficient, is given in reference 19. Note also that the specifications for this airfoil are, in essence, identical to those for the S813 airfoil (ref. 9) except that all the lift coefficients are reduced by 0.40.

PHILOSOPHY

Given the above objectives and constraints, certain characteristics of the design are apparent. The following sketch illustrates a drag polar that meets the goals for this design.

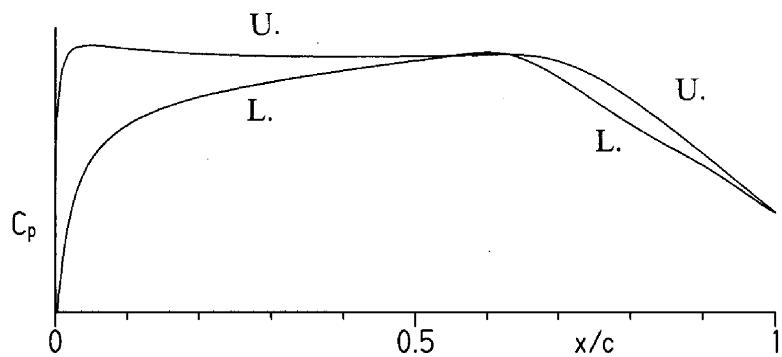


Sketch 1

The desired airfoil shape can be traced to the pressure distributions that occur at the various points in sketch 1. Point A is the lower limit of the low-drag, lift-coefficient range. The lift coefficient at point A is 0.15 lower than the objective specified in table I. The difference is intended as a margin against such contingencies as manufacturing tolerances, operational deviations, three-dimensional effects, and inaccuracies in the theoretical method. A similar margin is also desirable at the upper limit of the low-drag range, point B, although this margin is constrained by the proximity of the upper limit to the maximum lift coefficient. The drag at point B is not as low as at point A, unlike the polars of many other laminar-flow airfoils where the drag within the laminar bucket is nearly constant. This characteristic is related to the elimination of significant (drag-producing) laminar separation bubbles on the upper surface. (See ref. 20.) The small increase in profile-drag coefficient with increasing lift coefficient is relatively inconsequential because the ratio of the profile drag to the total drag of the wind-turbine blade decreases with increasing lift coefficient. The drag increases very rapidly outside the low-drag range because the boundary-layer transition point moves quickly toward the leading edge with increasing (or decreasing) lift coefficient. This feature results in a leading edge that produces a suction peak at higher lift coefficients, which ensures that transition on the upper surface will occur very near the leading edge. Thus, the maximum lift coefficient, point C, occurs with turbulent flow along the entire upper surface and, therefore, should be relatively insensitive to roughness at the leading edge.

Because the airfoil thickness allows a wider low-drag range than specified, the lower limit of the low-drag range should be below point A.

From the preceding discussion, the pressure distributions along the polar can be deduced. The pressure distribution at point A should look something like sketch 2.



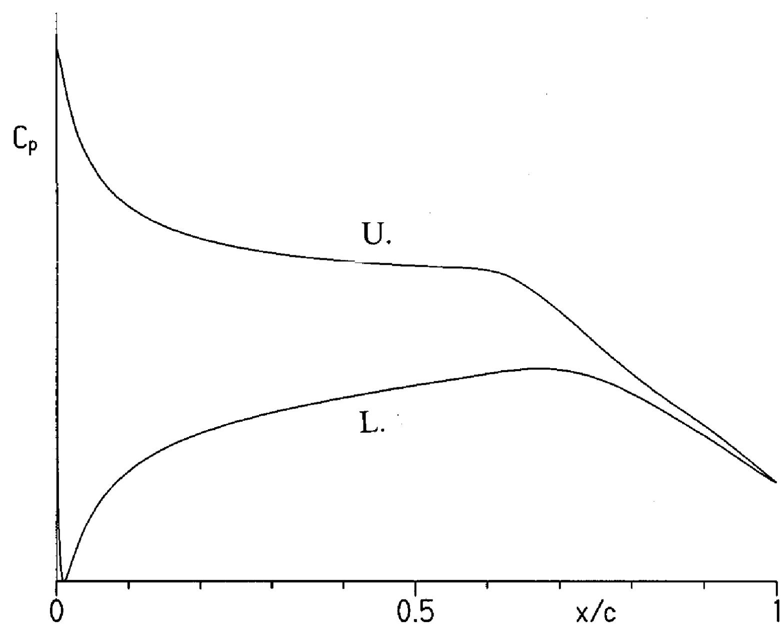
Sketch 2

To achieve low drag, a favorable pressure gradient is desirable along the upper surface to about 60-percent chord. Aft of this point, a short region having a shallow, adverse pressure gradient ("transition ramp") promotes the efficient transition from laminar to turbulent flow (ref. 21). The transition ramp is followed by a nearly linear pressure recovery. The specific pressure recovery employed represents a compromise between maximum lift, drag, and stall characteristics.

A generally neutral pressure gradient is desirable along the lower surface to about 65-percent chord to achieve low drag. This region is followed by a curved transition ramp (ref. 20) that is longer than the one on the upper surface. The ramp is followed by a nearly linear pressure recovery.

The amounts of pressure recovery on the upper and lower surfaces are determined by the airfoil-thickness and pitching-moment constraints.

At point B, the pressure distribution should look like sketch 3.



Sketch 3

No suction spike exists at the leading edge. Transition is essentially imminent over the entire forward portion of the upper surface. This feature allows a wider low-drag range to be achieved and higher lift coefficients to be reached without significant separation. It also causes the transition point to move very quickly toward the leading edge with increasing lift coefficient, which leads to the roughness insensitivity of the maximum lift coefficient.

EXECUTION

Given the pressure distributions previously discussed, the design of the airfoil is reduced to the inverse problem of transforming the pressure distributions into an airfoil shape.

The Eppler Airfoil Design and Analysis Code (refs. 17 and 18) was used because of its unique capability for multipoint design and because of confidence gained during the design, analysis, and experimental verification of several other airfoils. (See refs. 22–25.)

The airfoil is designated the S829. The airfoil shape is shown in figure 1 and the coordinates are contained in table II. The airfoil thickness is 16-percent chord.

THEORETICAL PROCEDURE

The section characteristics are predicted for Reynolds numbers of 1.0×10^6, 1.5×10^6, 2.0×10^6, 2.5×10^6, and 3.0×10^6. The computations were performed with transition free using transition mode 3.0, with transition fixed at 2-percent chord on the upper surface and 5-percent chord on the lower surface using transition mode 1.3, and "rough" using transition mode 9.0, which simulates distributed roughness due to, for example, leading-edge contamination by insects or rain. (See ref. 18.) Because the free-stream Mach number for all relevant operating conditions remains below 0.3, all results are incompressible.

DISCUSSION OF RESULTS

PRESSURE DISTRIBUTIONS

The inviscid pressure distributions at various angles of attack are shown in figure 2 and tabulated in the appendix.

TRANSITION AND SEPARATION LOCATIONS

The variation of boundary-layer transition location with lift coefficient is shown in figure 3 and tabulated in the appendix. In the method of references 17 and 18, the transition location is defined as the end of the laminar boundary layer whether due to natural transition or laminar separation. Transition is normally confirmed in experiments, however, by the detection of an attached turbulent boundary layer. Thus, for conditions that result in relatively long laminar separation bubbles (low lift coefficients for the upper surface, high lift coefficients for the lower surface, and low Reynolds numbers), the apparent agreement between the theoretical and experimental transition locations is poor. In actuality, the difference between the predicted and measured transition locations represents the length of the laminar separation bubble (from laminar separation to turbulent reattachment). Accordingly, for conditions that result in shorter laminar separation bubbles (high lift coefficients for the upper surface, low lift coefficients for the lower surface, and high Reynolds numbers), the apparent agreement between theory and experiment improves. (See refs. 22 and 26.)

The variation of turbulent boundary-layer separation location with lift coefficient is shown in figure 3 and tabulated in the appendix. Trailing-edge separation is predicted on the upper surface at almost all lift coefficients. This separation increases in length with transition fixed and rough. Separation is predicted on the lower surface at lower lift coefficients. Such separation usually has little effect on the section characteristics. (See ref. 22.)

SECTION CHARACTERISTICS

Reynolds Number Effects

The section characteristics are shown in figure 3 and tabulated in the appendix. It should be noted that the maximum lift coefficient computed by the method of references 17 and 18, as well as other theoretical methods, is not always realistic. Accordingly, an empirical criterion has been applied to the computed results. This criterion assumes that the maximum lift coefficient has been reached if the drag coefficient of the upper surface is greater than 0.0150 or if the length of turbulent separation on the upper surface is greater than 0.10. Thus, the maximum lift coefficient for the design Reynolds number of 2.0×10^6 is estimated to be 0.70, which meets the design objective. Based on the variation of the upper-surface separation location with lift coefficient, the stall characteristics are expected to docile, which meets the design goal. Low profile-drag coefficients are predicted over the range of lift coefficients from below 0 to about 0.6, which exceeds the range specified (0 to 0.50). The drag coefficient at the specified lower limit of the low-drag range ($c_l = 0$) is predicted to be 0.0045, which is 36 percent below the design objective. The zero-lift pitching-moment coefficient is predicted to be –0.003, which satisfies the constraint.

An additional analysis (not shown) indicates that significant (drag-producing) laminar separation bubbles should not occur on either surface for any relevant operating condition.

Effect of Roughness

The effect of roughness on the section characteristics is shown in figure 3. The maximum lift coefficient for the design Reynolds number of 2.0×10^6 is unaffected by fixing transition because transition on the upper surface is predicted to occur forward of 2-percent chord at the maximum lift coefficient. For the rough condition, the maximum lift coefficient for the design Reynolds number is estimated to be 0.68, a reduction of less than 3 percent from that for the transition-free condition. Thus, the design requirement has been satisfied. The effect of roughness on the maximum lift coefficient increases with decreasing Reynolds number. The drag coefficients are, of course, adversely affected by the roughness.

CONCLUDING REMARKS

A 16-percent-thick, natural-laminar-flow airfoil, the S829, for the tip region of 20- to 40-meter-diameter, stall-regulated, horizontal-axis wind turbines has been designed and analyzed theoretically. The two primary objectives of restrained maximum lift coefficient, insensitive to leading-edge roughness, and low profile-drag coefficients have been achieved. The constraints on the zero-lift pitching-moment coefficient and the airfoil thickness have been satisfied. The airfoil should exhibit docile stall characteristics.

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TABLE I.– AIRFOIL DESIGN SPECIFICATIONS

Parameter	Objective/Constraint
Blade radial station	0.95
Reynolds number	2.0×10^6
Maximum lift coefficient	0.70
Low-drag, lift-coefficient range	
Lower limit	0
Upper limit	0.50
Minimum profile-drag coefficient	≤ 0.0070
Zero-lift pitching-moment coefficient	≥ -0.05
Thickness	0.16c

TABLE II.– S829 AIRFOIL COORDINATES

Upper Surface		Lower Surface	
x/c	y/c	x/c	y/c
0.00013	0.00108	0.00002	–0.00045
.00067	.00276	.00044	–.00194
.00489	.00902	.00134	–.00354
.01452	.01709	.00212	–.00461
.02906	.02536	.01005	–.01163
.04837	.03359	.02315	–.01890
.07229	.04160	.04127	–.02606
.10057	.04930	.06425	–.03296
.13289	.05659	.09185	–.03951
.16888	.06335	.12378	–.04562
.20815	.06949	.15967	–.05125
.25023	.07491	.19913	–.05633
.29466	.07951	.24170	–.06080
.34092	.08321	.28689	–.06461
.38849	.08591	.33419	–.06770
.43683	.08750	.38303	–.07002
.48538	.08789	.43287	–.07151
.53360	.08695	.48311	–.07211
.58093	.08447	.53320	–.07173
.62698	.08006	.58256	–.07031
.67187	.07345	.63061	–.06769
.71580	.06493	.67694	–.06362
.75874	.05514	.72141	–.05794
.80038	.04479	.76401	–.05077
.84011	.03463	.80466	–.04249
.87719	.02518	.84317	–.03364
.91085	.01682	.87913	–.02486
.94045	.00986	.91199	–.01676
.96518	.00473	.94106	–.00992
.98404	.00161	.96546	–.00480
.99593	.00028	.98414	–.00166
1.00000	.00000	.99595	–.00029
		1.00000	.00000

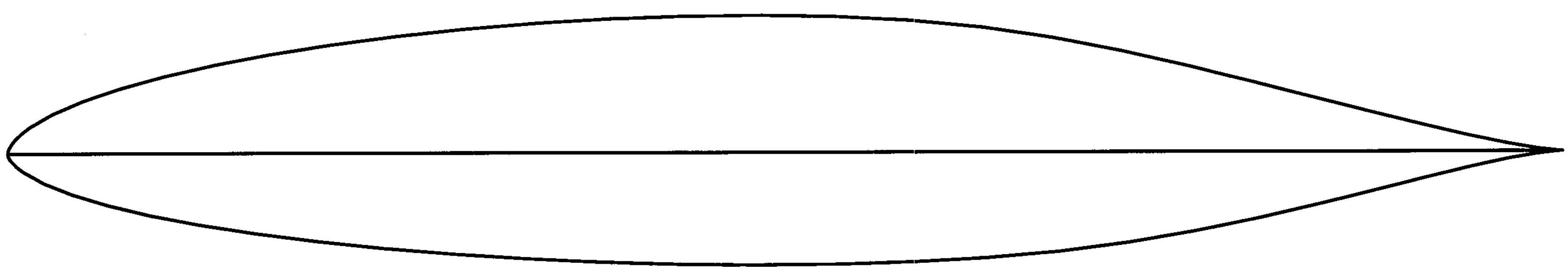
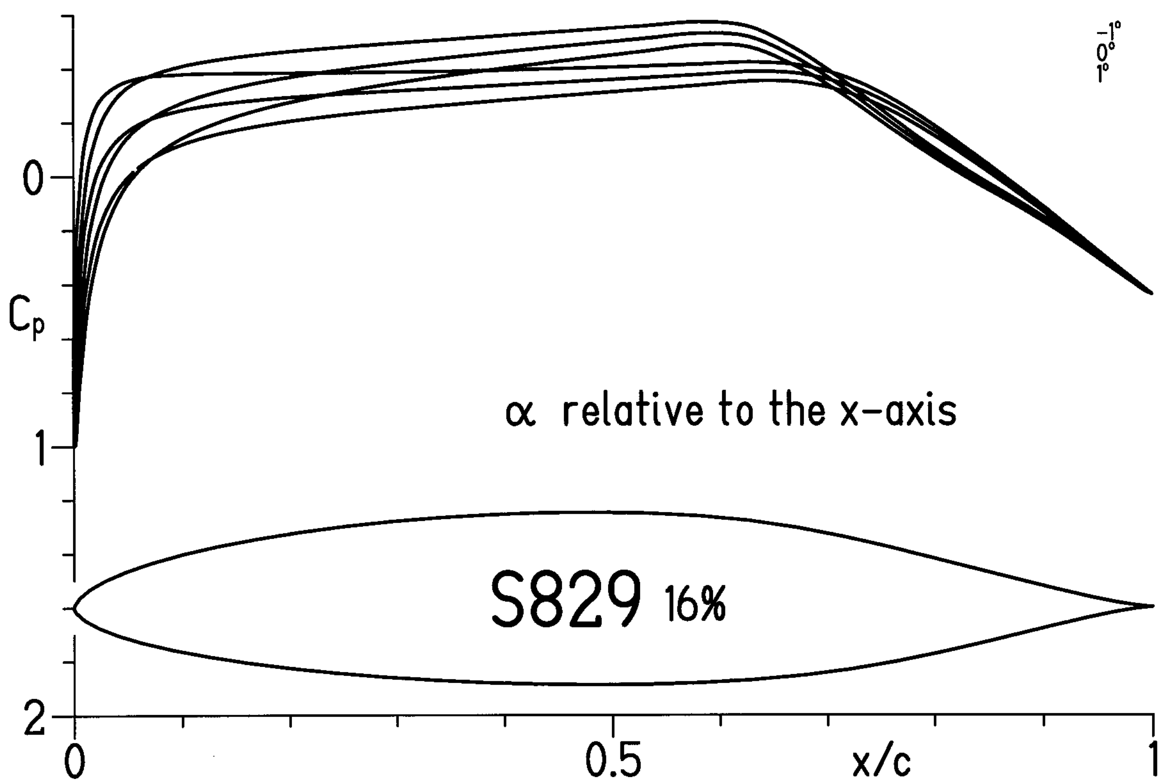
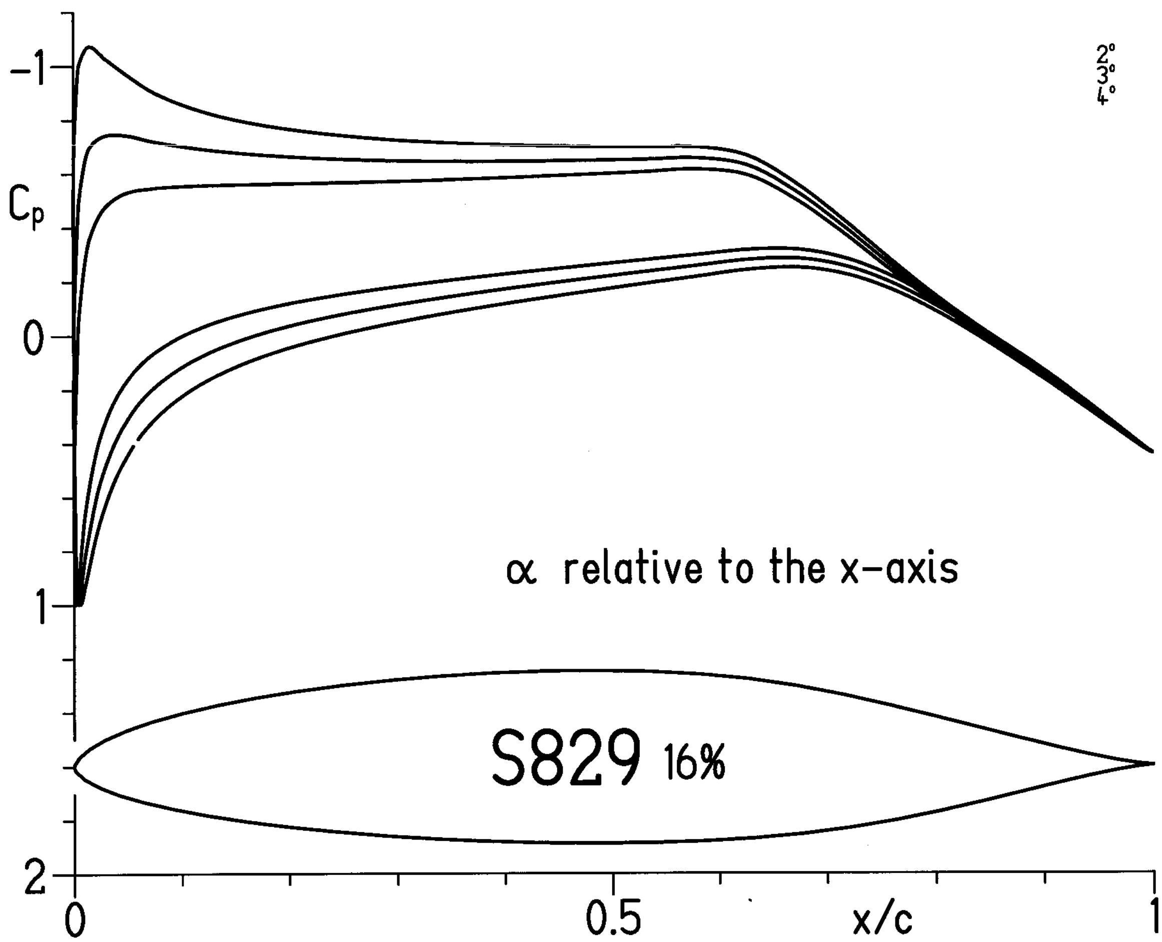


Figure 1.– S829 airfoil shape.



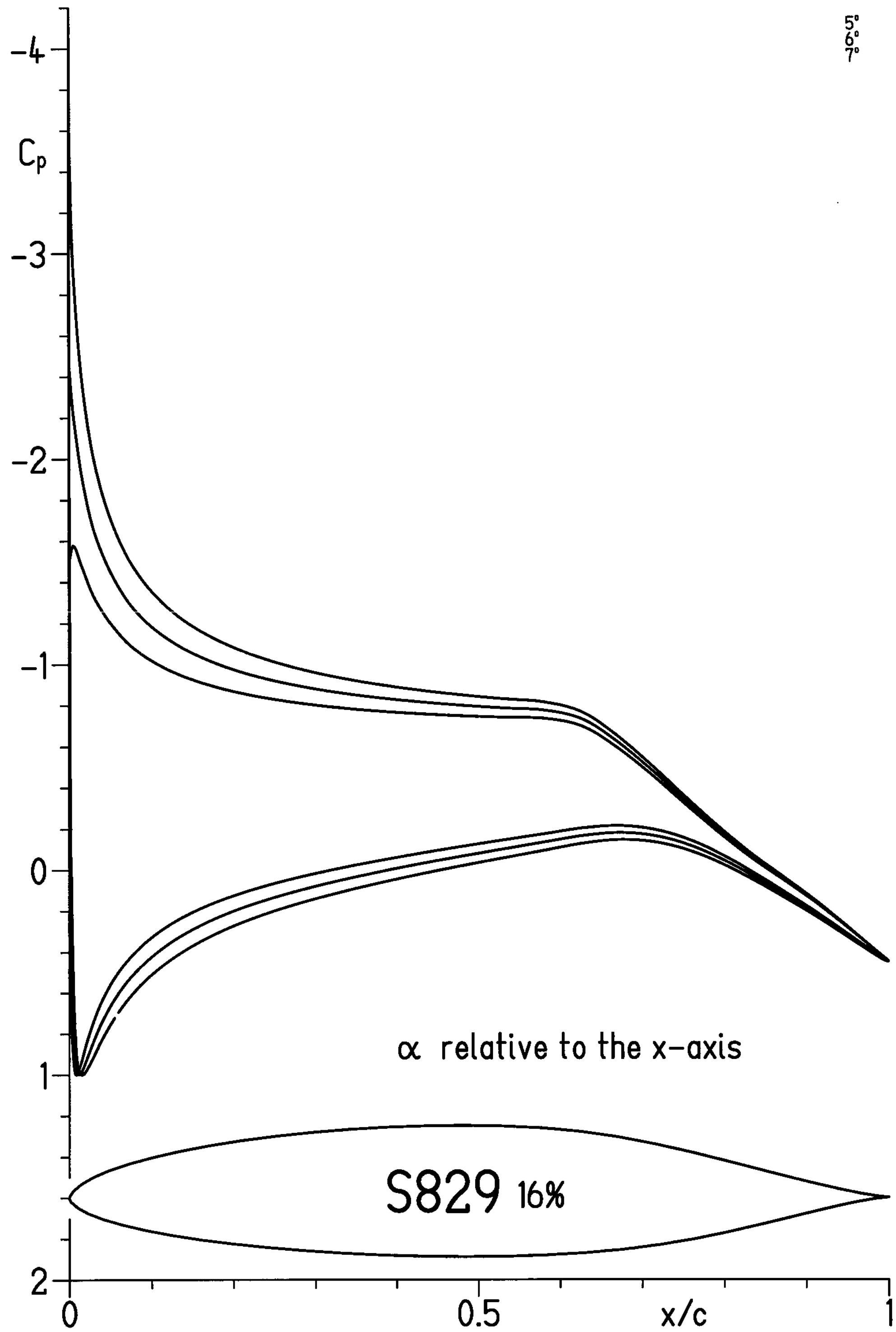
(a) $\alpha = -1°$, $0°$, and $1°$.

Figure 2.– Inviscid pressure distributions.



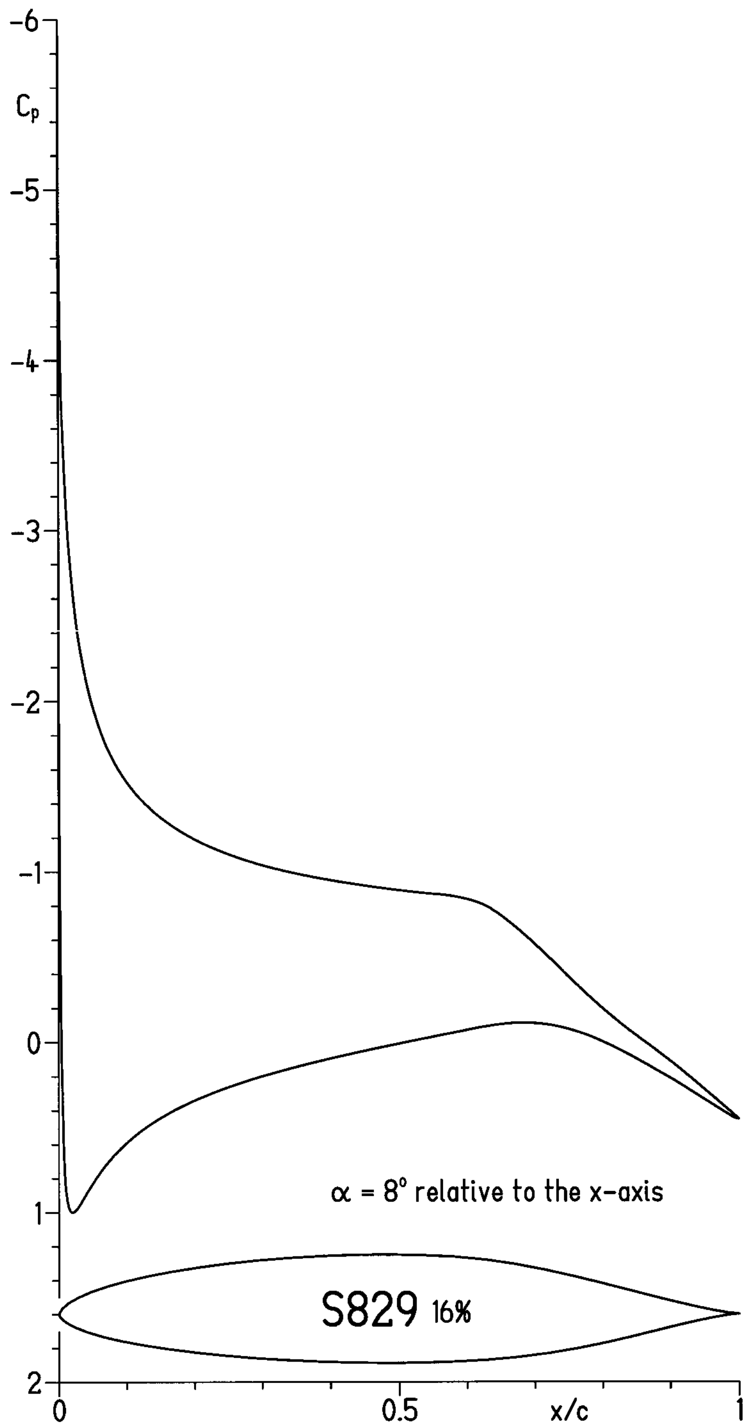
(b) $\alpha = 2°$, 3°, and 4°.

Figure 2.– Continued.



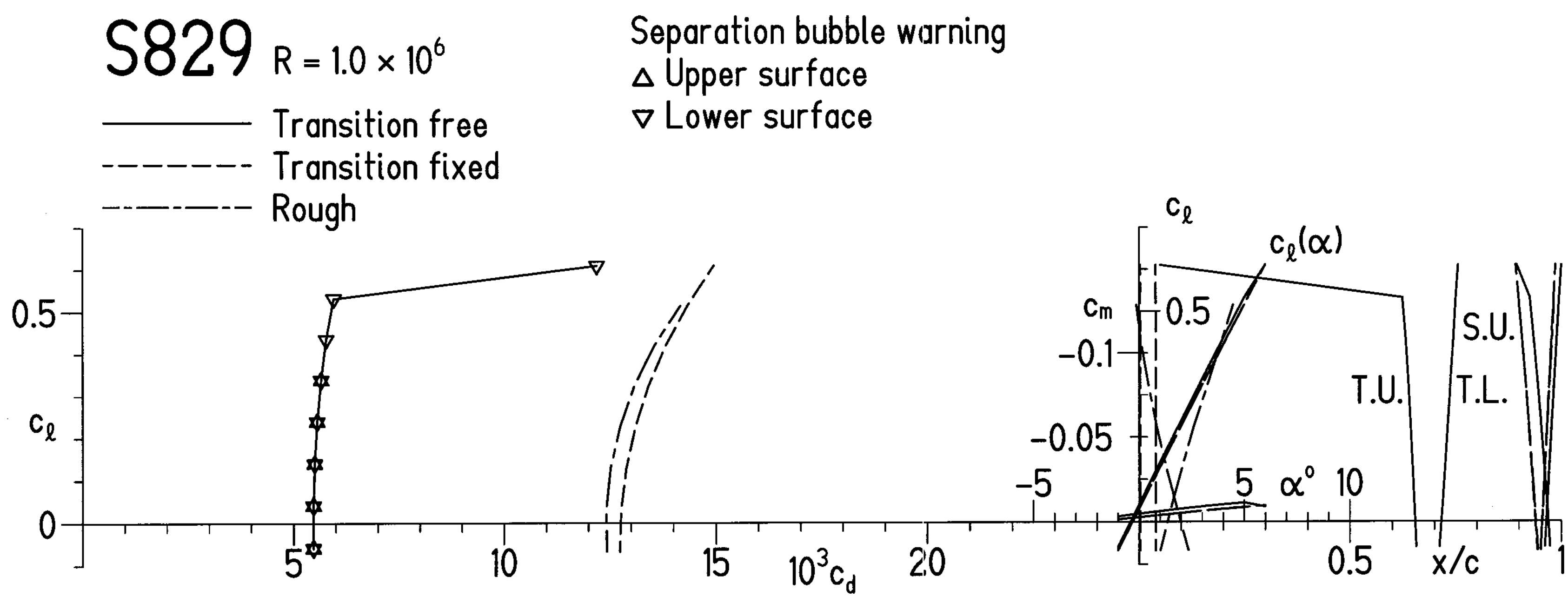
(c) α = 5°, 6°, and 7°.

Figure 2.– Continued.



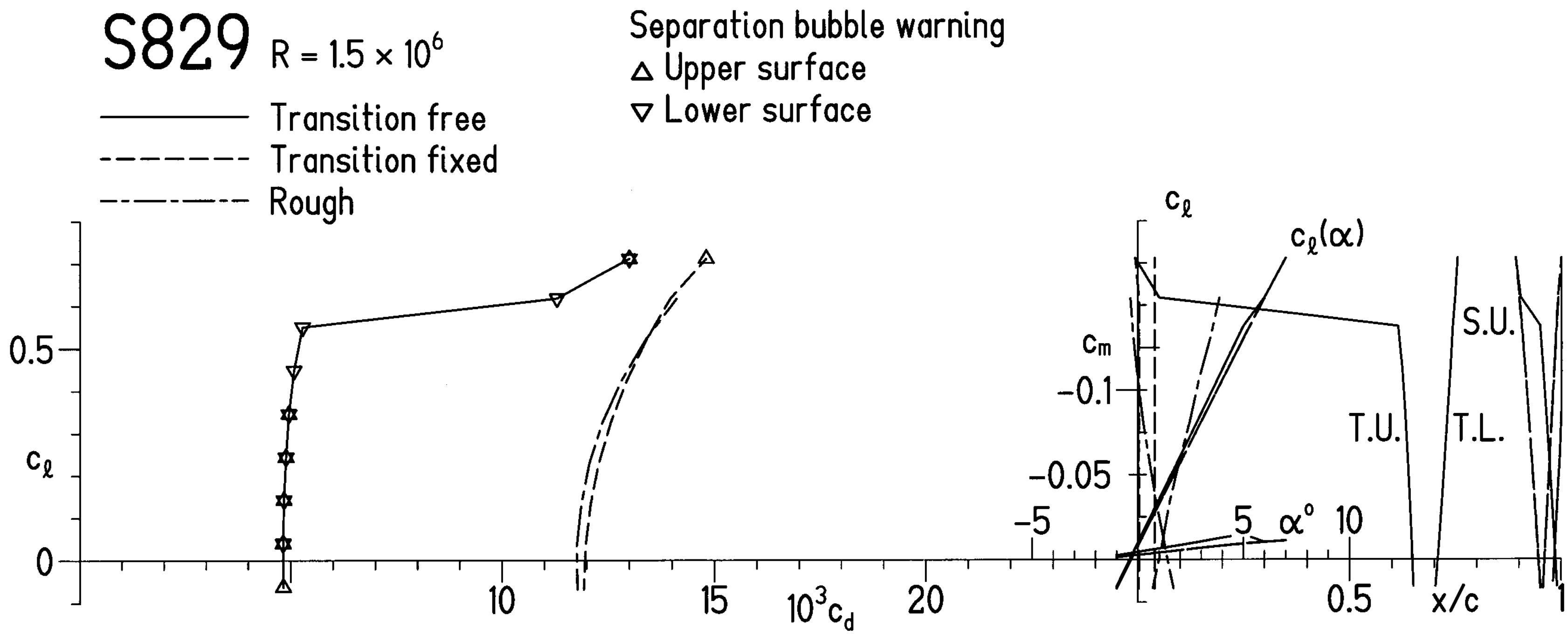
(d) α = 8°.

Figure 2.– Concluded.



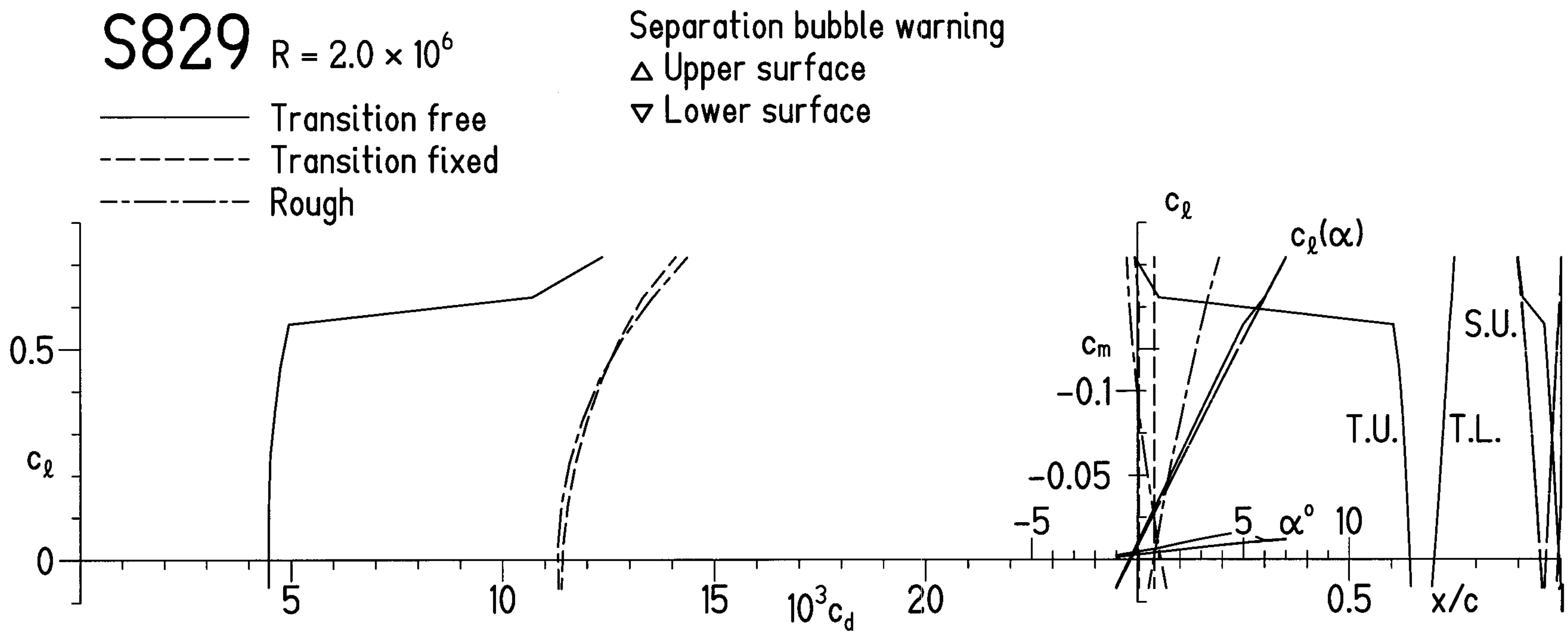
(a) $R = 1.0 \times 10^6$.

Figure 3.– Section characteristics with transition free, transition fixed, and rough.



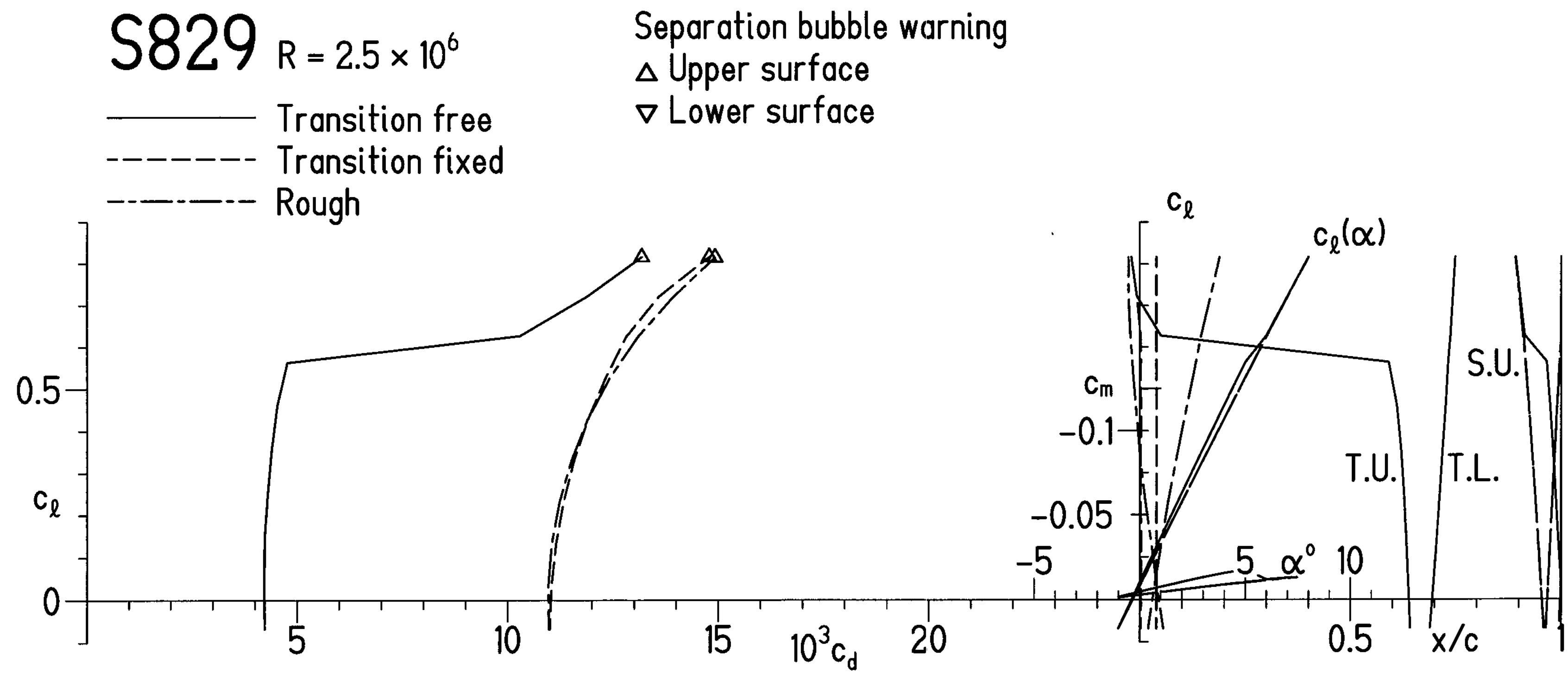
(b) $R = 1.5 \times 10^6$.

Figure 3.– Continued.



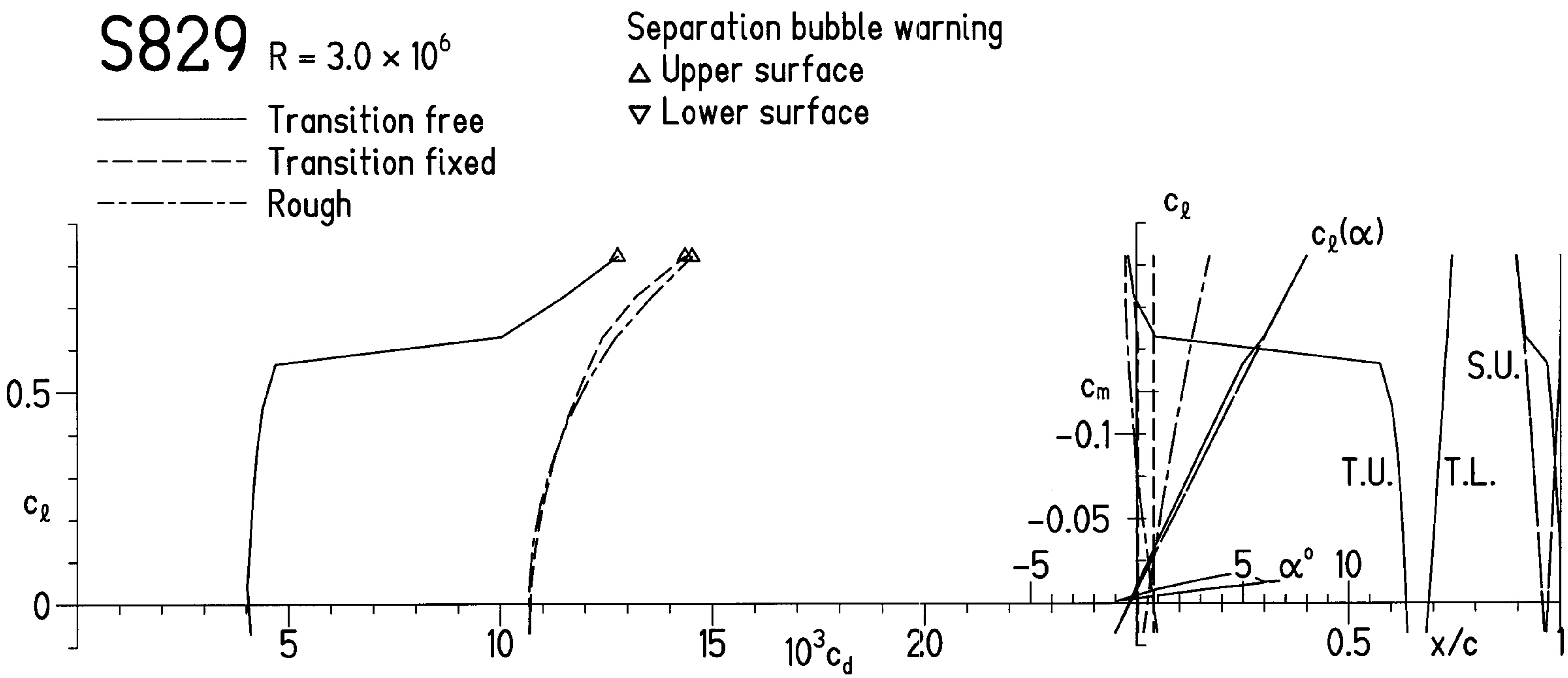
(c) $R = 2.0 \times 10^6$.

Figure 3.– Continued.



(d) $R = 2.5 \times 10^6$.

Figure 3.– Continued.



(e) $R = 3.0 \times 10^6$.

Figure 3.– Concluded.

APPENDIX

PRESSURE DISTRIBUTIONS, TRANSITION AND SEPARATION LOCATIONS, AND SECTION CHARACTERISTICS

AIRFOIL S829 16%

N	X	Y	NUE	-1.00	0.00	1.00	2.00	3.00	4.00
				CP-DISTR. FOR THE ABOVE ALPHA REL. CHORD LINE					
1	1.00000	0.00000	0.00	0.438	0.438	0.438	0.439	0.440	0.441
2	0.99593	0.00028	1.00	0.431	0.430	0.430	0.429	0.429	0.429
3	0.98404	0.00161	2.00	0.399	0.397	0.395	0.393	0.392	0.391
4	0.96518	0.00473	3.00	0.345	0.342	0.338	0.335	0.333	0.331
5	0.94045	0.00986	4.00	0.275	0.269	0.264	0.260	0.256	0.252
6	0.91085	0.01682	5.00	0.195	0.187	0.180	0.173	0.167	0.161
7	0.87719	0.02518	6.00	0.114	0.104	0.094	0.085	0.076	0.068
8	0.84011	0.03463	7.00	0.030	0.017	0.005	-0.007	-0.019	-0.030
9	0.80038	0.04479	8.00	-0.068	-0.084	-0.101	-0.116	-0.132	-0.146
10	0.75874	0.05514	9.00	-0.180	-0.201	-0.222	-0.242	-0.262	-0.281
11	0.71580	0.06493	10.00	-0.300	-0.327	-0.353	-0.378	-0.403	-0.427
12	0.67187	0.07345	11.00	-0.406	-0.439	-0.470	-0.502	-0.533	-0.563
13	0.62698	0.08006	12.00	-0.479	-0.517	-0.555	-0.592	-0.629	-0.665
14	0.58093	0.08447	13.00	-0.486	-0.529	-0.571	-0.613	-0.655	-0.696
15	0.53360	0.08695	14.00	-0.464	-0.511	-0.558	-0.604	-0.650	-0.696
16	0.48538	0.08789	15.00	-0.441	-0.493	-0.544	-0.596	-0.647	-0.698
17	0.43683	0.08750	16.00	-0.418	-0.475	-0.531	-0.588	-0.644	-0.701
18	0.38849	0.08591	17.00	-0.394	-0.456	-0.518	-0.581	-0.643	-0.706
19	0.34092	0.08321	18.00	-0.369	-0.437	-0.505	-0.574	-0.644	-0.714
20	0.29466	0.07951	19.00	-0.342	-0.417	-0.492	-0.569	-0.646	-0.725
21	0.25023	0.07491	20.00	-0.313	-0.395	-0.479	-0.565	-0.652	-0.740
22	0.20815	0.06949	21.00	-0.281	-0.372	-0.466	-0.562	-0.659	-0.759
23	0.16888	0.06335	22.00	-0.244	-0.346	-0.451	-0.559	-0.670	-0.784
24	0.13289	0.05659	23.00	-0.198	-0.313	-0.433	-0.556	-0.684	-0.816
25	0.10057	0.04930	24.00	-0.142	-0.273	-0.410	-0.553	-0.701	-0.856
26	0.07229	0.04160	25.00	-0.067	-0.217	-0.376	-0.544	-0.721	-0.906
27	0.04837	0.03359	26.00	0.036	-0.138	-0.326	-0.528	-0.743	-0.971
28	0.02906	0.02536	27.00	0.196	-0.006	-0.230	-0.475	-0.742	-1.029
29	0.01452	0.01709	28.00	0.440	0.213	-0.053	-0.356	-0.696	-1.073
30	0.00489	0.00902	29.00	0.792	0.580	0.294	-0.065	-0.497	-1.002
31	0.00067	0.00276	29.84	0.998	0.947	0.749	0.404	-0.088	-0.725
32	0.00013	0.00108	30.09	0.923	0.999	0.885	0.580	0.085	-0.599
33	0.00002	-0.00045	30.34	0.650	0.946	0.984	0.766	0.290	-0.441
34	0.00044	-0.00194	30.59	0.476	0.822	0.985	0.967	0.767	0.385
35	0.00134	-0.00354	30.84	0.328	0.687	0.910	0.998	0.951	0.768
36	0.00212	-0.00461	31.00	0.245	0.603	0.847	0.977	0.992	0.893
37	0.01005	-0.01163	32.00	-0.114	0.195	0.455	0.665	0.824	0.932
38	0.02315	-0.01890	33.00	-0.276	-0.026	0.196	0.392	0.561	0.703
39	0.04127	-0.02606	34.00	-0.339	-0.138	0.047	0.216	0.369	0.506
40	0.06425	-0.03296	35.00	-0.368	-0.202	-0.046	0.099	0.234	0.359
41	0.09185	-0.03951	36.00	-0.377	-0.238	-0.105	0.021	0.139	0.251
42	0.12378	-0.04562	37.00	-0.381	-0.262	-0.147	-0.037	0.068	0.167
43	0.15967	-0.05125	38.00	-0.382	-0.279	-0.178	-0.081	0.012	0.102
44	0.19913	-0.05633	39.00	-0.383	-0.292	-0.203	-0.117	-0.033	0.048
45	0.24170	-0.06080	40.00	-0.384	-0.303	-0.224	-0.147	-0.071	0.003
46	0.28689	-0.06461	41.00	-0.385	-0.313	-0.242	-0.172	-0.104	-0.037
47	0.33419	-0.06770	42.00	-0.388	-0.323	-0.259	-0.196	-0.134	-0.072
48	0.38303	-0.07002	43.00	-0.391	-0.333	-0.275	-0.218	-0.161	-0.105
49	0.43287	-0.07151	44.00	-0.396	-0.343	-0.291	-0.238	-0.186	-0.135
50	0.48311	-0.07211	45.00	-0.402	-0.354	-0.306	-0.258	-0.211	-0.163
51	0.53320	-0.07173	46.00	-0.408	-0.365	-0.321	-0.277	-0.234	-0.190
52	0.58256	-0.07031	47.00	-0.415	-0.375	-0.336	-0.296	-0.256	-0.216
53	0.63061	-0.06769	48.00	-0.422	-0.386	-0.351	-0.314	-0.278	-0.241
54	0.67694	-0.06362	49.00	-0.409	-0.378	-0.346	-0.314	-0.281	-0.248
55	0.72141	-0.05794	50.00	-0.360	-0.333	-0.306	-0.278	-0.249	-0.220
56	0.76401	-0.05077	51.00	-0.279	-0.256	-0.233	-0.210	-0.186	-0.161
57	0.80466	-0.04249	52.00	-0.175	-0.157	-0.138	-0.119	-0.099	-0.079
58	0.84317	-0.03364	53.00	-0.062	-0.048	-0.033	-0.018	-0.003	0.014
59	0.87913	-0.02486	54.00	0.048	0.059	0.070	0.082	0.094	0.107
60	0.91199	-0.01676	55.00	0.151	0.159	0.167	0.176	0.185	0.195
61	0.94106	-0.00992	56.00	0.246	0.251	0.257	0.264	0.271	0.278
62	0.96546	-0.00480	57.00	0.326	0.330	0.334	0.338	0.343	0.348
63	0.98414	-0.00166	58.00	0.387	0.389	0.392	0.395	0.398	0.402
64	0.99595	-0.00029	59.00	0.425	0.426	0.427	0.429	0.431	0.434
65	1.00000	0.00000	60.00	0.438	0.438	0.438	0.439	0.440	0.441

ALPHA0= 0.37 DEGREES CM0=-0.0031 ETA= 1.125

AIRFOIL S829		16%		5.00	6.00	7.00	8.00	9.00	10.00
N	X	Y	NUE	CP-DISTR. FOR THE ABOVE ALPHA REL. CHORD LINE					
1	1.00000	0.00000	0.00	0.443	0.445	0.447	0.450	0.453	0.456
2	0.99593	0.00028	1.00	0.430	0.431	0.432	0.434	0.436	0.438
3	0.98404	0.00161	2.00	0.391	0.391	0.391	0.392	0.393	0.394
4	0.96518	0.00473	3.00	0.329	0.328	0.327	0.326	0.326	0.327
5	0.94045	0.00986	4.00	0.249	0.246	0.243	0.241	0.240	0.239
6	0.91085	0.01682	5.00	0.156	0.151	0.147	0.143	0.140	0.137
7	0.87719	0.02518	6.00	0.060	0.053	0.047	0.041	0.035	0.031
8	0.84011	0.03463	7.00	-0.041	-0.050	-0.060	-0.068	-0.076	-0.084
9	0.80038	0.04479	8.00	-0.160	-0.173	-0.186	-0.198	-0.210	-0.220
10	0.75874	0.05514	9.00	-0.299	-0.316	-0.333	-0.350	-0.365	-0.380
11	0.71580	0.06493	10.00	-0.451	-0.474	-0.496	-0.517	-0.538	-0.558
12	0.67187	0.07345	11.00	-0.592	-0.621	-0.649	-0.676	-0.702	-0.728
13	0.62698	0.08006	12.00	-0.700	-0.735	-0.769	-0.803	-0.835	-0.867
14	0.58093	0.08447	13.00	-0.736	-0.776	-0.816	-0.855	-0.893	-0.930
15	0.53360	0.08695	14.00	-0.742	-0.787	-0.831	-0.875	-0.918	-0.961
16	0.48538	0.08789	15.00	-0.749	-0.799	-0.849	-0.898	-0.947	-0.996
17	0.43683	0.08750	16.00	-0.758	-0.814	-0.870	-0.926	-0.982	-1.037
18	0.38849	0.08591	17.00	-0.769	-0.833	-0.896	-0.959	-1.022	-1.084
19	0.34092	0.08321	18.00	-0.785	-0.855	-0.927	-0.998	-1.069	-1.140
20	0.29466	0.07951	19.00	-0.804	-0.884	-0.964	-1.045	-1.126	-1.208
21	0.25023	0.07491	20.00	-0.829	-0.920	-1.011	-1.104	-1.197	-1.291
22	0.20815	0.06949	21.00	-0.861	-0.964	-1.069	-1.175	-1.283	-1.392
23	0.16888	0.06335	22.00	-0.901	-1.020	-1.142	-1.266	-1.391	-1.519
24	0.13289	0.05659	23.00	-0.951	-1.091	-1.233	-1.379	-1.528	-1.680
25	0.10057	0.04930	24.00	-1.016	-1.182	-1.353	-1.528	-1.709	-1.893
26	0.07229	0.04160	25.00	-1.099	-1.300	-1.510	-1.726	-1.950	-2.181
27	0.04837	0.03359	26.00	-1.211	-1.464	-1.729	-2.006	-2.295	-2.594
28	0.02906	0.02536	27.00	-1.338	-1.667	-2.015	-2.383	-2.770	-3.176
29	0.01452	0.01709	28.00	-1.487	-1.937	-2.422	-2.942	-3.496	-4.084
30	0.00489	0.00902	29.00	-1.578	-2.225	-2.943	-3.730	-4.585	-5.508
31	0.00067	0.00276	29.84	-1.507	-2.432	-3.501	-4.711	-6.061	-7.550
32	0.00013	0.00108	30.09	-1.473	-2.534	-3.781	-5.213	-6.828	-8.624
33	0.00002	-0.00045	30.34	-1.428	-2.670	-4.164	-5.909	-7.902	-10.142
34	0.00044	-0.00194	30.59	-0.178	-0.921	-1.845	-2.947	-4.226	-5.681
35	0.00134	-0.00354	30.84	0.450	-0.003	-0.591	-1.312	-2.166	-3.152
36	0.00212	-0.00461	31.00	0.679	0.351	-0.090	-0.645	-1.313	-2.092
37	0.01005	-0.01163	32.00	0.990	0.997	0.953	0.858	0.712	0.516
38	0.02315	-0.01890	33.00	0.817	0.904	0.963	0.994	0.998	0.974
39	0.04127	-0.02606	34.00	0.626	0.730	0.817	0.888	0.941	0.977
40	0.06425	-0.03296	35.00	0.473	0.576	0.668	0.749	0.819	0.877
41	0.09185	-0.03951	36.00	0.355	0.452	0.541	0.622	0.696	0.762
42	0.12378	-0.04562	37.00	0.262	0.351	0.435	0.514	0.587	0.654
43	0.15967	-0.05125	38.00	0.188	0.270	0.348	0.422	0.492	0.558
44	0.19913	-0.05633	39.00	0.126	0.202	0.274	0.344	0.410	0.473
45	0.24170	-0.06080	40.00	0.074	0.143	0.211	0.276	0.338	0.398
46	0.28689	-0.06461	41.00	0.029	0.092	0.155	0.215	0.274	0.331
47	0.33419	-0.06770	42.00	-0.012	0.047	0.105	0.161	0.217	0.271
48	0.38303	-0.07002	43.00	-0.049	0.005	0.059	0.112	0.164	0.215
49	0.43287	-0.07151	44.00	-0.084	-0.033	0.017	0.066	0.115	0.163
50	0.48311	-0.07211	45.00	-0.116	-0.069	-0.023	0.023	0.069	0.114
51	0.53320	-0.07173	46.00	-0.147	-0.103	-0.060	-0.017	0.026	0.068
52	0.58256	-0.07031	47.00	-0.176	-0.136	-0.096	-0.056	-0.016	0.024
53	0.63061	-0.06769	48.00	-0.204	-0.167	-0.130	-0.093	-0.055	-0.018
54	0.67694	-0.06362	49.00	-0.214	-0.181	-0.147	-0.113	-0.078	-0.044
55	0.72141	-0.05794	50.00	-0.191	-0.161	-0.131	-0.101	-0.071	-0.040
56	0.76401	-0.05077	51.00	-0.136	-0.111	-0.085	-0.059	-0.033	-0.006
57	0.80466	-0.04249	52.00	-0.059	-0.038	-0.016	0.006	0.028	0.050
58	0.84317	-0.03364	53.00	0.030	0.047	0.065	0.082	0.101	0.119
59	0.87913	-0.02486	54.00	0.120	0.133	0.147	0.161	0.176	0.191
60	0.91199	-0.01676	55.00	0.205	0.215	0.226	0.237	0.249	0.261
61	0.94106	-0.00992	56.00	0.285	0.293	0.302	0.310	0.320	0.329
62	0.96546	-0.00480	57.00	0.354	0.360	0.366	0.373	0.380	0.387
63	0.98414	-0.00166	58.00	0.406	0.410	0.415	0.420	0.425	0.431
64	0.99595	-0.00029	59.00	0.436	0.439	0.443	0.446	0.450	0.455
65	1.00000	0.00000	60.00	0.443	0.445	0.447	0.450	0.453	0.456

ALPHA0= 0.37 DEGREES CM0=-0.0031 ETA= 1.125

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B.L.SUMMARY AIRFOIL S829  16%  ALPHA0=  0.367 DEG.
 *-WARNING WITH VARIABLE LIMIT  ALPHA REL. CHORD LINE

ALPHA(DEG.) R= 1000000 MU=3.0       R= 1000000 MU=1.3       R= 1000000 MU=9.0
-1.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3429 0.0260 0.0028*    0.9973 0.0562 0.0061     0.8828 0.0546 0.0059
   LOWER 0.2882 0.0383 0.0027*    0.9602 0.0485 0.0066     0.9490 0.0484 0.0066
   TOTAL CL=-0.059 CD=0.00547     CL=-0.068 CD=0.01274     CL=-0.067 CD=0.01244
         CM=-0.0032               CM=-0.0014               CM=-0.0015
 0.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3476 0.0331 0.0029*    0.9973 0.0631 0.0067     0.9098 0.0618 0.0064
   LOWER 0.2808 0.0331 0.0025*    0.9602 0.0437 0.0061     0.9243 0.0434 0.0060
   TOTAL CL= 0.041 CD=0.00547     CL= 0.031 CD=0.01277     CL= 0.031 CD=0.01242
         CM=-0.0048               CM=-0.0026               CM=-0.0027
 1.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3524 0.0407 0.0031*    0.9973 0.0699 0.0073     0.9353 0.0690 0.0070
   LOWER 0.2743 0.0277 0.0024*    0.9602 0.0389 0.0056     0.8975 0.0383 0.0055
   TOTAL CL= 0.140 CD=0.00550     CL= 0.128 CD=0.01289     CL= 0.129 CD=0.01252
         CM=-0.0062               CM=-0.0039               CM=-0.0040
 2.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3573 0.0485 0.0033*    0.9973 0.0770 0.0079     0.9584 0.0763 0.0077
   LOWER 0.2682 0.0223 0.0022*    0.9602 0.0340 0.0052     0.8698 0.0333 0.0050
   TOTAL CL= 0.239 CD=0.00556     CL= 0.226 CD=0.01310     CL= 0.226 CD=0.01275
         CM=-0.0076               CM=-0.0052               CM=-0.0052
 3.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3626 0.0568 0.0036*    0.9973 0.0842 0.0086     0.9776 0.0838 0.0085
   LOWER 0.2624 0.0167 0.0021*    0.9602 0.0291 0.0048     0.8375 0.0282 0.0046
   TOTAL CL= 0.337 CD=0.00565     CL= 0.323 CD=0.01341     CL= 0.323 CD=0.01308
         CM=-0.0089               CM=-0.0064               CM=-0.0063
 4.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3687 0.0656 0.0038     0.9973 0.0918 0.0094     0.9946 0.0917 0.0094
   LOWER 0.2558 0.0112 0.0019*    0.9602 0.0242 0.0044     0.8067 0.0230 0.0042
   TOTAL CL= 0.435 CD=0.00577     CL= 0.420 CD=0.01382     CL= 0.419 CD=0.01355
         CM=-0.0101               CM=-0.0075               CM=-0.0074
 5.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.3765 0.0747 0.0041     0.9973 0.0998 0.0102     1.0067 0.1001 0.0103
   LOWER 0.2503 0.0051 0.0018*    0.9602 0.0191 0.0041     0.7762 0.0176 0.0038
   TOTAL CL= 0.532 CD=0.00595     CL= 0.516 CD=0.01433     CL= 0.515 CD=0.01417
         CM=-0.0111               CM=-0.0085               CM=-0.0083
 6.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 0.9496 0.1058 0.0105     0.9973 0.1082 0.0112     1.0147 0.1091 0.0114
   LOWER 0.2446 0.0000 0.0017*    0.9602 0.0138 0.0038     0.7425 0.0121 0.0035
   TOTAL CL= 0.610 CD=0.01220     CL= 0.611 CD=0.01495     CL= 0.610 CD=0.01493
         CM=-0.0088               CM=-0.0094               CM=-0.0092
 7.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 1.0063 0.1177 0.0124*    1.0063 0.1177 0.0124*    1.0213 0.1187 0.0127
   LOWER 0.2389 0.0000 0.0016*    0.9602 0.0085 0.0035     0.7052 0.0060 0.0032
   TOTAL CL= 0.704 CD=0.01397     CL= 0.705 CD=0.01587     CL= 0.704 CD=0.01588
         CM=-0.0096               CM=-0.0101               CM=-0.0098
 8.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 1.0194 0.1287 0.0139*    1.0194 0.1287 0.0139*    1.0258 0.1293 0.0141*
   LOWER 0.2333 0.0000 0.0015*    0.9602 0.0000 0.0032     0.6779 0.0000 0.0029
   TOTAL CL= 0.797 CD=0.01547     CL= 0.797 CD=0.01717     CL= 0.796 CD=0.01703
         CM=-0.0103               CM=-0.0103               CM=-0.0102
 9.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 1.0259 0.1420 0.0157*    1.0259 0.1420 0.0157*    1.0261 0.1420 0.0157*
   LOWER 0.2278 0.0000 0.0015*    0.9602 0.0000 0.0030     0.6360 0.0000 0.0027
   TOTAL CL= 0.886 CD=0.01716     CL= 0.886 CD=0.01867     CL= 0.886 CD=0.01840
         CM=-0.0106               CM=-0.0106               CM=-0.0106
10.00    S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
   UPPER 1.0261 0.1563 0.0174*    1.0261 0.1563 0.0174*    1.0263 0.1564 0.0175*
   LOWER 0.2227 0.0000 0.0014*    0.9453 0.0000 0.0028     0.5939 0.0000 0.0025
   TOTAL CL= 0.973 CD=0.01883     CL= 0.973 CD=0.02025     CL= 0.973 CD=0.01995
         CM=-0.0107               CM=-0.0107               CM=-0.0107
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B.L.SUMMARY AIRFOIL S829  16%  ALPHA0=  0.367 DEG.
 *-WARNING WITH VARIABLE LIMIT  ALPHA REL. CHORD LINE

ALPHA(DEG.) R= 1500000 MU=3.0      R= 1500000 MU=1.3      R= 1500000 MU=9.0
-1.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3491 0.0096 0.0024*    0.9973 0.0494 0.0058    0.9158 0.0485 0.0056
   LOWER 0.2971 0.0196 0.0024     0.9602 0.0428 0.0062    0.9645 0.0428 0.0062
   TOTAL CL=-0.063 CD=0.00483     CL=-0.068 CD=0.01194    CL=-0.067 CD=0.01179
         CM=-0.0026               CM=-0.0013              CM=-0.0014
 0.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3537 0.0158 0.0026*    0.9973 0.0561 0.0063    0.9362 0.0553 0.0061
   LOWER 0.2893 0.0144 0.0022*    0.9602 0.0380 0.0057    0.9434 0.0379 0.0057
   TOTAL CL= 0.040 CD=0.00482     CL= 0.031 CD=0.01197    CL= 0.032 CD=0.01176
         CM=-0.0046               CM=-0.0027              CM=-0.0028
 1.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3584 0.0222 0.0028*    0.9973 0.0629 0.0068    0.9559 0.0623 0.0067
   LOWER 0.2822 0.0092 0.0021*    0.9602 0.0332 0.0053    0.9261 0.0329 0.0052
   TOTAL CL= 0.142 CD=0.00484     CL= 0.130 CD=0.01209    CL= 0.130 CD=0.01187
         CM=-0.0065               CM=-0.0041              CM=-0.0042
 2.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3634 0.0289 0.0029*    0.9973 0.0697 0.0074    0.9722 0.0693 0.0073
   LOWER 0.2757 0.0037 0.0020*    0.9602 0.0284 0.0049    0.9029 0.0280 0.0048
   TOTAL CL= 0.244 CD=0.00489     CL= 0.228 CD=0.01228    CL= 0.228 CD=0.01206
         CM=-0.0084               CM=-0.0055              CM=-0.0055
 3.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3691 0.0358 0.0031*    0.9973 0.0766 0.0080    0.9879 0.0764 0.0080
   LOWER 0.2697 0.0000 0.0018*    0.9602 0.0236 0.0045    0.8773 0.0230 0.0044
   TOTAL CL= 0.346 CD=0.00496     CL= 0.326 CD=0.01257    CL= 0.326 CD=0.01237
         CM=-0.0104               CM=-0.0068              CM=-0.0068
 4.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3760 0.0430 0.0034     0.9973 0.0838 0.0088    1.0002 0.0839 0.0088
   LOWER 0.2629 0.0000 0.0017*    0.9602 0.0186 0.0042    0.8560 0.0179 0.0040
   TOTAL CL= 0.448 CD=0.00508     CL= 0.424 CD=0.01294    CL= 0.424 CD=0.01281
         CM=-0.0126               CM=-0.0081              CM=-0.0080
 5.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.3861 0.0505 0.0036     0.9973 0.0914 0.0095    1.0104 0.0919 0.0097
   LOWER 0.2574 0.0000 0.0016*    0.9602 0.0134 0.0039    0.8291 0.0126 0.0037
   TOTAL CL= 0.550 CD=0.00528     CL= 0.521 CD=0.01340    CL= 0.520 CD=0.01338
         CM=-0.0146               CM=-0.0093              CM=-0.0091
 6.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 0.9496 0.0969 0.0097     0.9973 0.0994 0.0104    1.0176 0.1004 0.0107
   LOWER 0.2518 0.0000 0.0016*    0.9602 0.0082 0.0036    0.8070 0.0072 0.0034
   TOTAL CL= 0.618 CD=0.01130     CL= 0.617 CD=0.01397    CL= 0.616 CD=0.01411
         CM=-0.0101               CM=-0.0103              CM=-0.0101
 7.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 1.0063 0.1085 0.0115*    1.0063 0.1085 0.0115*   1.0233 0.1098 0.0119*
   LOWER 0.2461 0.0000 0.0015*    0.9602 0.0000 0.0033    0.7733 0.0000 0.0031
   TOTAL CL= 0.712 CD=0.01300     CL= 0.712 CD=0.01481    CL= 0.711 CD=0.01499
         CM=-0.0110               CM=-0.0110              CM=-0.0107
 8.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 1.0194 0.1193 0.0130*    1.0194 0.1193 0.0130*   1.0260 0.1201 0.0132*
   LOWER 0.2403 0.0000 0.0014*    0.9602 0.0000 0.0030    0.7476 0.0000 0.0029
   TOTAL CL= 0.806 CD=0.01440     CL= 0.806 CD=0.01602    CL= 0.805 CD=0.01606
         CM=-0.0118               CM=-0.0118              CM=-0.0117
 9.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 1.0259 0.1322 0.0147*    1.0259 0.1322 0.0147*   1.0262 0.1323 0.0147*
   LOWER 0.2345 0.0000 0.0013*    0.9602 0.0000 0.0029    0.7159 0.0000 0.0027
   TOTAL CL= 0.896 CD=0.01600     CL= 0.896 CD=0.01753    CL= 0.896 CD=0.01737
         CM=-0.0122               CM=-0.0122              CM=-0.0121
10.00    S TURB  S SEP   CD       S TURB  S SEP   CD      S TURB  S SEP   CD
   UPPER 1.0261 0.1461 0.0163*    1.0261 0.1461 0.0163*   1.0264 0.1463 0.0163*
   LOWER 0.2293 0.0000 0.0013*    0.9453 0.0000 0.0027    0.6875 0.0000 0.0025
   TOTAL CL= 0.984 CD=0.01756     CL= 0.984 CD=0.01899    CL= 0.983 CD=0.01883
         CM=-0.0122               CM=-0.0122              CM=-0.0122
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B.L.SUMMARY AIRFOIL S829  16%  ALPHA0=  0.367 DEG.
 *-WARNING WITH VARIABLE LIMIT  ALPHA REL. CHORD LINE

ALPHA(DEG.) R= 2000000 MU=3.0       R= 2000000 MU=1.3       R= 2000000 MU=9.0
-1.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3539 0.0000 0.0023      0.9973 0.0446 0.0055     0.9324 0.0439 0.0054
    LOWER 0.3044 0.0102 0.0022      0.9602 0.0387 0.0059     0.9739 0.0388 0.0059
    TOTAL CL=-0.064 CD=0.00447      CL=-0.068 CD=0.01140     CL=-0.067 CD=0.01133
          CM=-0.0024                CM=-0.0013               CM=-0.0014
 0.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3584 0.0068 0.0024      0.9973 0.0512 0.0060     0.9511 0.0506 0.0059
    LOWER 0.2963 0.0051 0.0021      0.9602 0.0339 0.0054     0.9562 0.0339 0.0054
    TOTAL CL= 0.039 CD=0.00446      CL= 0.032 CD=0.01144     CL= 0.032 CD=0.01131
          CM=-0.0045                CM=-0.0028               CM=-0.0028
 1.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3632 0.0129 0.0025      0.9973 0.0578 0.0065     0.9658 0.0573 0.0064
    LOWER 0.2889 0.0000 0.0019      0.9602 0.0291 0.0050     0.9397 0.0290 0.0050
    TOTAL CL= 0.143 CD=0.00448      CL= 0.131 CD=0.01155     CL= 0.131 CD=0.01140
          CM=-0.0067                CM=-0.0043               CM=-0.0043
 2.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3684 0.0190 0.0027      0.9973 0.0645 0.0071     0.9807 0.0642 0.0070
    LOWER 0.2820 0.0000 0.0018      0.9602 0.0244 0.0047     0.9212 0.0241 0.0046
    TOTAL CL= 0.248 CD=0.00451      CL= 0.230 CD=0.01173     CL= 0.230 CD=0.01159
          CM=-0.0095                CM=-0.0057               CM=-0.0057
 3.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3746 0.0254 0.0029      0.9973 0.0713 0.0077     0.9944 0.0712 0.0077
    LOWER 0.2757 0.0000 0.0017      0.9602 0.0195 0.0043     0.8994 0.0191 0.0042
    TOTAL CL= 0.353 CD=0.00462      CL= 0.328 CD=0.01200     CL= 0.328 CD=0.01188
          CM=-0.0120                CM=-0.0072               CM=-0.0071
 4.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3827 0.0321 0.0031      0.9973 0.0783 0.0084     1.0037 0.0784 0.0084
    LOWER 0.2686 0.0000 0.0016      0.9602 0.0145 0.0040     0.8786 0.0140 0.0039
    TOTAL CL= 0.457 CD=0.00475      CL= 0.427 CD=0.01235     CL= 0.426 CD=0.01229
          CM=-0.0144                CM=-0.0085               CM=-0.0084
 5.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3962 0.0395 0.0034      0.9973 0.0855 0.0091     1.0128 0.0861 0.0093
    LOWER 0.2630 0.0000 0.0016      0.9602 0.0094 0.0037     0.8570 0.0088 0.0036
    TOTAL CL= 0.559 CD=0.00495      CL= 0.525 CD=0.01278     CL= 0.524 CD=0.01283
          CM=-0.0165                CM=-0.0098               CM=-0.0097
 6.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.9496 0.0906 0.0092      0.9973 0.0932 0.0099     1.0197 0.0944 0.0102
    LOWER 0.2574 0.0000 0.0015      0.9602 0.0032 0.0034     0.8343 0.0017 0.0033
    TOTAL CL= 0.623 CD=0.01072      CL= 0.622 CD=0.01331     CL= 0.620 CD=0.01353
          CM=-0.0111                CM=-0.0109               CM=-0.0106
 7.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0063 0.1020 0.0110      1.0063 0.1020 0.0110     1.0250 0.1035 0.0114
    LOWER 0.2518 0.0000 0.0014      0.9602 0.0000 0.0031     0.8074 0.0000 0.0030
    TOTAL CL= 0.718 CD=0.01236      CL= 0.718 CD=0.01409     CL= 0.716 CD=0.01436
          CM=-0.0120                CM=-0.0120               CM=-0.0117
 8.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0194 0.1126 0.0124*     1.0194 0.1126 0.0124*    1.0262 0.1135 0.0126*
    LOWER 0.2461 0.0000 0.0013*     0.9602 0.0000 0.0029     0.7874 0.0000 0.0028
    TOTAL CL= 0.812 CD=0.01370      CL= 0.812 CD=0.01532     CL= 0.811 CD=0.01542
          CM=-0.0129                CM=-0.0129               CM=-0.0127
 9.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0259 0.1247 0.0139*     1.0259 0.1247 0.0139*    1.0263 0.1254 0.0140*
    LOWER 0.2402 0.0000 0.0012*     0.9602 0.0000 0.0028     0.7648 0.0000 0.0027
    TOTAL CL= 0.904 CD=0.01519      CL= 0.904 CD=0.01671     CL= 0.903 CD=0.01667
          CM=-0.0134                CM=-0.0134               CM=-0.0133
10.00     S TURB  S SEP   CD        S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0261 0.1388 0.0155*     1.0261 0.1388 0.0155*    1.0264 0.1390 0.0156*
    LOWER 0.2348 0.0000 0.0012*     0.9453 0.0000 0.0026     0.7319 0.0000 0.0025
    TOTAL CL= 0.992 CD=0.01672      CL= 0.992 CD=0.01814     CL= 0.991 CD=0.01804
          CM=-0.0134                CM=-0.0134               CM=-0.0134
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B.L.SUMMARY AIRFOIL S829  16%  ALPHA0=  0.367 DEG.
 *-WARNING WITH VARIABLE LIMIT  ALPHA REL. CHORD LINE

ALPHA(DEG.) R= 2500000 MU=3.0      R= 2500000 MU=1.3      R= 2500000 MU=9.0
-1.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3577 0.0000 0.0021    0.9973 0.0409 0.0053    0.9442 0.0403 0.0052
    LOWER 0.3107 0.0046 0.0021    0.9602 0.0354 0.0057    0.9798 0.0356 0.0058
    TOTAL CL=-0.067 CD=0.00423    CL=-0.068 CD=0.01100    CL=-0.068 CD=0.01098
          CM=-0.0016              CM=-0.0013              CM=-0.0013
 0.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3623 0.0000 0.0023    0.9973 0.0473 0.0058    0.9593 0.0469 0.0057
    LOWER 0.3022 0.0000 0.0020    0.9602 0.0307 0.0053    0.9650 0.0307 0.0053
    TOTAL CL= 0.040 CD=0.00422    CL= 0.032 CD=0.01103    CL= 0.032 CD=0.01096
          CM=-0.0047              CM=-0.0028              CM=-0.0029
 1.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3672 0.0070 0.0024    0.9973 0.0539 0.0063    0.9723 0.0535 0.0062
    LOWER 0.2946 0.0000 0.0018    0.9602 0.0259 0.0049    0.9488 0.0258 0.0048
    TOTAL CL= 0.146 CD=0.00423    CL= 0.132 CD=0.01114    CL= 0.132 CD=0.01104
          CM=-0.0075              CM=-0.0044              CM=-0.0044
 2.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3727 0.0129 0.0026    0.9973 0.0605 0.0068    0.9867 0.0603 0.0068
    LOWER 0.2875 0.0000 0.0017    0.9602 0.0212 0.0045    0.9326 0.0210 0.0045
    TOTAL CL= 0.252 CD=0.00431    CL= 0.231 CD=0.01133    CL= 0.231 CD=0.01123
          CM=-0.0104              CM=-0.0059              CM=-0.0059
 3.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3796 0.0190 0.0027    0.9973 0.0671 0.0074    0.9986 0.0672 0.0074
    LOWER 0.2808 0.0000 0.0017    0.9602 0.0163 0.0042    0.9140 0.0160 0.0041
    TOTAL CL= 0.357 CD=0.00440    CL= 0.330 CD=0.01158    CL= 0.330 CD=0.01151
          CM=-0.0130              CM=-0.0074              CM=-0.0074
 4.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.3897 0.0258 0.0030    0.9973 0.0740 0.0081    1.0065 0.0742 0.0081
    LOWER 0.2734 0.0000 0.0016    0.9602 0.0113 0.0039    0.8947 0.0109 0.0038
    TOTAL CL= 0.461 CD=0.00453    CL= 0.429 CD=0.01191    CL= 0.429 CD=0.01190
          CM=-0.0155              CM=-0.0088              CM=-0.0088
 5.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.4088 0.0337 0.0033    0.9973 0.0810 0.0088    1.0145 0.0817 0.0089
    LOWER 0.2677 0.0000 0.0015    0.9602 0.0060 0.0036    0.8742 0.0055 0.0035
    TOTAL CL= 0.563 CD=0.00477    CL= 0.527 CD=0.01232    CL= 0.527 CD=0.01242
          CM=-0.0176              CM=-0.0102              CM=-0.0101
 6.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 0.9496 0.0860 0.0089    0.9973 0.0884 0.0095    1.0212 0.0897 0.0099
    LOWER 0.2621 0.0000 0.0014    0.9602 0.0000 0.0033    0.8551 0.0000 0.0032
    TOTAL CL= 0.627 CD=0.01029    CL= 0.625 CD=0.01281    CL= 0.624 CD=0.01308
          CM=-0.0118              CM=-0.0114              CM=-0.0112
 7.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 1.0063 0.0970 0.0105    1.0063 0.0970 0.0105    1.0258 0.0987 0.0110
    LOWER 0.2566 0.0000 0.0013    0.9602 0.0000 0.0030    0.8326 0.0000 0.0030
    TOTAL CL= 0.722 CD=0.01188    CL= 0.722 CD=0.01359    CL= 0.721 CD=0.01393
          CM=-0.0128              CM=-0.0128              CM=-0.0125
 8.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 1.0194 0.1074 0.0119*   1.0194 0.1074 0.0119*   1.0262 0.1084 0.0121*
    LOWER 0.2509 0.0000 0.0013    0.9602 0.0000 0.0029    0.8111 0.0000 0.0028
    TOTAL CL= 0.817 CD=0.01318    CL= 0.817 CD=0.01479    CL= 0.816 CD=0.01493
          CM=-0.0137              CM=-0.0137              CM=-0.0136
 9.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 1.0259 0.1193 0.0134*   1.0259 0.1193 0.0134*   1.0264 0.1195 0.0135*
    LOWER 0.2451 0.0000 0.0012    0.9602 0.0000 0.0027    0.7898 0.0000 0.0026
    TOTAL CL= 0.909 CD=0.01463    CL= 0.909 CD=0.01614    CL= 0.909 CD=0.01608
          CM=-0.0143              CM=-0.0143              CM=-0.0142
10.00     S TURB  S SEP   CD      S TURB  S SEP   CD      S TURB  S SEP   CD
    UPPER 1.0261 0.1330 0.0150*   1.0261 0.1330 0.0150*   1.0265 0.1333 0.0150*
    LOWER 0.2396 0.0000 0.0011    0.9453 0.0000 0.0025    0.7618 0.0000 0.0024
    TOTAL CL= 0.998 CD=0.01609    CL= 0.998 CD=0.01750    CL= 0.997 CD=0.01744
          CM=-0.0144              CM=-0.0144              CM=-0.0143
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B.L.SUMMARY AIRFOIL S829  16%  ALPHA0=  0.367 DEG.
 *-WARNING WITH VARIABLE LIMIT  ALPHA REL. CHORD LINE

ALPHA(DEG.) R= 3000000 MU=3.0       R= 3000000 MU=1.3        R= 3000000 MU=9.0
-1.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3611 0.0000 0.0021     0.9973 0.0378 0.0052     0.9519 0.0373 0.0051
    LOWER 0.3163 0.0008 0.0020     0.9602 0.0327 0.0055     0.9839 0.0329 0.0056
    TOTAL CL=-0.069 CD=0.00410     CL=-0.068 CD=0.01068     CL=-0.068 CD=0.01069
          CM=-0.0010               CM=-0.0012               CM=-0.0013
 0.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3657 0.0000 0.0022     0.9973 0.0442 0.0056     0.9653 0.0438 0.0055
    LOWER 0.3074 0.0000 0.0019     0.9602 0.0280 0.0051     0.9707 0.0281 0.0051
    TOTAL CL= 0.040 CD=0.00402     CL= 0.032 CD=0.01072     CL= 0.032 CD=0.01068
          CM=-0.0047               CM=-0.0029               CM=-0.0029
 1.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3708 0.0016 0.0023     0.9973 0.0506 0.0061     0.9773 0.0504 0.0060
    LOWER 0.2996 0.0000 0.0018     0.9602 0.0233 0.0047     0.9555 0.0233 0.0047
    TOTAL CL= 0.149 CD=0.00409     CL= 0.132 CD=0.01083     CL= 0.132 CD=0.01075
          CM=-0.0083               CM=-0.0045               CM=-0.0045
 2.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3767 0.0087 0.0025     0.9973 0.0571 0.0066     0.9904 0.0570 0.0066
    LOWER 0.2923 0.0000 0.0017     0.9602 0.0185 0.0044     0.9406 0.0184 0.0043
    TOTAL CL= 0.255 CD=0.00416     CL= 0.232 CD=0.01100     CL= 0.232 CD=0.01094
          CM=-0.0110               CM=-0.0061               CM=-0.0061
 3.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3848 0.0148 0.0026     0.9973 0.0638 0.0072     1.0014 0.0639 0.0072
    LOWER 0.2855 0.0000 0.0016     0.9602 0.0136 0.0040     0.9237 0.0134 0.0040
    TOTAL CL= 0.360 CD=0.00425     CL= 0.331 CD=0.01125     CL= 0.331 CD=0.01122
          CM=-0.0137               CM=-0.0076               CM=-0.0076
 4.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.3973 0.0218 0.0029     0.9973 0.0705 0.0078     1.0090 0.0708 0.0079
    LOWER 0.2777 0.0000 0.0015     0.9602 0.0087 0.0037     0.9064 0.0084 0.0037
    TOTAL CL= 0.464 CD=0.00439     CL= 0.431 CD=0.01156     CL= 0.430 CD=0.01159
          CM=-0.0162               CM=-0.0091               CM=-0.0091
 5.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.4251 0.0310 0.0033     0.9973 0.0774 0.0085     1.0159 0.0781 0.0087
    LOWER 0.2719 0.0000 0.0014     0.9602 0.0025 0.0035     0.8862 0.0019 0.0034
    TOTAL CL= 0.566 CD=0.00470     CL= 0.529 CD=0.01196     CL= 0.529 CD=0.01209
          CM=-0.0180               CM=-0.0105               CM=-0.0103
 6.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 0.9555 0.0824 0.0087     0.9973 0.0846 0.0092     1.0224 0.0860 0.0096
    LOWER 0.2662 0.0000 0.0014     0.9602 0.0000 0.0032     0.8696 0.0000 0.0031
    TOTAL CL= 0.630 CD=0.01003     CL= 0.628 CD=0.01241     CL= 0.627 CD=0.01272
          CM=-0.0124               CM=-0.0120               CM=-0.0118
 7.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0063 0.0930 0.0102     1.0063 0.0930 0.0102     1.0260 0.0946 0.0107
    LOWER 0.2607 0.0000 0.0013     0.9602 0.0000 0.0030     0.8488 0.0000 0.0029
    TOTAL CL= 0.726 CD=0.01152     CL= 0.726 CD=0.01321     CL= 0.725 CD=0.01358
          CM=-0.0134               CM=-0.0134               CM=-0.0132
 8.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0194 0.1032 0.0116*    1.0194 0.1032 0.0116*    1.0263 0.1042 0.0118*
    LOWER 0.2550 0.0000 0.0012     0.9602 0.0000 0.0028     0.8288 0.0000 0.0027
    TOTAL CL= 0.821 CD=0.01278     CL= 0.821 CD=0.01437     CL= 0.820 CD=0.01453
          CM=-0.0144               CM=-0.0144               CM=-0.0143
 9.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0259 0.1149 0.0130*    1.0259 0.1149 0.0130*    1.0265 0.1151 0.0131*
    LOWER 0.2493 0.0000 0.0012     0.9602 0.0000 0.0026     0.8080 0.0000 0.0026
    TOTAL CL= 0.913 CD=0.01419     CL= 0.913 CD=0.01568     CL= 0.913 CD=0.01564
          CM=-0.0150               CM=-0.0150               CM=-0.0150
10.00     S TURB  S SEP   CD       S TURB  S SEP   CD       S TURB  S SEP   CD
    UPPER 1.0261 0.1283 0.0145*    1.0261 0.1283 0.0145*    1.0266 0.1286 0.0146*
    LOWER 0.2440 0.0000 0.0011     0.9453 0.0000 0.0025     0.7868 0.0000 0.0024
    TOTAL CL= 1.003 CD=0.01561     CL= 1.003 CD=0.01699     CL= 1.002 CD=0.01696
          CM=-0.0151               CM=-0.0151               CM=-0.0151
```

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14. ABSTRACT *(Maximum 200 Words)*
A 16%-thick, natural-laminar-flow airfoil, the S829, for the tip region of 20- to 40-meter-diameter, stall-regulated, horizontal-axis wind turbines has been designed and analyzed theoretically. The two primary objectives of restrained maximum lift, insensitive to roughness, and low profile drag have been achieved. The constraints on the pitching moment and the airfoil thickness have been satisfied. The airfoil should exhibit a docile stall.

15. SUBJECT TERMS
airfoils; wind turbine; airfoil design; Pennsylvania State University; wind energy

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