NASA Research Related to Sailplane Airfoils

Dan M. Somers
NASA Langley Research Center
Hampton, VA 23665

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ABSTRACT

The theoretical methods and experimental facilities at the NASA Langley Research Center have been employed to conduct investigations of sailplane airfoils. Wind-tunnel investigations of two sailplane airfoils have been conducted in the Langley low-turbulence pressure tunnel. A procedure for sailplane performance improvement has been outlined.

INTRODUCTION

Over the past decade, a considerable amount of research directly applicable to sailplanes has been performed in such diverse areas as advanced composites, handling qualities, and airfoils. While most of the effort on aeronautics and structures is directed toward powered aircraft, the vast majority of the technology developed can be easily transferred to sailplanes. Some of the effort, however, is directed toward sailplanes in particular. Most of this research has been conducted on airfoils.

Research on airfoils includes both theoretical and experimental work. Over the past five years, Prof. Richard Eppler of the University of Stuttgart, West Germany, has continued the development of his airfoil design and analysis program in cooperation with Langley. In addition, wind-tunnel investigations of two sailplane airfoils have been conducted in the Langley low-turbulence pressure tunnel (LTPT). Also, a number of Wortmann airfoils have been smoothed theoretically. The smoothed coordinates for these airfoils are given in the appendix.

SYMBOLS

C_p	pressure coefficient
c	airfoil chord
c_d	section profile-drag coefficient
c_l	section lift coefficient
c_m	section pitching-moment coefficient about quarter-chord point
R	Reynolds number
x	airfoil abscissa
z	airfoil ordinate
α	angle of attack, deg

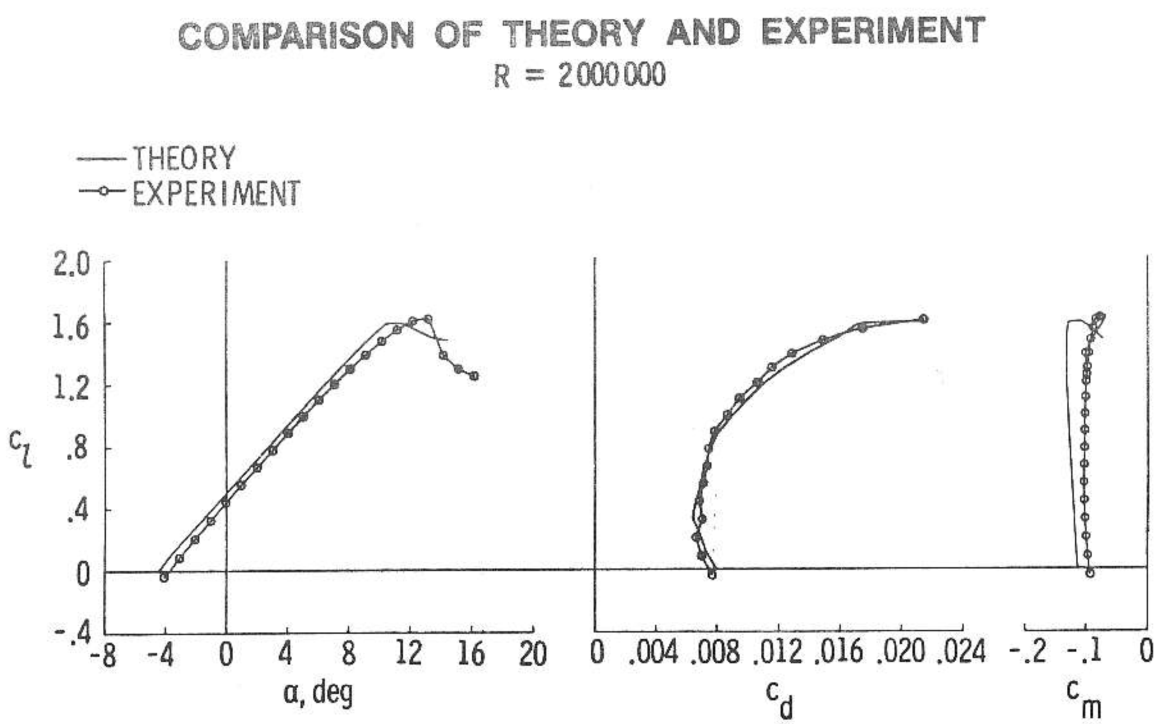
THEORY

The Eppler Airfoil Design and Analysis Program contains a method for the design of airfoils with prescribed pressure-distribution characteristics, a method for the analysis of the flow about given airfoils, and a method for the analysis of boundary layers. With this program, airfoils with prescribed boundary-layer characteristics can be designed and airfoils with prescribed shapes can be analyzed. The program also has the capability of analyzing the effects of the simple flap deflections typical of most Open and 15-Meter Class sailplanes as well as the more complicated variable-geometry deflections like that on the SB-11. Finally, the program can analyze the effects of certain surface imperfections such as the steps which result from aileron and flap hinges and poorly faired spoilers.

Numerous comparisons between the predictions of the program and experimental results have been made. One such comparison using data obtained in LTPT is shown in Figure 1. The agreement between theory and experiment is excellent and typical of our experience with the program.

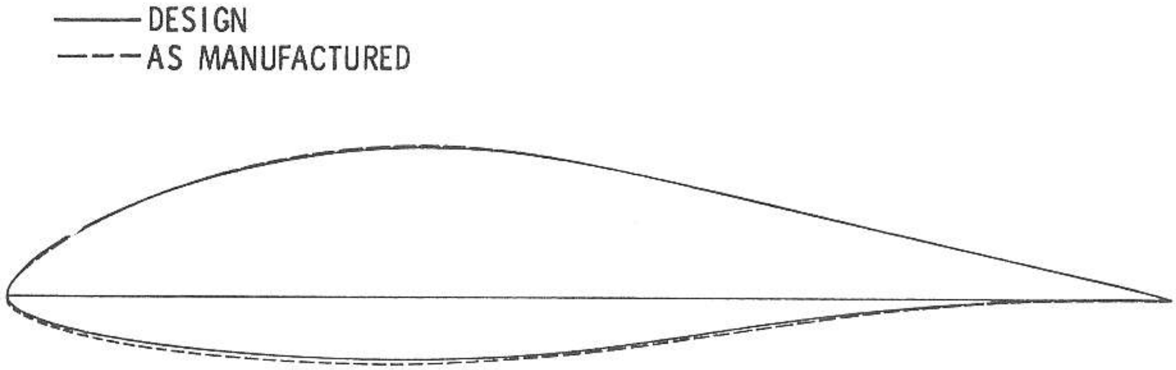
EXPERIMENT

Wind-tunnel investigations of two sailplane airfoils have been conducted in LTPT. For the first experiment, two templates were taken of a fiberglass Standard Class sailplane wing and a wind-tunnel model constructed to the coordinates of the inboard template. The shapes of the inboard template and the design airfoil, the FX 66-17AII-182, are compared in Figure 2. At the maximum thickness point on the upper surface, the difference between the two shapes is approximately 1.5 mm (0.06 in.) whereas, at the maximum thickness point on the lower surface, the difference is about 3.3 mm (0.13 in.). These differences assume a chord equal to that at the inboard station - 81.10 cm (31.93 in.). The shapes of the inboard and outboard templates are compared in Figure 3. Again,



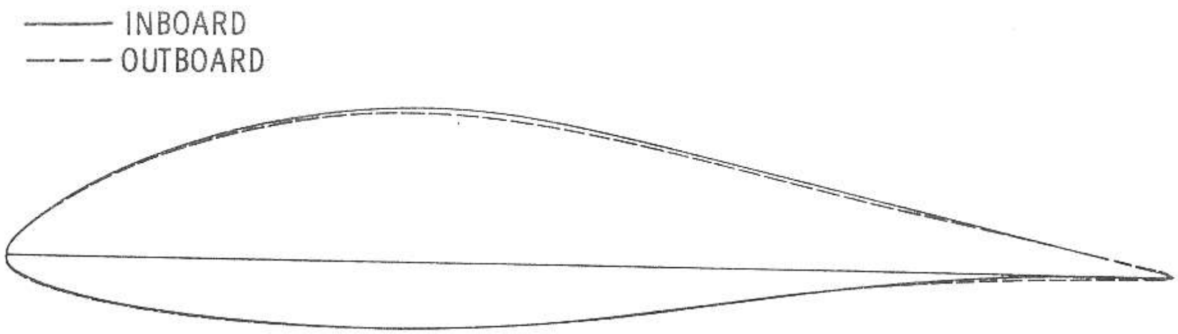
NASA FIGURE I D.SOMERS 1/14-18/81

COMPARISON OF DESIGN AND AS MANUFACTURED SHAPES



NASA FIGURE 2 D.SOMERS 1/14-18/81

COMPARISON OF INBOARD AND OUTBOARD SHAPES



NASA FIGURE 3 D.SOMERS 1/14-18/81

considerable differences are apparent. Obviously, these differences cannot be corrected by sanding alone. The results from this wind-tunnel test are given in NASA TN D-8324 entitled "Experimental and Theoretical Low-Speed Aerodynamic Characteristics of a Wortmann Airfoil as Manufactured on a Fiberglass Sailplane" by Dan M. Somers.

For the second experiment, a windtunnel model was constructed by an American sailplane manufacturer using the same sheet-metal fabrication techniques used in constructing the corresponding production wing. As part of the test, the model, which corresponds to the FX 67-K-170/17 airfoil, was coated with a plastic film in order to determine the effect of the coating on the profile drag of the section. The results of this test are given in the paper, contained in NASA CP-2085, entitled "An Exploratory Investigation of the Effect of a Plastic Coating on the Profile Drag of a Practical-Metal-Construction Sailplane Airfoil" by Dan M. Sommers.

SMOOTHING

As the result of an inquiry by Dick Johnson, a number of Wortmann airfoils have been smoothed theoretically using the Eppler Program. The airfoil coordinates published in the Stuttgarter Profilkatalog I are not smooth probably because of numerical errors contained in the method used to design the airfoils. The "waves" in the resulting shapes are apparent in full-size drawings of the airfoils. These waves are removed at the factories either by geometrically fairing the coordinates used to construct the molds or by sanding during the finishing of the sailplane. Unfortunately, neither of these techniques necessarily results in an aerodynamically smooth contour. Accordingly, the coordinates of a number of Wortmann airfoils have been manually adjusted using the Eppler Program.

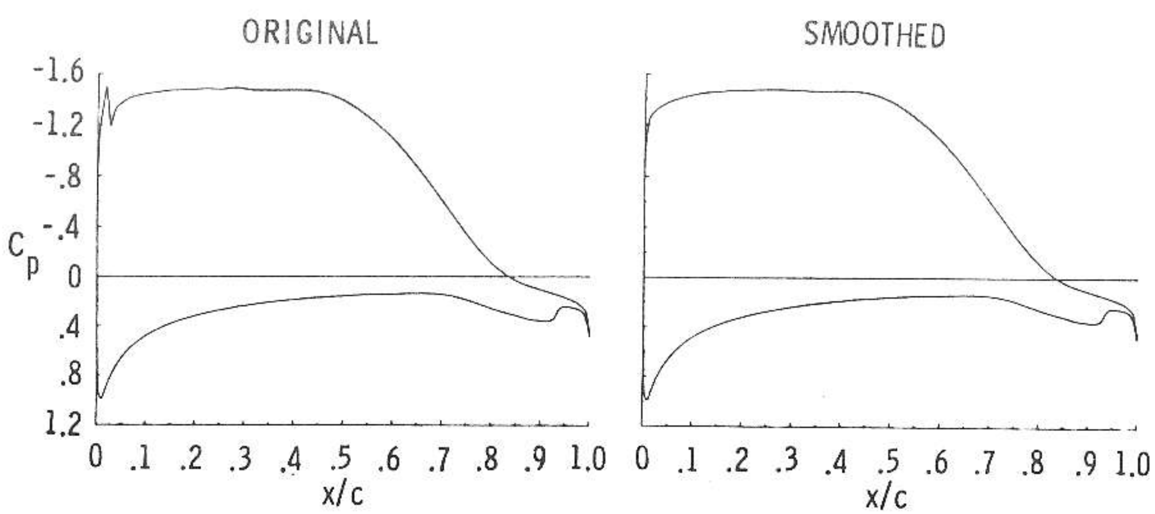
To illustrate the procedure, the theoretical pressure distributions "before and after" are shown in Figure 4. The left-hand pressure distribution is for the original FX 67-K-170/17 airfoil coordinates. These coordinates were then adjusted until a smooth pressure distribution was obtained. The coordinates were further adjusted until a smooth (and desirable) boundary-layer development was obtained. The resulting pressure distribution is shown in the right-hand portion of Figure 4. The final coordinates are the result of 75 individual changes, all of which are forward of about 30 percent chord. It should be noted, however, that the largest of the resulting differences between the original and smoothed shapes is only 0.45 mm (0.018 in.) based on a chord of 1 m (39.4 in.).

In conjunction with this work, Prof. Eppler smoothed several Wortmann airfoils as well. The smoothed coordinates for these airfoils, as well as those for the FX-67-K-170/17 airfoil, are given in the appendix.

PERFORMANCE IMPROVEMENT

As a result of the previously described studies, as well as many others, it is possible to recommend a procedure for

SMOOTHING



NASA FIGURE 4 D.SOMERS 1/14-18/81

sailplane performance improvement. This procedure should be very efficient and productive and follows the outline long advocated by A. J. Smith. Do the easy things first. Measure the ship's dimensions, deflections, weights, etc. When weighing the ship, weigh the individual components as well as the entire ship. Is one wing heavier than the other? If the controls are not properly rigged or the c.g. is not where it should be, adjust it. Then seal the ship. Make sure the air enters and exits only where it should. Next, before you start sanding, find out if any major aerodynamic problems exist. Why spend hours fixing something that doesn't need to be fixed? Tuft the ship, particularly the wing-fuselage juncture. Then determine the transition points on the wing and the fuselage using a stethoscope. Then, if problems are found, correct them. Obviously, comparison flying in straight glides as well as thermalling will help identify the areas which should be examined more thoroughly.

CONCLUDING REMARKS

The theoretical methods and experimental facilities at the NASA Langley Research Center have been employed to conduct investigations of sailplane airfoils. The unique and powerful capabilities of the Eppler Program have been used to design and analyze many airfoils and to smooth several Wortmann airfoils. Wind-tunnel investigations of two sailplane airfoils, corresponding to the FX66-17AII-182 and the FX 67-K-170/17, have been conducted in the Langley low-turbulence pressure tunnel. Comparisons between design and as manufactured airfoil shapes indicate that sanding alone cannot produce the correct contour and that correcting only the first 10 percent or so of the chord will probably not drastically improve the performance of the sailplane.

Finally, a prioritized procedure for sailplane performance improvement has been outlined. This procedure should allow the performance of the sailplane to be improved in an efficient and productive manner.

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(For sale by the National Technical Information Service, Springfield, Virginia 22161.)

APPENDIX SMOOTHED AIRFOIL COORDINATES

FX 60-126 SMOOTHED (EPPLER)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00675	.00107	-.00301
.00428	.01349	.00428	-.00641
.00961	.02096	.00961	-.01012
.01704	.02802	.01704	-.01404
.02653	.03493	.02638	-.01777
.03806	.04174	.03806	-.02132
.05134	.04823	.05149	-.02458
.06699	.05457	.06699	-.02761
.08413	.06037	.08422	-.03030
.10332	.06585	.10332	-.03262
.12400	.07090	.12406	-.03452
.14645	.07555	.14645	-.03598
.17027	.07967	.17032	-.03698
.19562	.08327	.19562	-.03746
.22218	.08627	.22222	-.03740
.25000	.08859	.25000	-.03683
.27886	.09019	.27886	-.03574
.30866	.09130	.30866	-.03392
.33928	.09160	.33928	-.03167
.37059	.09138	.37059	-.02877
.40245	.09041	.40245	-.02553
.43474	.08893	.43474	-.02188
.46730	.08679	.46730	-.01814
.50000	.08425	.50000	-.01421
.53270	.08118	.53270	-.01036
.56526	.07781	.56526	-.00653
.59755	.07402	.59755	-.00298
.62941	.06994	.62941	.00029
.66072	.06549	.66072	.00307
.69134	.06082	.69134	.00547
.72114	.05589	.72114	.00741
.75000	.05084	.75000	.00897
.77779	.04567	.77779	.01006
.80438	.04055	.80438	.01073
.82967	.03552	.82967	.01093
.85355	.03070	.85355	.01074
.87592	.02611	.87592	.01022
.89668	.02181	.89668	.00944
.91573	.01777	.91573	.00845
.93301	.01412	.93301	.00732
.94844	.01084	.94844	.00610
.96194	.00798	.96194	.00483
.97347	.00554	.97347	.00357
.98296	.00353	.98296	.00239
.99039	.00198	.99039	.00146
.99572	.00088	.99572	.00068
.99893	.00024	.99893	.00014
1.00000	0.00000	1.00000	0.00000

FX 62-K-131/17 SMOOTHED (EPPLER)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00516	.00107	-.00159
.00428	.01032	.00428	-.00386
.00961	.01606	.00961	-.00613
.01704	.02215	.01704	-.00837
.02653	.02855	.02653	-.01061
.03806	.03511	.03806	-.01282
.05156	.04175	.05156	-.01486
.06699	.04830	.06699	-.01682
.08427	.05477	.08427	-.01862
.10332	.06108	.10332	-.02037
.12408	.06721	.12408	-.02195
.14645	.07306	.14645	-.02345
.17033	.07859	.17033	-.02476
.19562	.08369	.19562	-.02596
.22221	.08829	.22221	-.02696
.25000	.09232	.25000	-.02776
.27886	.09577	.27886	-.02828
.30866	.09860	.30866	-.02853
.33928	.10084	.33928	-.02846
.37059	.10245	.37059	-.02814
.40245	.10337	.40245	-.02752
.43474	.10355	.43474	-.02666
.46730	.10300	.46730	-.02548
.50000	.10173	.50000	-.02395
.53270	.09983	.53270	-.02199
.56526	.09728	.56526	-.01962
.59755	.09402	.59755	-.01683
.62941	.09000	.62941	-.01370
.66072	.08523	.66072	-.01025
.69134	.07976	.69134	-.00646
.72114	.07374	.72114	-.00239
.75000	.06732	.75000	.00177
.77779	.06076	.77779	.00573
.80438	.05425	.80438	.00919
.82967	.04797	.82967	.01191
.85355	.04203	.85355	.01386
.87592	.03645	.87592	.01503
.89668	.03123	.89668	.01548
.91573	.02637	.91573	.01523
.93301	.02183	.93301	.01437
.94844	.01759	.94844	.01293
.96194	.01363	.96194	.01102
.97347	.00994	.97347	.00860
.98296	.00661	.98296	.00600
.99039	.00394	.99039	.00355
.99572	.00180	.99572	.00150
.99893	.00036	.99893	.00032
1.00000	0.00000	1.00000	0.00000

FX 66-17AII-182 SMOOTHED (EPPLER)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00596	.00107	-.00340
.00428	.01208	.00428	-.00741
.00961	.01910	.00961	-.01128
.01704	.02676	.01704	-.01517
.02653	.03489	.02653	-.01909
.03806	.04335	.03806	-.02297
.05156	.05201	.05156	-.02674
.06699	.06076	.06699	-.03035
.08427	.06949	.08427	-.03379
.10332	.07805	.10332	-.03702
.12408	.08635	.12408	-.04004
.14645	.09426	.14645	-.04280
.17033	.10169	.17033	-.04532
.19562	.10850	.19562	-.04752
.22221	.11460	.22221	-.04944
.25000	.11984	.25000	-.05098
.27886	.12409	.27886	-.05218
.30866	.12705	.30866	-.05292
.33928	.12874	.33928	-.05321
.37059	.12897	.37059	-.05288
.40245	.12774	.40245	-.05198
.43474	.12492	.43474	-.05037
.46730	.12065	.46730	-.04796
.50000	.11512	.50000	-.04464
.53270	.10873	.53270	-.04050
.56526	.10185	.56526	-.03573
.59755	.09476	.59755	-.03072
.62941	.08755	.62941	-.02575
.66072	.08032	.66072	-.02112
.69134	.07315	.69134	-.01693
.72114	.06614	.72114	-.01326
.75000	.05934	.75000	-.01010
.77779	.05282	.77779	-.00744
.80438	.04662	.80438	-.00522
.82967	.04078	.82967	-.00342
.85355	.03531	.85355	-.00201
.87592	.03026	.87592	-.00097
.89667	.02563	.89667	-.00027
.91573	.02139	.91573	.00019
.93303	.01752	.93301	.00048
.94844	.01396	.94844	.00063
.96197	.01065	.96194	.00068
.97347	.00759	.97347	.00068
.98298	.00483	.98296	.00063
.99039	.00258	.99039	.00051
.99570	.00101	.99573	.00032
.99893	.00022	.99893	.00010
1.00000	0.00000	1.00000	0.00000

FX 66-S-196V1 SMOOTHED (EPPLER)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00581	.00107	-.00354
.00428	.01205	.00428	-.00784
.00961	.01923	.00961	-.01211
.01704	.02703	.01704	-.01639
.02653	.03530	.02653	-.02065
.03806	.04390	.03806	-.02489
.05156	.05273	.05156	-.02903
.06699	.06170	.06699	-.03307
.08427	.07067	.08427	-.03695
.10332	.07946	.10332	-.04063
.12408	.08803	.12408	-.04410
.14645	.09621	.14645	-.04729
.17033	.10398	.17033	-.05022
.19562	.11114	.19562	-.05279
.22221	.11772	.22221	-.05503
.25000	.12348	.25000	-.05681
.27886	.12848	.27886	-.05820
.30866	.13243	.30866	-.05901
.33928	.13537	.33928	-.05931
.37059	.13690	.37059	-.05880
.40245	.13691	.40245	-.05743
.43474	.13467	.43474	-.05451
.46730	.13095	.46730	-.05076
.50000	.12585	.50000	-.04628
.53270	.11995	.53270	-.04161
.56526	.11321	.56526	-.03667
.59755	.10607	.59755	-.03186
.62941	.09844	.62941	-.02707
.66072	.09067	.66072	-.02256
.69134	.08272	.69134	-.01827
.72114	.07482	.72114	-.01435
.75000	.06699	.75000	-.01080
.77779	.05936	.77779	-.00764
.80438	.05197	.80438	-.00489
.82967	.04501	.82967	-.00260
.85355	.03845	.85355	-.00068
.87592	.03242	.87592	.00080
.89667	.02692	.89667	.00186
.91573	.02193	.91573	.00254
.93300	.01747	.93301	.00288
.94844	.01357	.94844	.00288
.96195	.01022	.96194	.00258
.97347	.00729	.97347	.00206
.98297	.00474	.98297	.00144
.99039	.00269	.99039	.00086
.99572	.00120	.99572	.00039
.99893	.00030	.99893	.00010
1.00000	0.00000	1.00000	0.00000

FX 67-K-150/17 SMOOTHED (EPPLER)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00495	.00107	-.00145
.00428	.01004	.00428	-.00375
.00961	.01619	.00961	-.00593
.01704	.02293	.01704	-.00804
.02653	.03012	.02653	-.01015
.03806	.03762	.03806	-.01224
.05156	.04536	.05156	-.01422
.06699	.05327	.06699	-.01611
.08427	.06110	.08427	-.01788
.10332	.06882	.10332	-.01955
.12408	.07629	.12408	-.02107
.14645	.08348	.14645	-.02246
.17033	.09027	.17033	-.02368
.19562	.09663	.19562	-.02474
.22221	.10246	.22221	-.02562
.25000	.10771	.250C0	-.02632
.27886	.11230	.27886	-.02684
.30866	.11619	.30866	-.02717
.33928	.11928	.33928	-.02730
.37059	.12152	.37059	-.02724
.40245	.12285	.40245	-.02698
.43474	.12318	.43474	-.02653
.46730	.12239	.46730	-.02588
.50000	.12041	.50000	-.02504
.53270	.11716	.53270	-.02399
.56526	.11269	.56526	-.02274
.59755	.10702	.59755	-.02130
.62941	.10025	.62941	-.01967
.66072	.09249	.66072	-.01784
.69134	.08395	.69134	-.01575
.72114	.07490	.72114	-.01339
.75000	.06570	.75000	-.01080
.77779	.05670	.77779	-.00813
.80438	.04827	.80438	-.00559
.82967	.04065	.82967	-.00334
.85355	.03394	.85355	-.00148
.87592	.02809	.87592	-.00006
.89665	.02301	.89667	.00094
.91573	.01856	.91573	.00157
.93300	.01468	.93301	.00189
.94844	.01130	.94844	.00193
.96193	.00841	.96194	.00175
.97347	.00599	.97347	.00142
.98297	.00399	.98297	.00100
.99039	.00233	.99039	.00060
.99572	.00104	.99572	.00028
.99893	.00026	.99893	.00007
1.00000	0.00000	1.00000	0.00000

FX 67-K-170/17 SMOOTHED (SOMERS)

UPPER SURFACE X/C	UPPER SURFACE Z/C	LOWER SURFACE X/C	LOWER SURFACE Z/C
0.00000	0.00000	0.00000	0.00000
.00107	.00678	.00107	-.00217
.00428	.01278	.00428	-.00513
.00961	.01974	.00961	-.00788
.01704	.02720	.01704	-.01057
.02653	.03509	.02653	-.01321
.03806	.04330	.03806	-.01579
.05156	.05169	.05156	-.01827
.06699	.06015	.06699	-.02062
.08427	.06857	.08427	-.02283
.10332	.07685	.10332	-.02490
.12408	.08490	.12408	-.02682
.14645	.09262	.14645	-.02856
.17033	.09994	.17033	-.03011
.19562	.10677	.19562	-.03146
.22221	.11305	.22221	-.03261
.25000	.11870	.25000	-.03354
.27886	.12365	.27886	-.03425
.30866	.12783	.30866	-.03474
.33928	.13119	.33928	-.03499
.37059	.13370	.37059	-.03501
.40245	.13526	.40245	-.03480
.43474	.13571	.43474	-.03435
.46730	.13490	.46730	-.03365
.50000	.13274	.50000	-.03272
.53270	.12919	.53270	-.03155
.56526	.12429	.56526	-.03012
.59755	.11808	.59755	-.02844
.62941	.11063	.62941	-.02654
.66072	.10208	.66072	-.02437
.69134	.09263	.69134	-.02187
.72114	.08259	.72114	-.01896
.75000	.07233	.75000	-.01572
.77779	.06229	.77779	-.01236
.80438	.05287	.80438	-.00913
.82967	.04437	.82967	-.00625
.85355	.03689	.85355	-.00386
.87592	.03040	.87592	-.00197
.91573	.01991	.91573	-.00037
.94844	.01201	.94844	-.00124
.97347	.00631	.97347	-.00105
.99039	.00243	.99039	-.00044
.99893	.00027	.99893	-.00005
1.00000	0.00000	1.00000	0.00000