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Engineering Report: **XFOIL Results For NLF(1)-0215M Airfoil**

Applicable paragraphs of airworthiness requirements: N/A

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SCOPE

NLF(1)-215M is a modification of a well-known airfoil NLF(1)-215F design for general aviation aircraft. It's intended use is the flap section of a wing. For the aileron section there is supposed to be used an airfoil with less hinge moment.

General

While designing NLF(1)-215M airfoil, several airfoils developed for general aviation applications have been selected for reference and comparison (see a table below). The primary design objectives and constraints for the new airfoil have been set as follows:

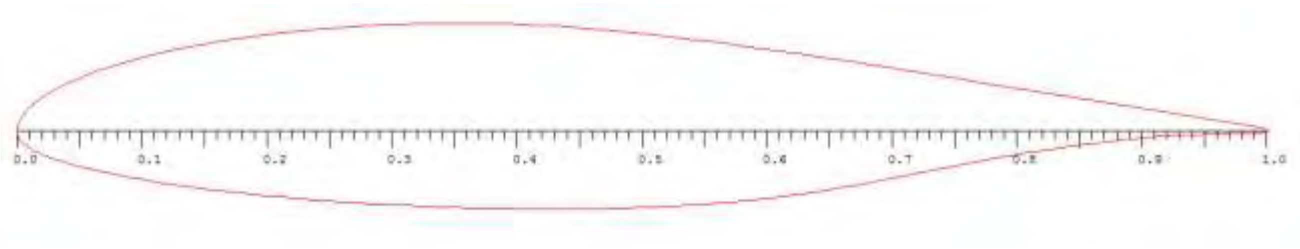
- airfoil thickness should not excess 0.15c;
- blunt trailing edge;
- Cd for cruise is less 0.004;
- the laminar bucket is at least within range of Cl=0…0.5;
- Clmax is higher 1.8;
- smooth stall;
- negative Cm is as less as possible to minimize trim drag;
- Clmax must not fall down significantly due leading edge roughness.

XFOIL 6.96 code has been utilized for the modification. Reynolds numbers of 3e6, 6e6, 9e6 and Mach 0, 0.3, and 0.4 have been analyzed. Rough LE has been simulated by locating the transition from 0.05c at the top surface and 0.05c at the bottom surface.

Results

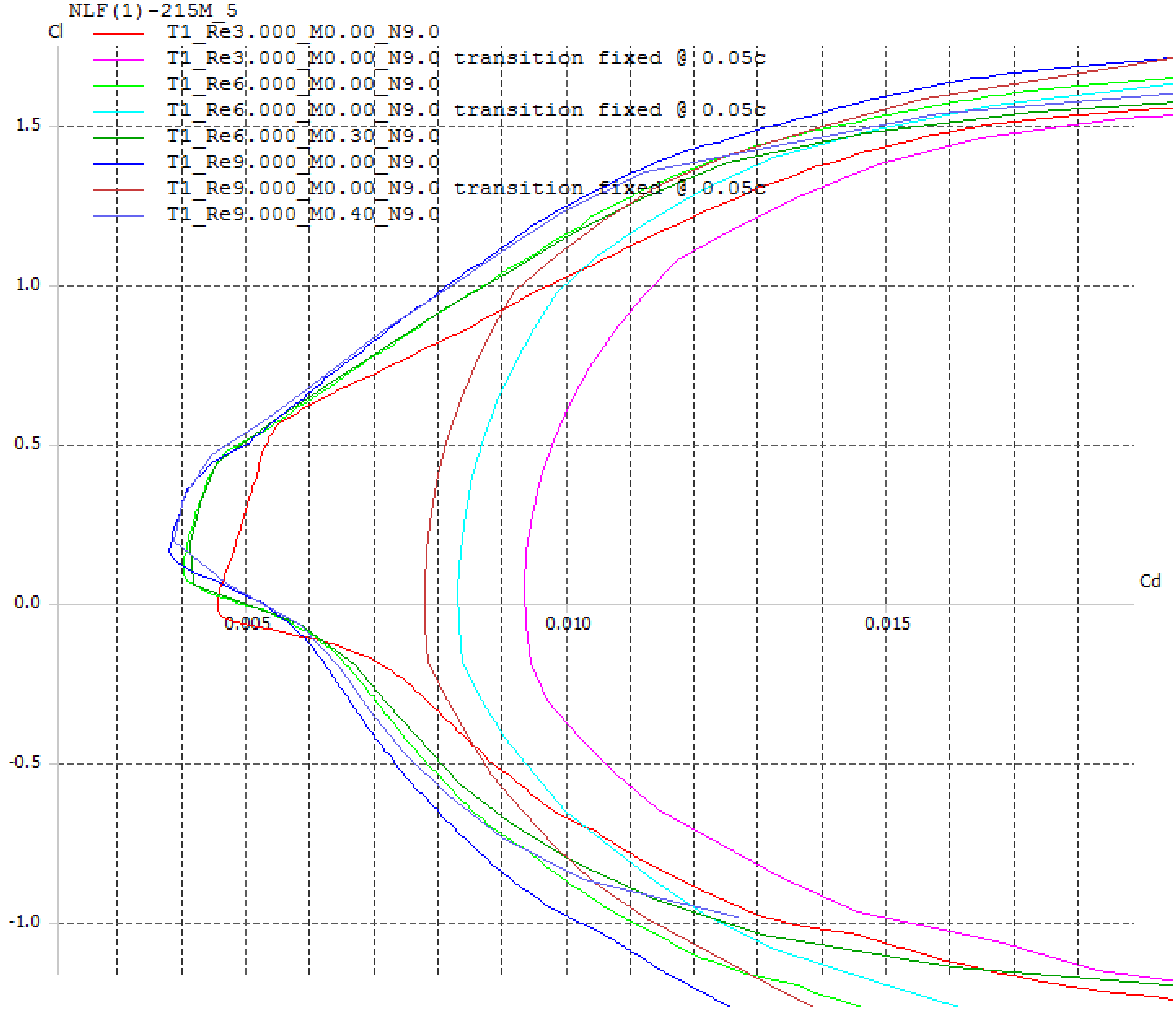
NLF(1)-215M Airfoil Coordinates

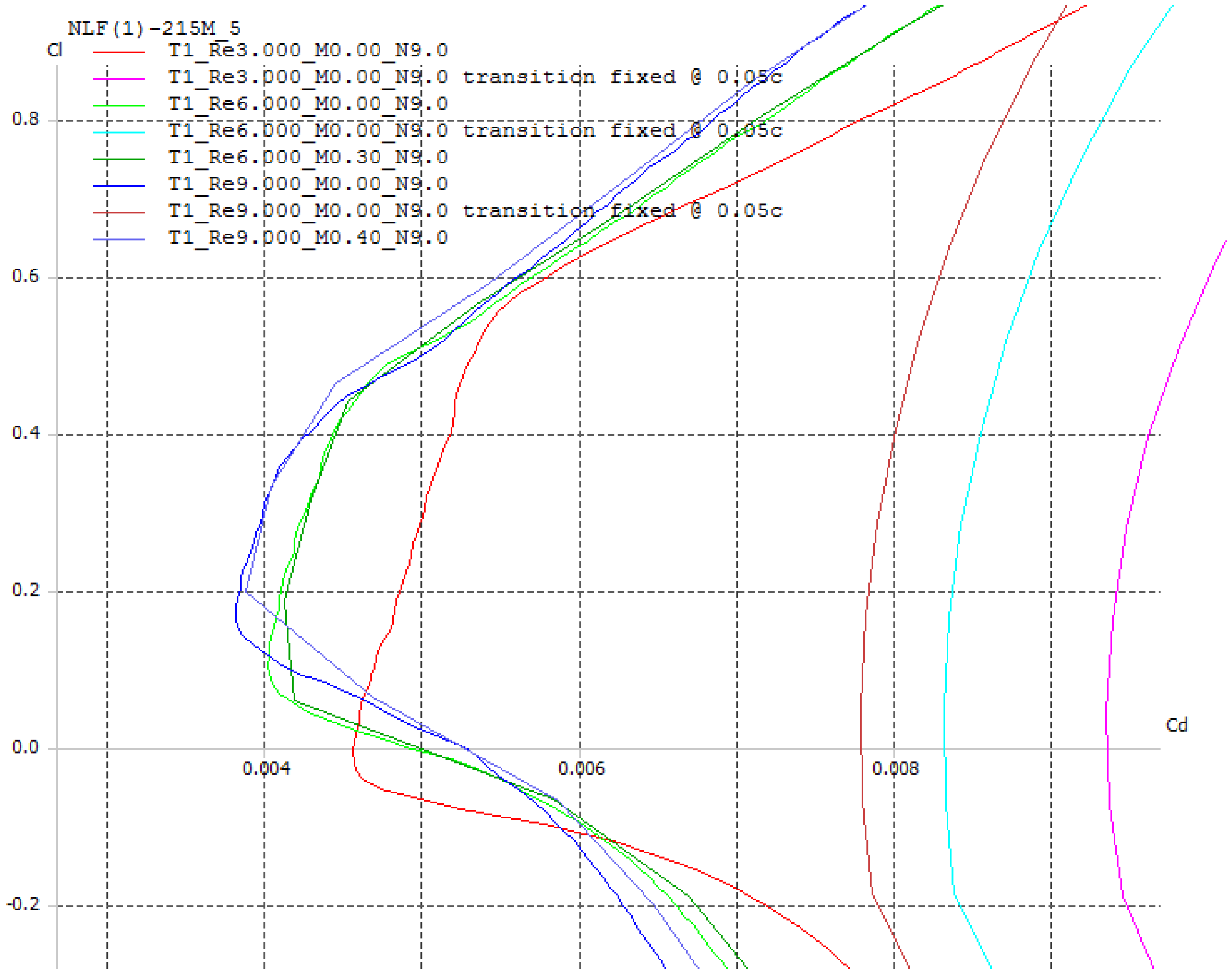
The newly designed airfoil has been re-paneled for 200 points.



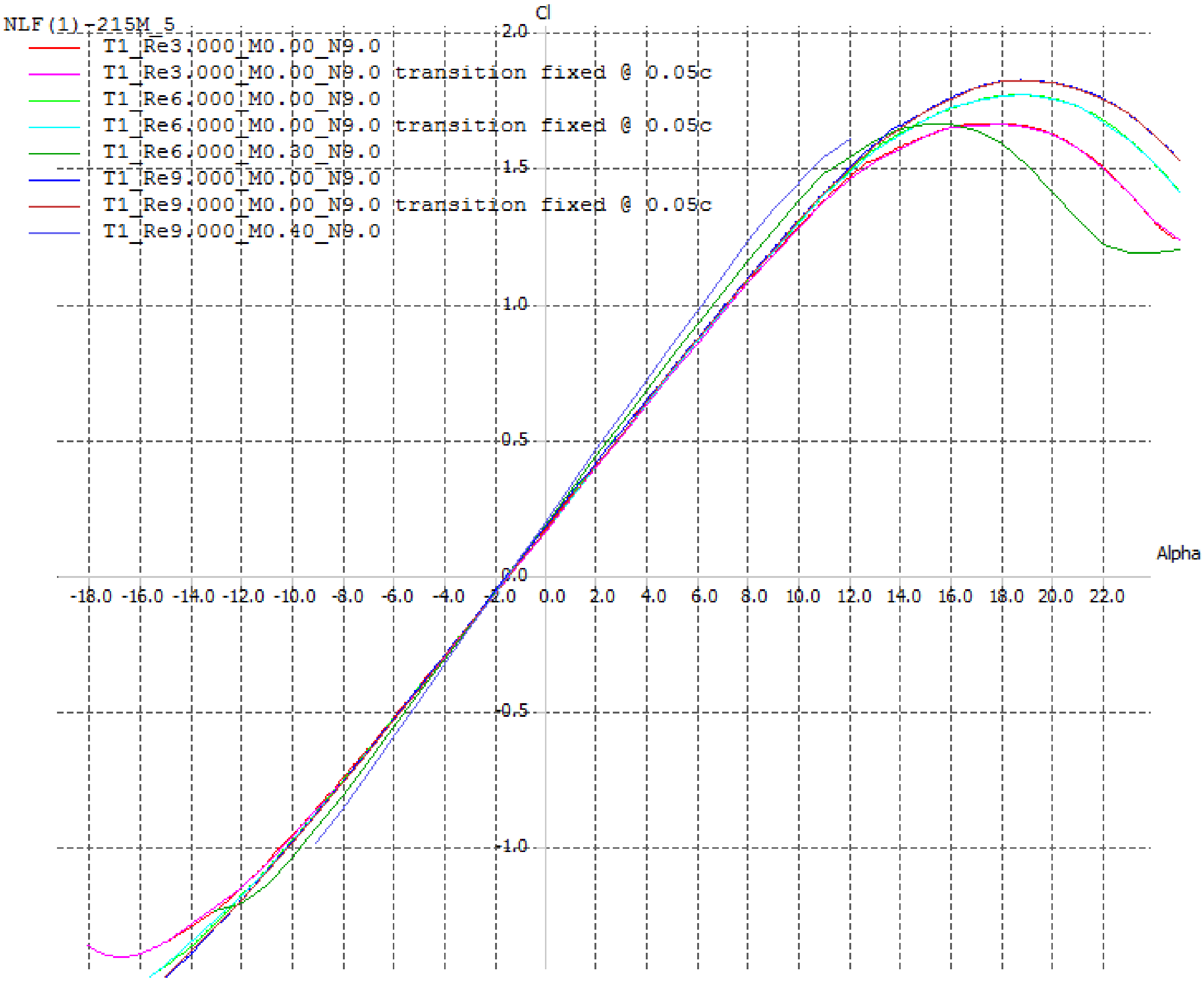
The coordinates have been intentionally removed from this version of the report.

Clean Airfoil Analysis

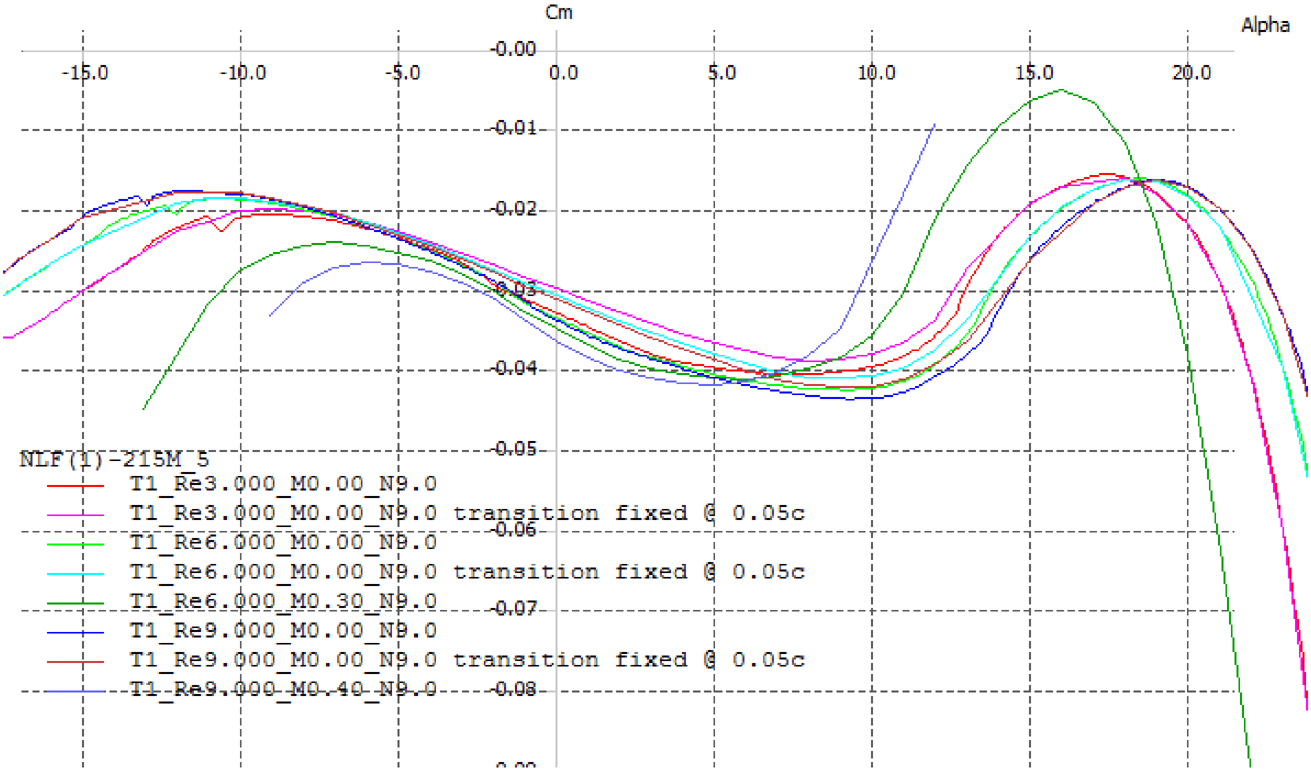




The laminar bucket starts at about Cl=-0.1 @ Re=3e6 and ends at about Cl=0.6 @ Re=9e6.



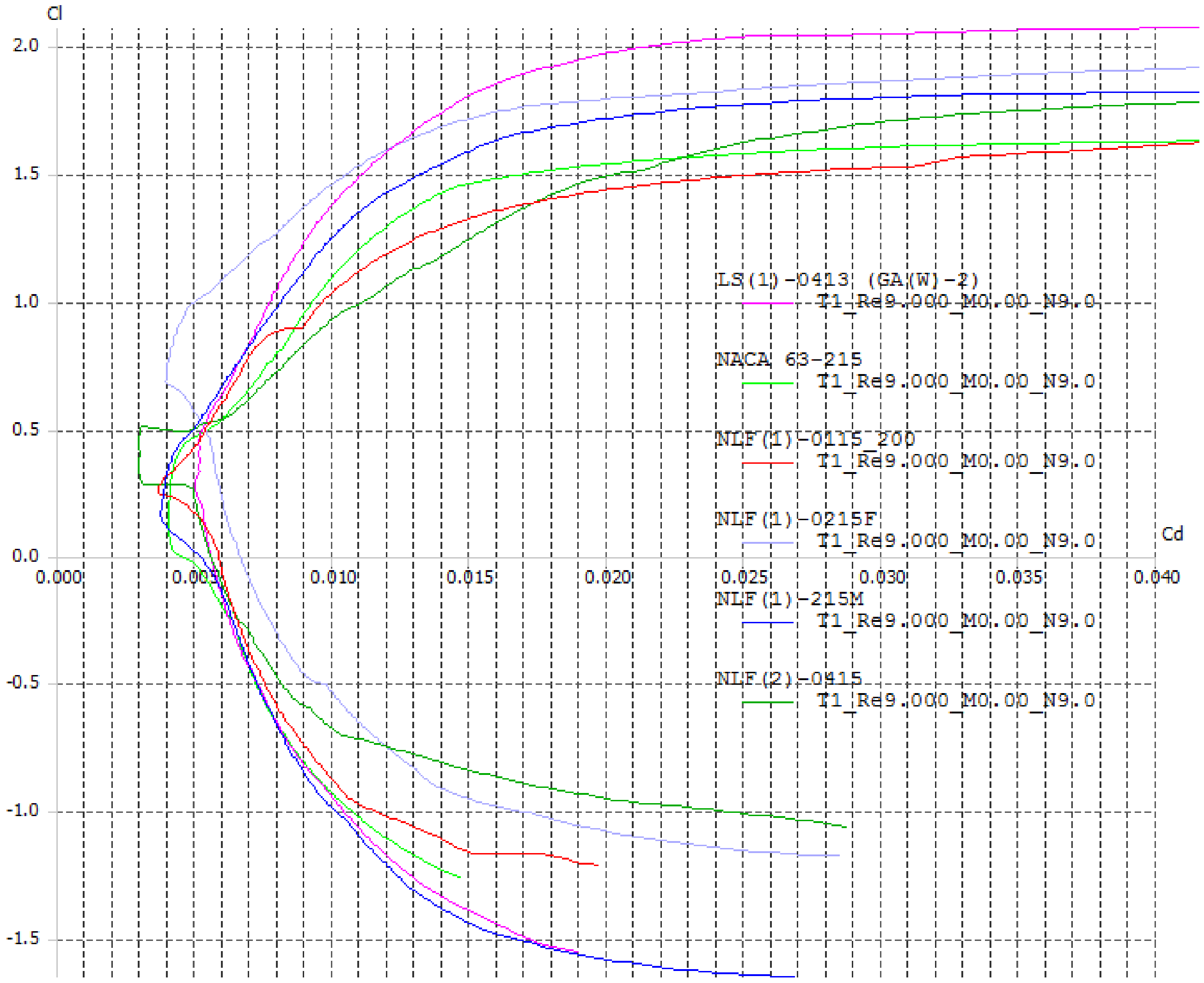
The polars with transition fixed show no significant fall of Clmax, if any at all.


Cm
Alpha
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
20.0
-0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
NLF(1)-215M_5
T1_Re3.000_M0.00_N9.0
T1_Re3.000_M0.00_N9.0 transition fixed @ 0.05c
T1_Re6.000_M0.00_N9.0
T1_Re6.000_M0.00_N9.0 transition fixed @ 0.05c
T1_Re6.000_M0.30_N9.0
T1_Re9.000_M0.00_N9.0
T1_Re9.000_M0.00_N9.0 transition fixed @ 0.05c
T1_Re9.000_M0.40_N9.0

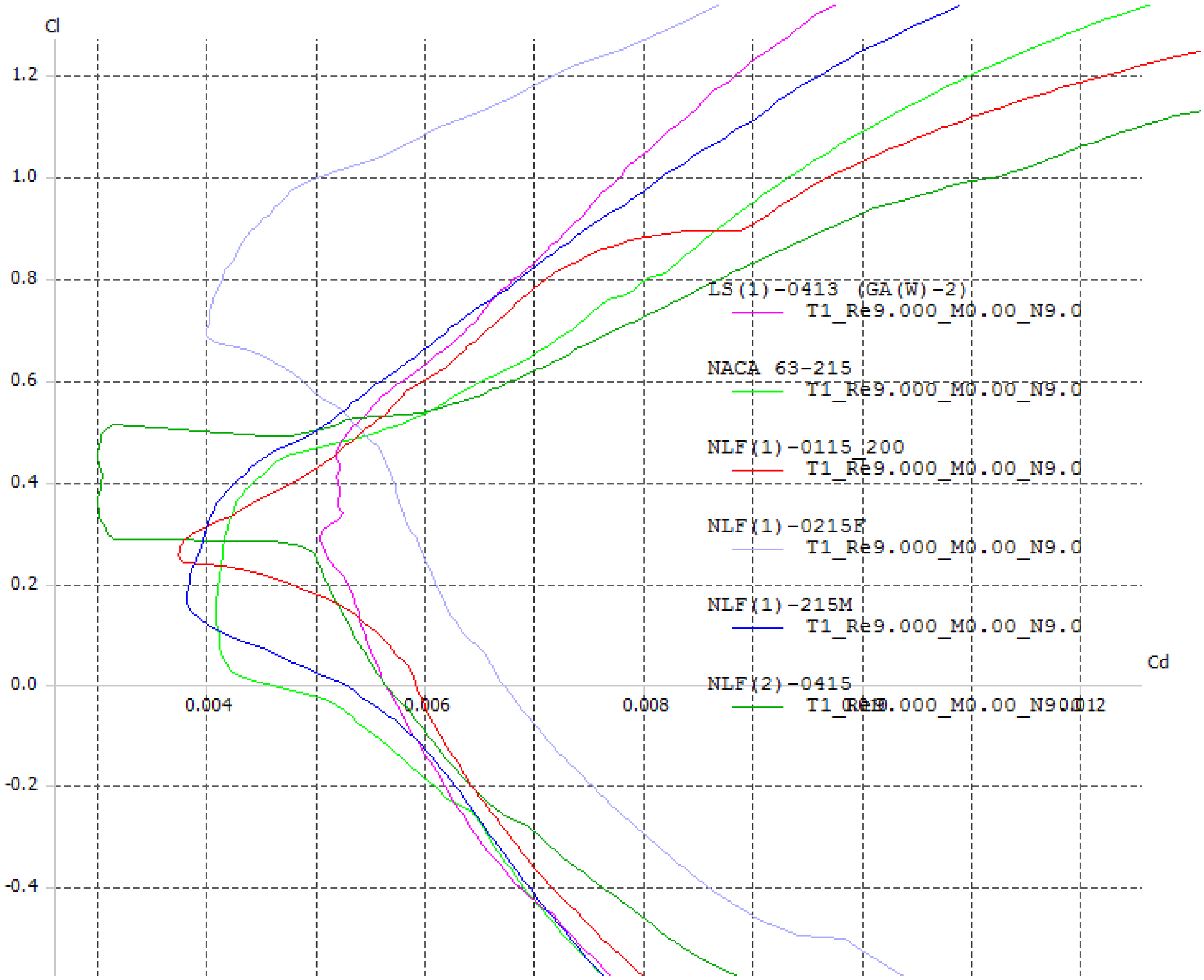
Comparison

For comparison purpose, the selected airfoils have been re-paneled to 200 points each.

Re=9e6, M=0



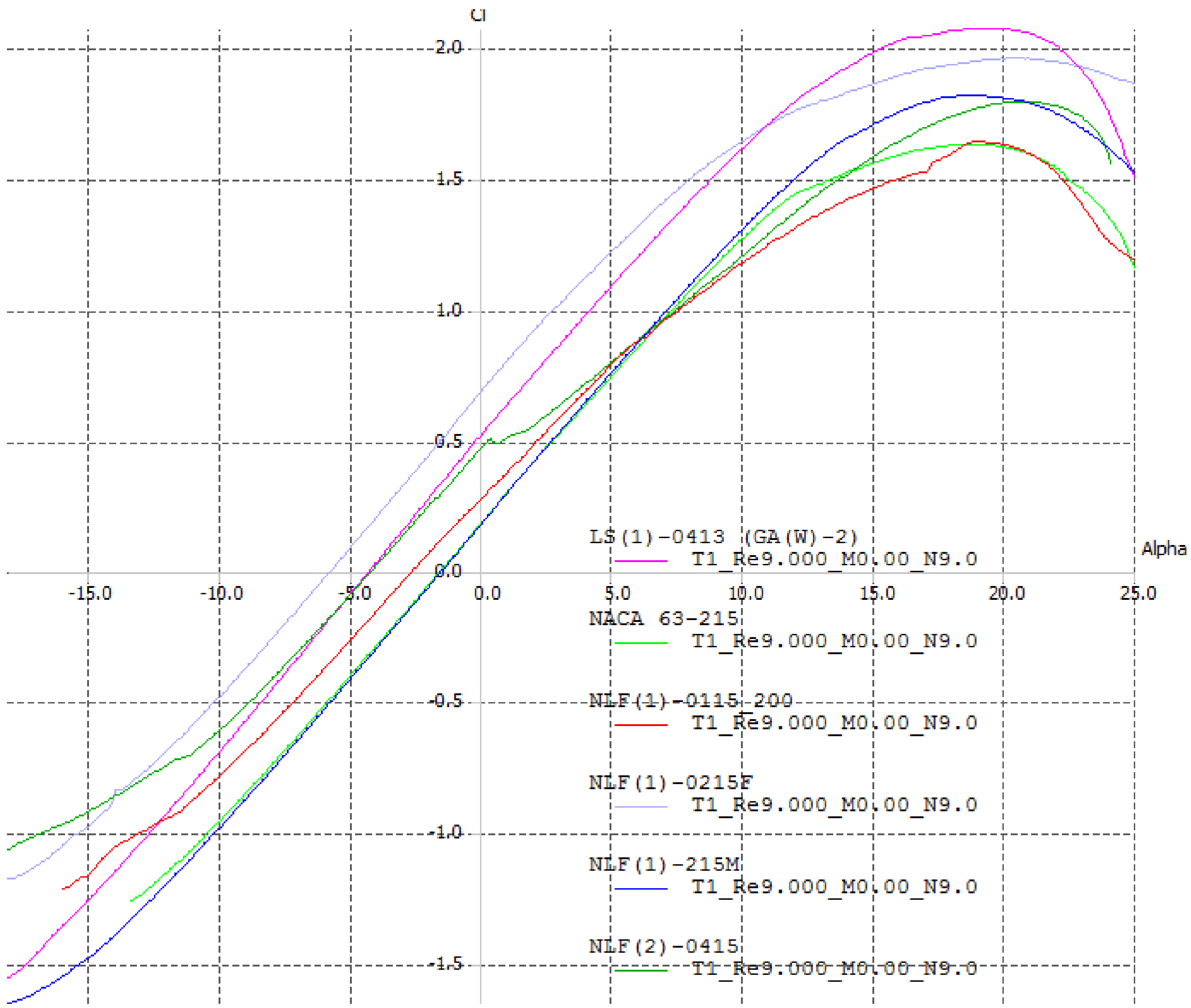
At Cl=1.0, except NLF(1)215F due to laminar zone at the range of Cl considered, it's only LS(1)-413 that has less drag, about 0.0077.



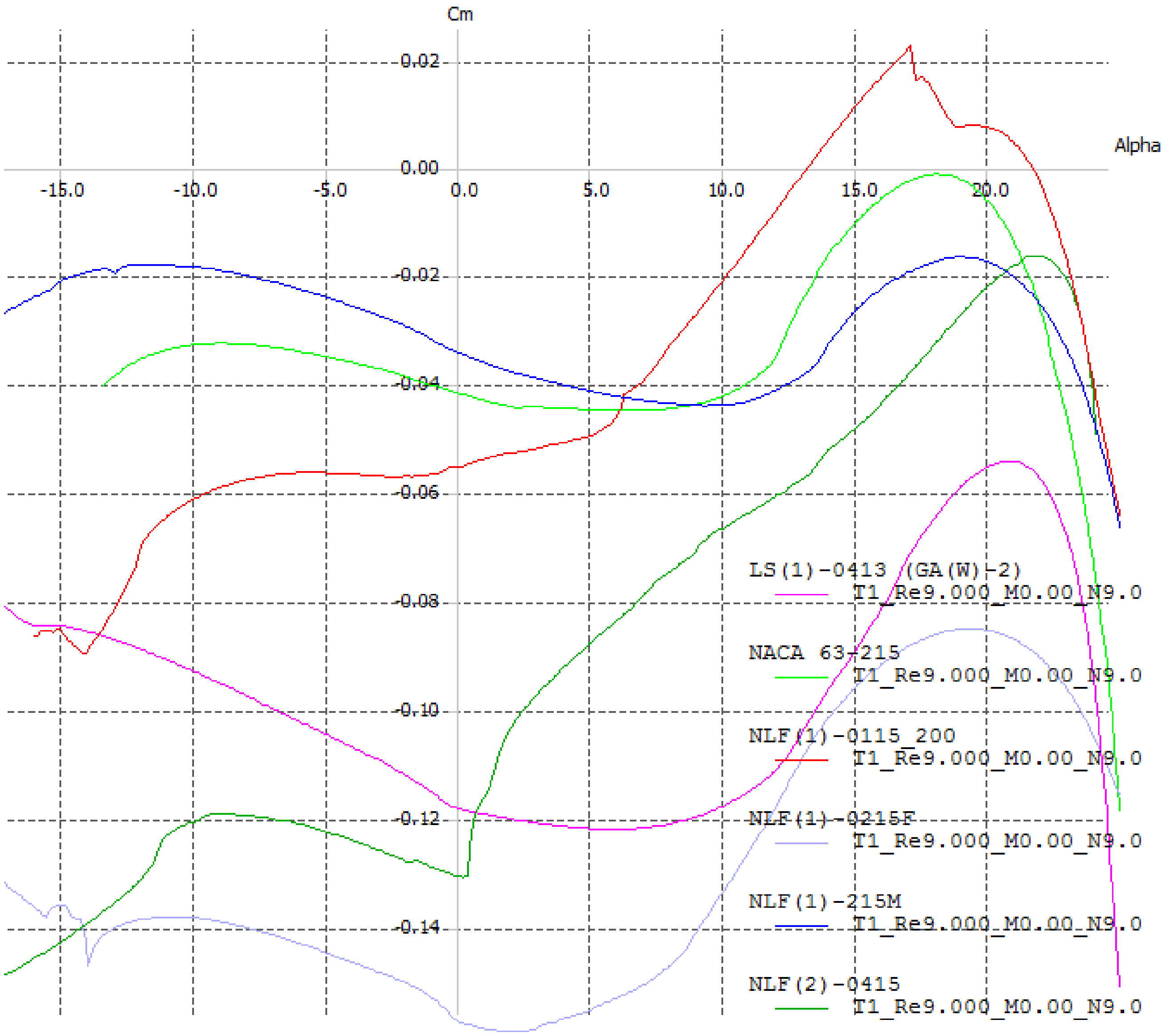
For Cl=0.5, where NLF(2)-0415 is laminar and therefore not considered, NLF(1)-215M has minimum Clmin=0.0049.

Only NLF(2)-0415 has Cdmin=0.0030, with about twice as narrower laminar bucket, located at higher Cl (starting from about 0.3), and max thickness located behind 0.5c. NLF(1)-0115 has the same Cdmin=0.0038, but very narrow laminar bucket.

For Cl=0.2 of interest for cruise purpose the new airfoil has not competitors. In fact the range with no competitors is about 0.1…0.25. Considering max Cl operating range for a given Cd=0.004, for the new airfoil its much wider than for NLF(1)-0115, and about the same as for NLF(2)-0415.



The theoretical Clmax=1.82 which is less only for LS(1)-0413 and NLF(1)-215F. A flap is supposed to solve a need in high Cl. The airfoil stall at 18.6 degrees, while the theoretical range of AOA is wider only for NLF(1)215F (stalls at about 20.5 degrees).



NLF(1)-215M positively demonstrates minimal Cm within normal operating range up to AOA=6 degrees, where NLF(1)-0115 starts doing better. However NLF(1)-0115 becomes positive after 13 degrees.

A detailed comparison is presented in Table 1.

Flapped Airfoil Analysis

TBD

Flap 10° Configuration

TBD

Flap -10° Configuration

TBD

Table 1

	NACA 63-215	LS(1)-0413 (GA(W)-2)	NLF(2)-415	NLF(1)-0215F	NLF(1)-0115	Design Targets	NLF(1)-0215M
Used on Aircraft	Mooney M20TN	Glassair III		Lancair 360			
Vc, km/h	438	505		416			
Re=9e6, M=0							
Thickness, %	15	12.93	15.02	14.99	14.99	<=15	14.76
Cdmin	0.0041	0.0050	0.0030	0.0040	0.0038	<0.004	0.0038
Cl for Cdmin	0.14	0.29	0.45	0.70	0.28	0.20	0.17
Cd @ Cl=0.2	0.0041	0.0053	0.0051	0.0061	0.0048	~0.004	0.0038
Laminar Bucket Clmin	-0.03	N/A	0.27	0.67	0.21	~0	-0.08
Laminar Bucket Clmax	0.5	N/A	0.51	1	0.4	0.51	0.54
Laminar Bucket Width, dCl	0.53	N/A	0.24	0.33	0.19	0.51	0.62
Cd @ Cl=0.5	0.0055	0.0053	0.0031	0.0054	0.0054	0.0040	0.0049
Cd @ Cl=1.0	0.0093	0.0077	0.0110	0.0049	0.0096	0.0069	0.0081
Cl0	0.18	0.53	0.48	0.69	0.28	0.50	0.18
a @ Cl=0	-1.6	-4.3	-4.3	-5.8	-2.7	-3.0	-1.5
a @ Cl=0.2	0.2	-2.6	-2.4	-3.9	-0.8	-1.0	0.2
Clmax	1.63	2.07	1.80	1.97	1.64	1.80	1.82
a @ Clmax	18.5	19.3	20.8	20.5	18.9	19	18.6
Cm0	-0.038	-0.105	-0.123	-0.143	-0.057	-0.030	-0.031
Cm @ a=0	-0.042	-0.117	-0.130	-0.157	-0.055	-0.030	-0.034
Cm @ a=5	-0.044	-0.121	-0.087	-0.155	-0.049	-0.040	-0.041
Cm @ Cl=0.2	-0.042	-0.110	-0.127	-0.146	-0.056	-0.040	-0.034
Cm @ Clmax	-0.008	-0.057	-0.018	-0.086	0.007	-0.008	-0.016

Conclusion

For Re=9e6:

- Cdmin=0.0038 is less than required 0.004;
- the laminar bucket starts at about Cl=-0.1 @ Re=3e6 and ends at about Cl=0.6 @ Re=9e6;
- Clmax=1.82 that is more than require 1.80;
- Clmax does not changes significantly for transition fixed at 0.05c (top and bottom);
- Cm within normal operating range is less than for the competing airfoils;
- smooth stall shall be demonstrated by additional simulation/analysis/tests.

References

1. NASA TP 1865 “Design and Experimental Results for Flapped NLF Airfoil”
2. XFOIL 6.96 User Guide