Open-Source Airfoils Summary

Version 1.0

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ACKNOWLEDGEMENTS

The Open-Source Offshore (OSO) airfoils have been developed by Sandia National Laboratories in collaboration with the university of California State Long Beach, the National Renewable Energy laboratory, as well as through the advisement of many experts and the support of the DOE Wind Energy Technologies Office.

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1. DESCRIPTION AND CHARACTERISTICS OF THE OPEN-SOURCE AIRFOILS

The Open-Source Offshore (OSO) airfoils have been developed for research purposes for offshore wind turbines, offering a set of airfoils that captures modern turbine design requirements and industry design practices without the proprietary constraints on research use. The eventual airfoil family will target the IEA 22 MW wind turbine [Zahle et al. 2024], which was originally developed with the FFA airfoils. The two airfoils summarized in Table 1 (OSO-21-WT1 and OSO-30-WT1) started development as part of a family of airfoils being developed targeting the IEA 22 MW wind turbine.

The criteria used to design these airfoils are summarized in Table 1, aim to encapsulate requirements of modern airfoils for offshore wind turbine applications, and were developed with feedback form industry and research experts. The airfoils were designed using XFOIL and candidate airfoils were then analyzed in RFOIL, which is considered more accurate than XFoil for high lift predictions of thicker airfoils. The design process for a preliminary family of airfoils is available, including a more detailed explanation of the design requirements and metrics similar to those used for these airfoils [Karcher et al. 2025].

Most of the design criteria are met for these two airfoils, with two exceptions. For both aifoils, the L/D Roughness Loss metric is exceeded (42% > 40% goal) and the desired lift coefficient travel beyond design value ("CL_Margin") was moderately exceeded (0.43 > 0.3) while smooth-stall (computed) were achieved. Note that all of the metrics are computed using RFOIL, and like other new airfoils, these will need to be experimentally validated before high-Reynolds number testing. The airfoil coordinates will be shared publicly on Sadia National Laboratories' public Github repository:

(https://github.com/sandialabs/released-oso-airfoils).

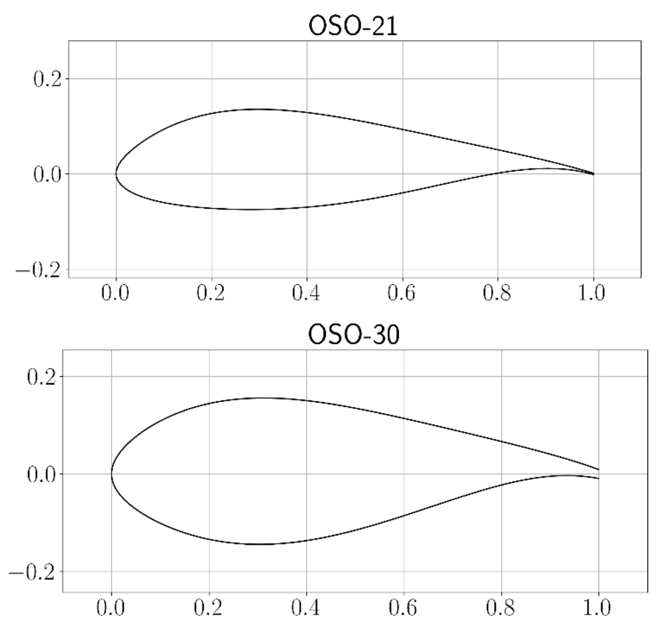


Figure 1-1. Shape of the OSO-21-WT1 (top) and OSO-30-WT1 (bottom) airfoils.

Table 1-1. Open-Source Offshore airfoil design criteria and performance (computed metrics)

	Design Criteria			
	Modern Airfoil tip region	Modern Airfoil mid-span	OSO-21-WT1 Airfoil, tip region	OSO-30-WT1 Airfoil, mid-span
Thickness - t/c	21%	30%	21%	30%
Reynolds Number, Chordwise, design target	Re=12e6+	Re=15e6+	Re=12e6	Re=18e6
CL_Design	1.2-1.5	1.1-1.3	1.47	1.43
L/D clean	>200	>160	205	171
L/D rough	>115	>95	121	100
L/D Roughness Loss %	<40%	<40%	41%	42%
Stall Margin (clean and tripped)	>3 deg.		6.0	5.8
Stall Margin - Rough	>3 deg.		6.0	4.8
CL Margin	Cl_Max - Cl_Des < 0.3		0.42	0.43
CL Loss Rough	CL Loss due to roughness at Alpha Design (< 10%)		4.3%	6.8%
Post Stall Slope - Clean	(dCL/dAlpha < -0.17/deg. over 2 deg. post stall)		-0.132	-0.103
Post stall slope - Rough	(dCL/dAlpha < -0.17/deg. over 2 deg. post stall)		-0.135	-0.091
L/D robustness - Clean	+/- 5% from peak L/D at +/- 15% from design AoA		1.5%	4.0%
L/D robustness - Rough	+/- 5% from peak L/D at +/- 15% from design AoA		3.5%	4.8%
CM Magnitude	~Equal or less than existing open airfoils (FFA , S-series)		-0.150	-0.156
Structures - TE angle	Last 2% of chord must have a wedge angle of at least 10 degrees		✓	✓
Structures - Leading Edge Curvature - Shaped for robust performance, manufacturing, and erosion	LE Radius > 0.01	LE Radius > 0.04	✓	✓
Structures - Aft section upper surface curvature	Limit concave curvature on aft airfoil upper surface for buckling resistance		✓	✓
Structures - Spar location and thickness	Maximum thickness of airfoil measured perpendicular to chord line and located aft of 25% normalized chord		✓	✓
Structures - Bending Stiffness	Quantify that structural performance is at least as good as existing open airfoils, for example by comparing area		✓	✓

2. AIRFOIL MODELED PERFORMANCE DATA

Airfoil performance predictions made using RFoil (v 1.1) and XFoil (v. 6.99).

2.1. OSO-21-WT1 Performance Data

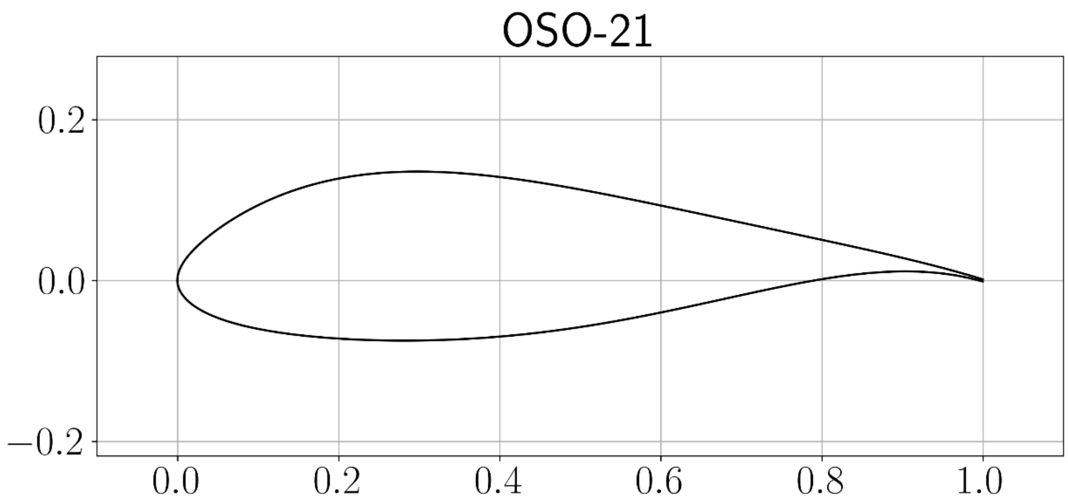
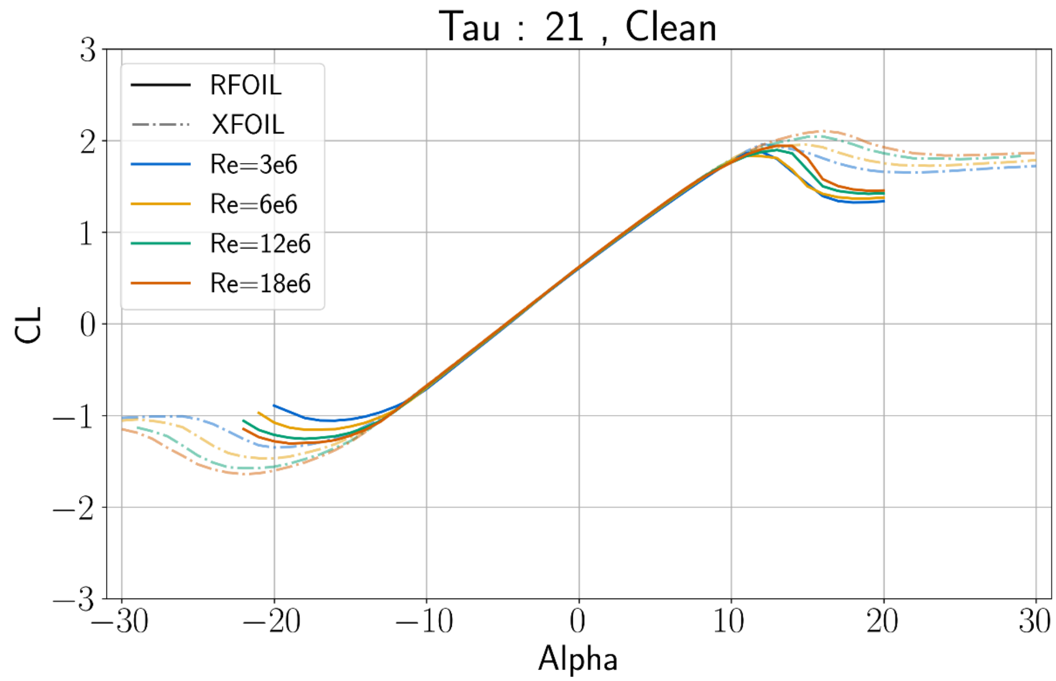


Figure 2-1. Shape of the OSO-21-WT1 airfoil.



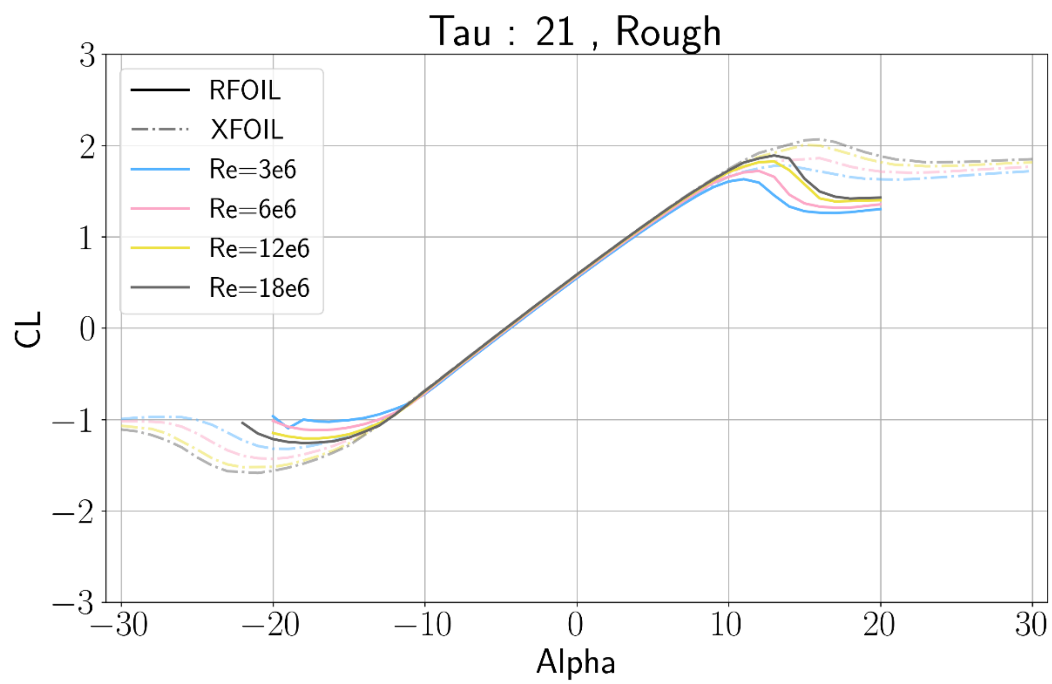


Figure 2-2. CL vs. Alpha, Clean and Rough, OSO-21-WT1

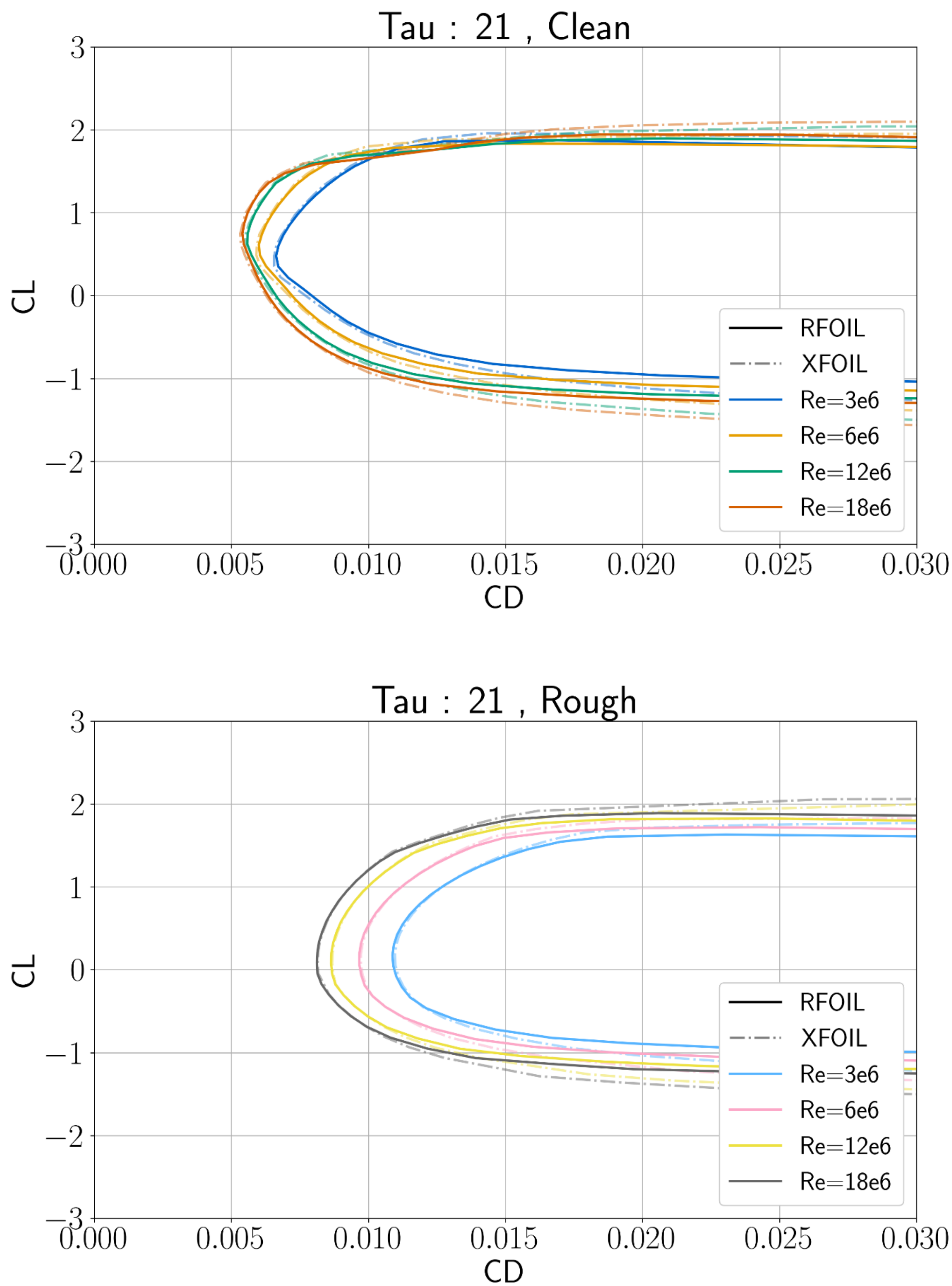


Figure 2-3. CL vs. CD, Clean and Rough, OSO-21-WT1

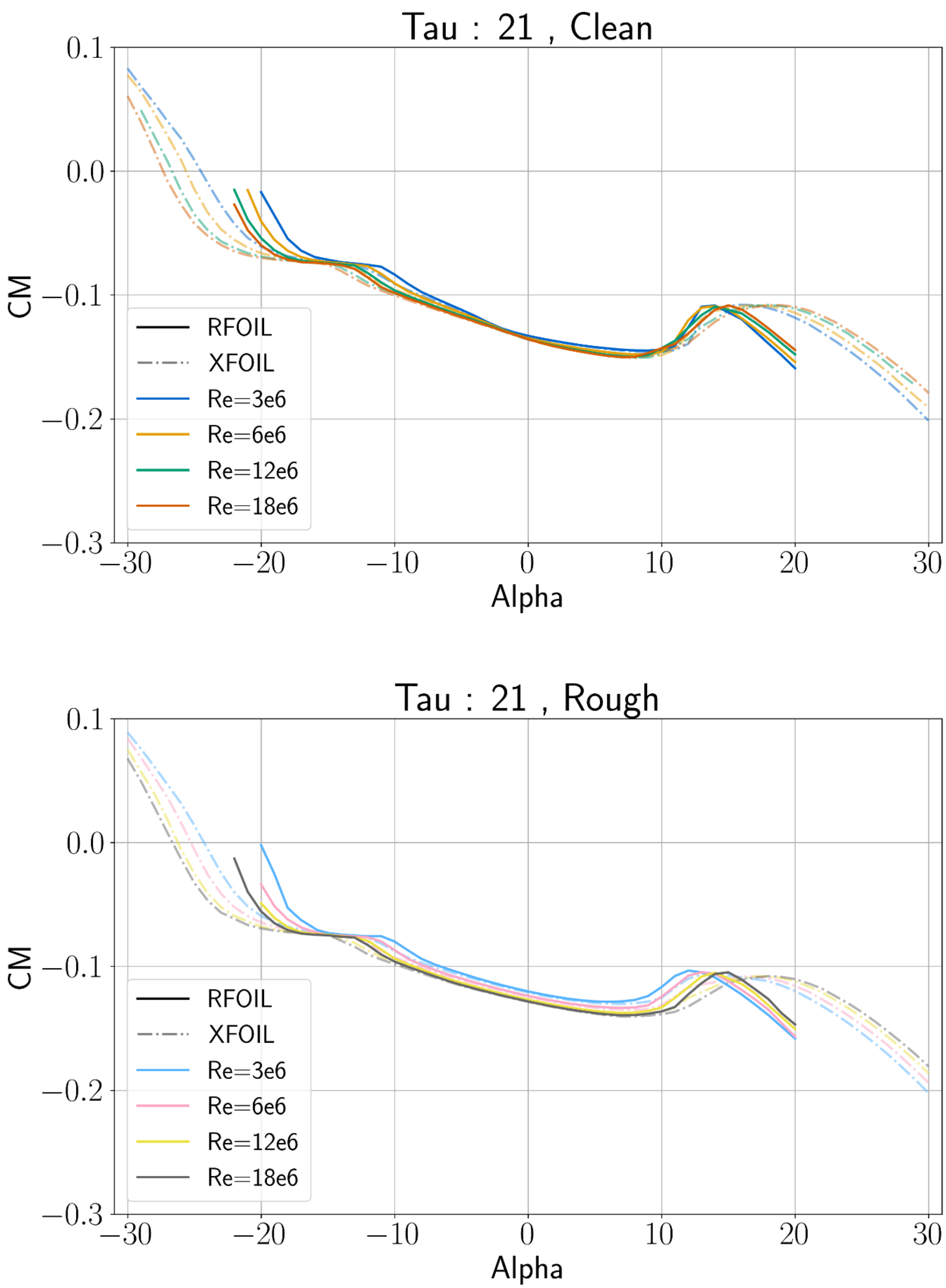


Figure 2-4. CM vs. Alpha, Clean and Rough, OSO-21-WT1

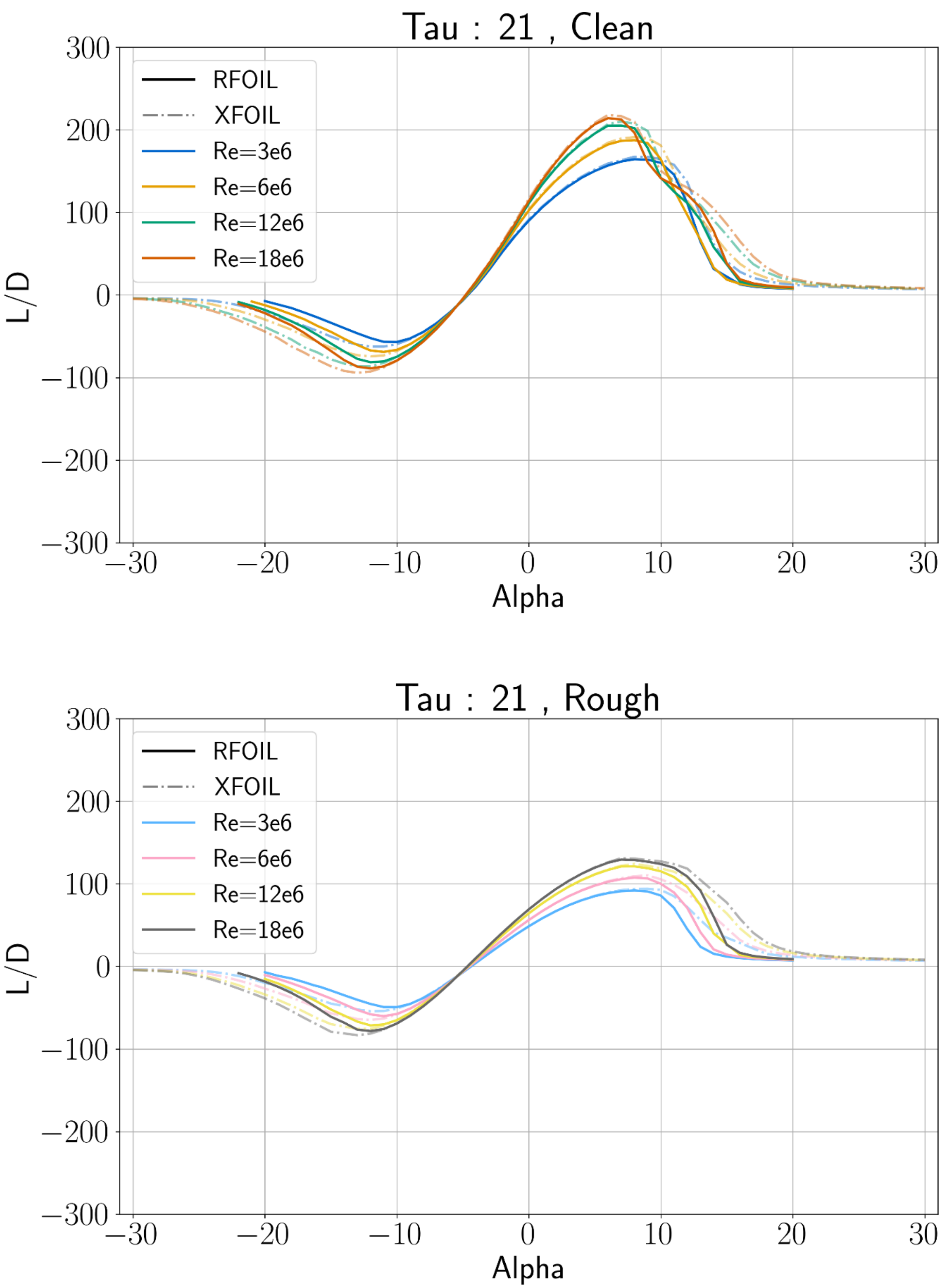


Figure 2-5. L/D vs. Alpha, Clean and Rough, OSO-21-WT1

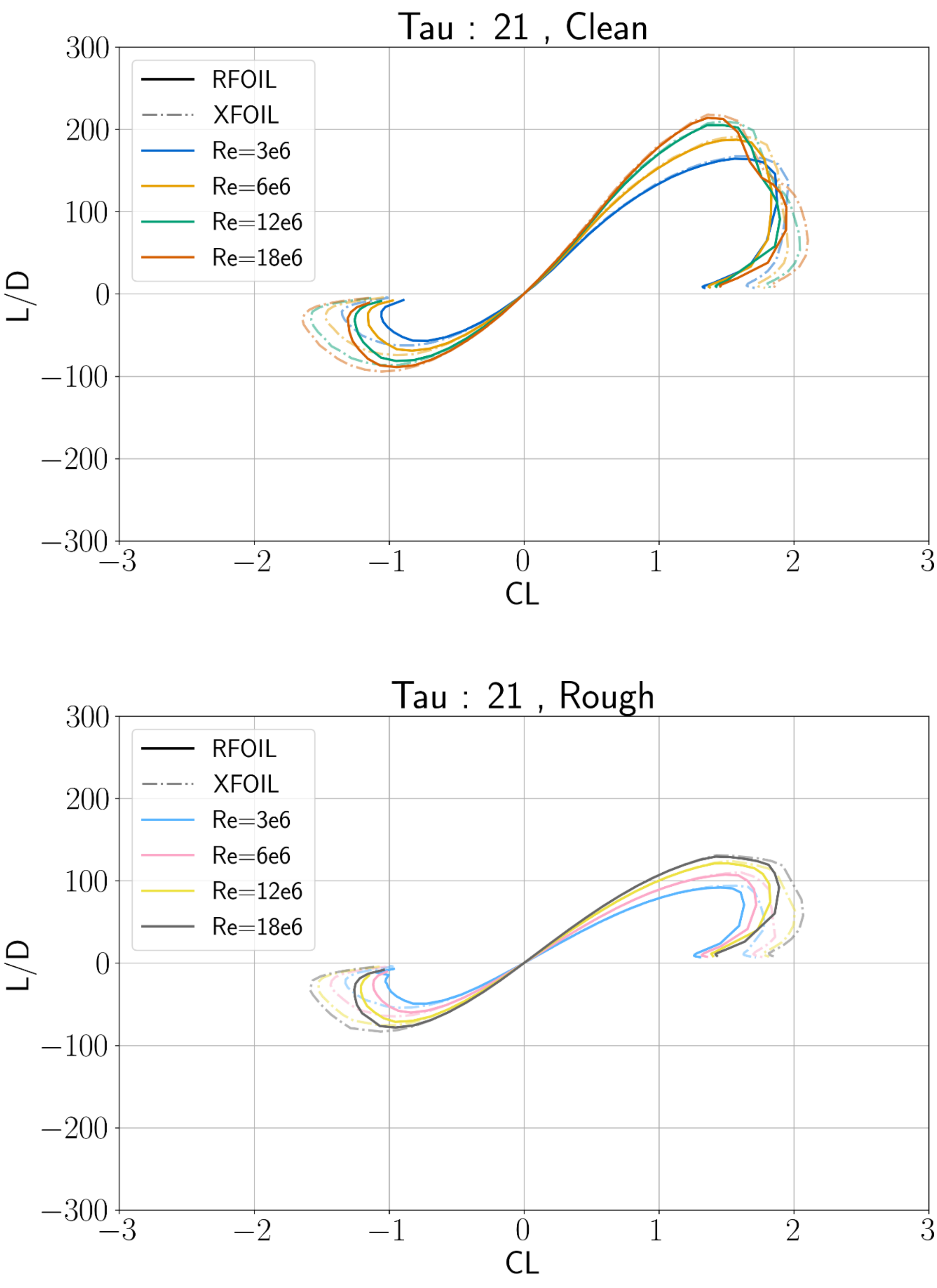


Figure 2-6. L/D vs. CL, Clean and Rough, OSO-21-WT1

2.2. OSO-30-WT1 Performance Data

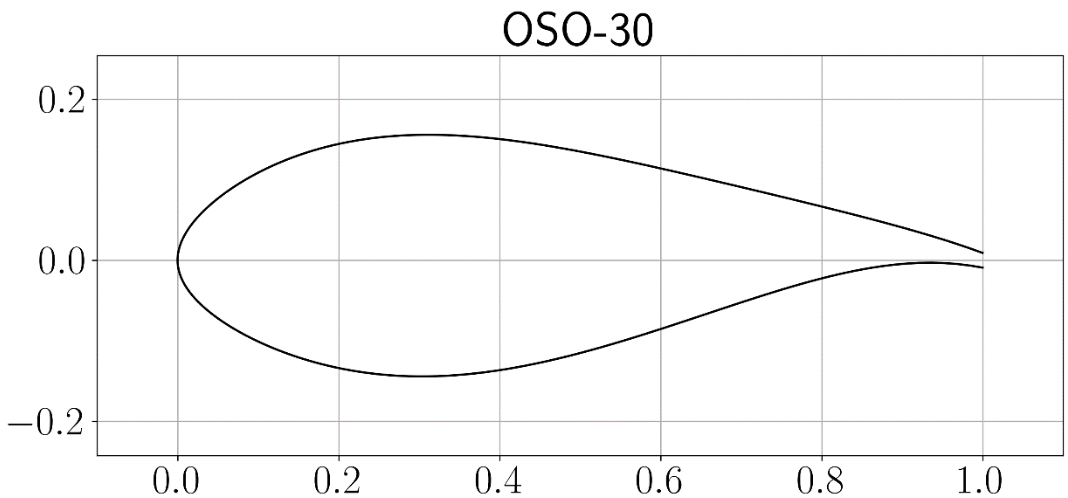
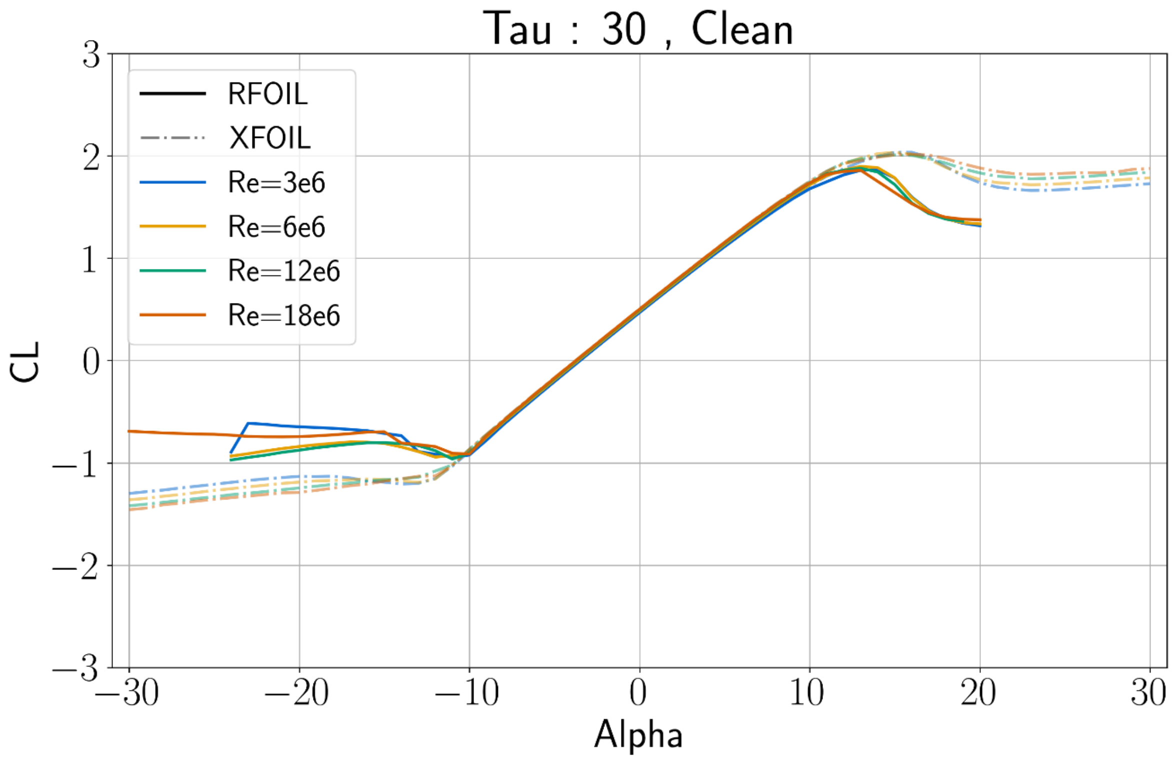


Figure 2-7. Shape of the OSO-30-WT1 airfoil.

For the 30% thick (OSO-30-WT1) airfoil, RFoil will converge to two lift curves at negative angles of attack post-stall for this airfoil. Only the lower in magnitude negative angle of attack lift curve is reported from the RFoil data, the higher in magnitude negative lift curve values are not included and are closer to the reported XFoil values.



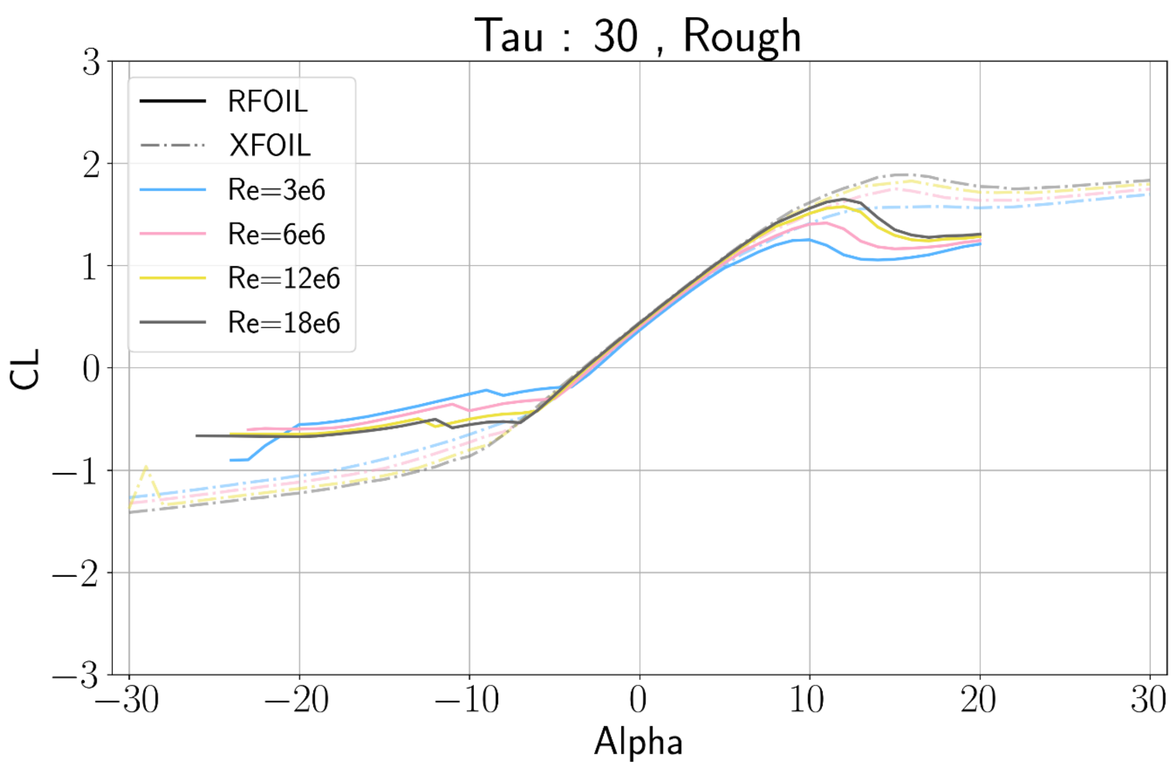


Figure 2-8. CL vs. Alpha, Clean and Rough, OSO-30-WT1

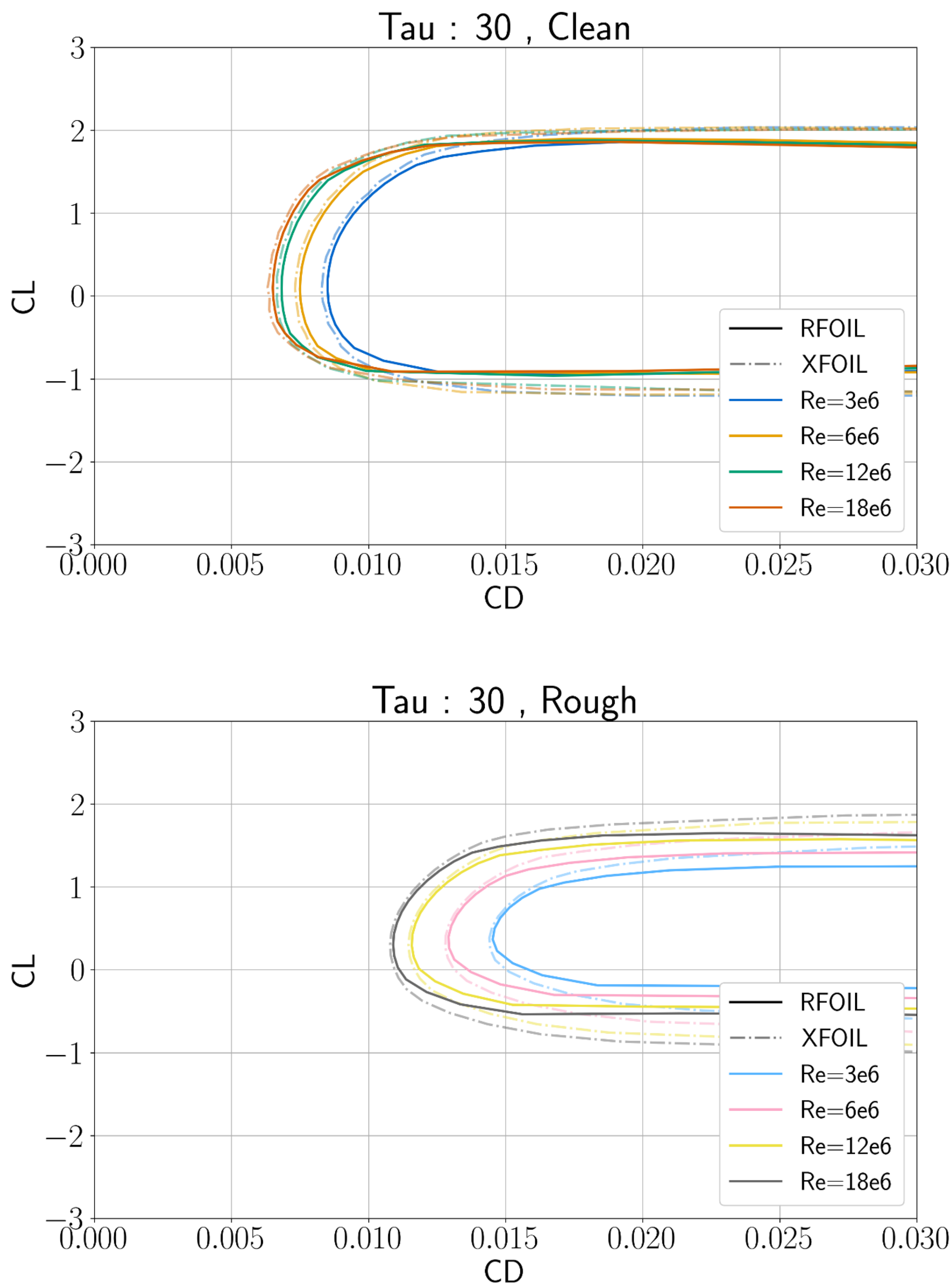
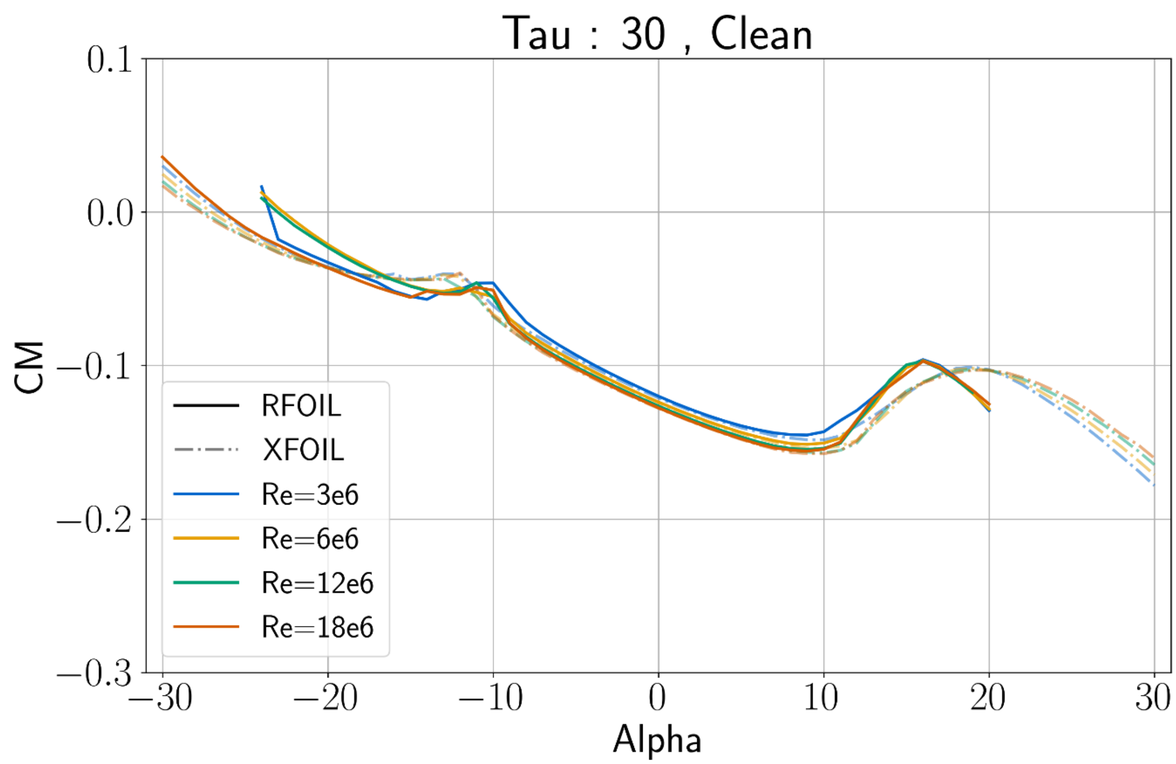


Figure 2-9. CL vs. CD, Clean and Rough, OSO-30-WT1



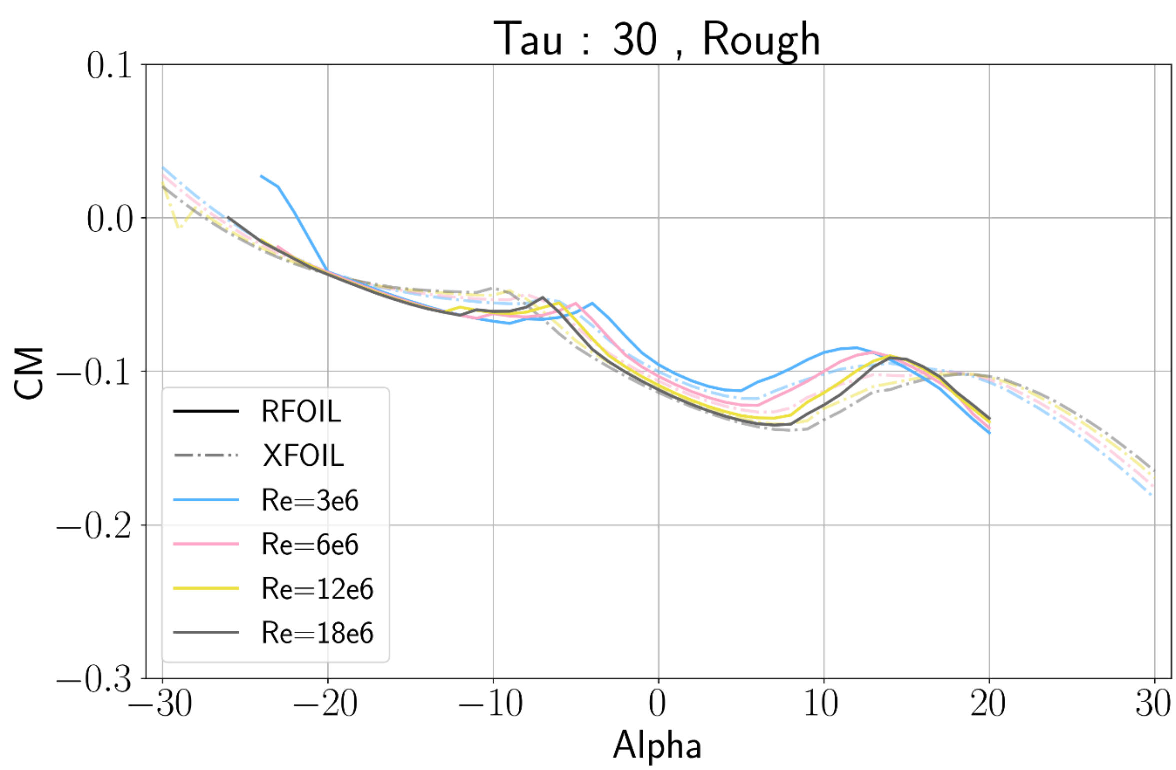


Figure 2-10. CM vs. Alpha, Clean and Rough, OSO-30-WT1

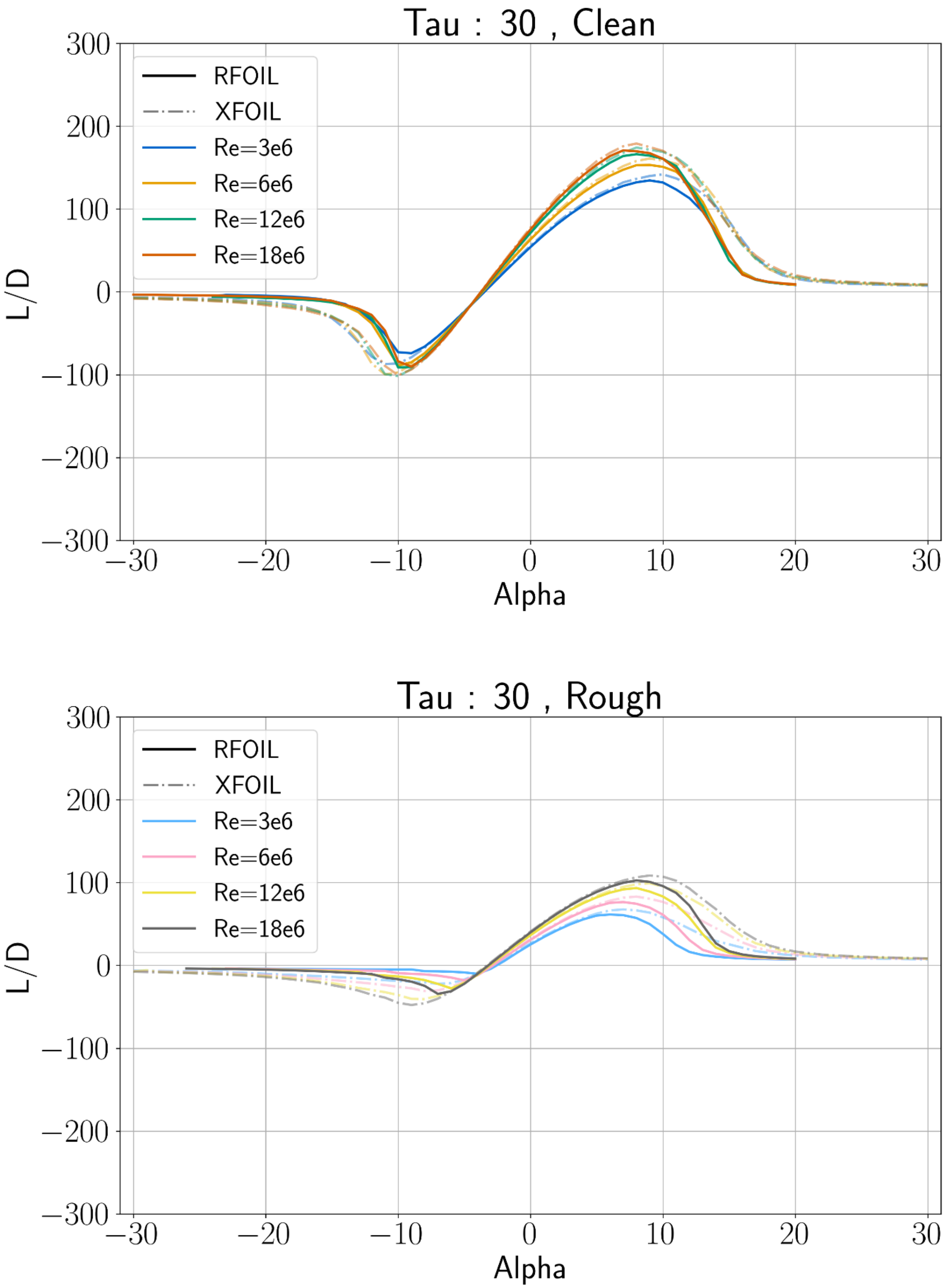


Figure 2-11. L/D vs. Alpha, Clean and Rough, OSO-30-WT1

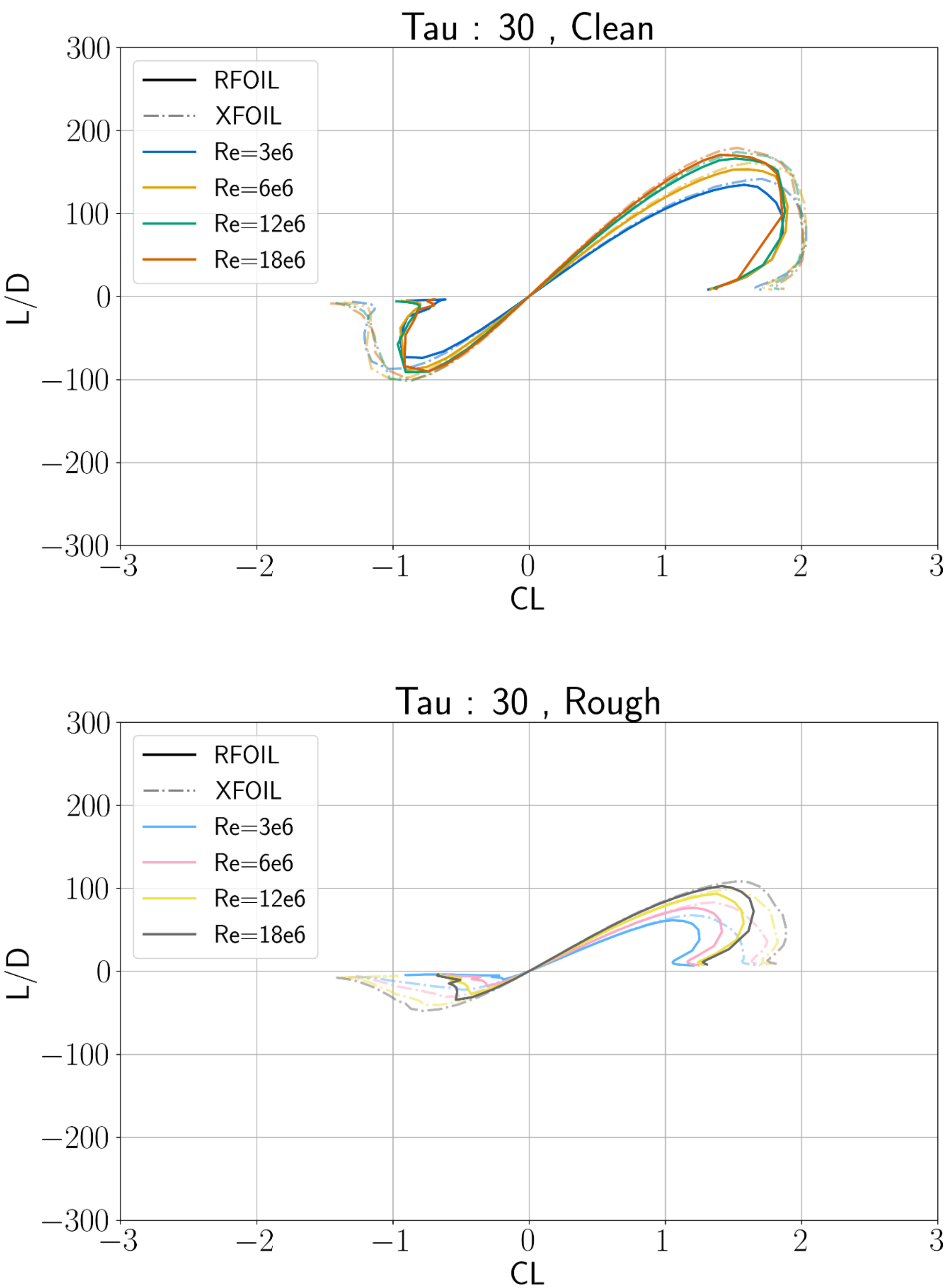


Figure 2-12. L/D vs. CL, Clean and Rough, OSO-30-WT1

REFERENCES

[1] Zahle, F., Barlas, A., Loenbaek, K., Bortolotti, P., Zalkind, D., Wang, L., Labuschagne, C., Sethuraman, L., and Barter, G., “Definition of the IEA Wind 22-Megawatt Offshore Reference Wind Turbine,” Technical University of Denmark, 2024. https://doi.org/10.11581/dtu.00000317.

[2] Cody J. Karcher, David C. Maniaci, Chris Kelley, Alan Hsieh, Nathaniel deVelder and Anurag Gupta. "Design of a Preliminary Family of Airfoils for High Reynolds Number Wind Turbine Applications," AIAA 2025-0840. AIAA SCITECH 2025 Forum. January 2025

APPENDIX A. AIRFOIL COORDINATES

A.1. OSO-21-WT1 Coordinates

Table 3-1. A.1. OSO-21-WT1 Coordinates

1.0000000	0.0013100	0.2873058	0.1351977	0.0001259	-0.0025697	0.3099210	-0.0745518
0.9841340	0.0060754	0.2762660	0.1349087	0.0005035	-0.0051356	0.3214906	-0.0742716
0.9682721	0.0106047	0.2654083	0.1344209	0.0011327	-0.0076936	0.3332310	-0.0738902
0.9524181	0.0149262	0.2547356	0.1337342	0.0020133	-0.0102396	0.3451393	-0.0734036
0.9365761	0.0190663	0.2442504	0.1328493	0.0031452	-0.0127697	0.3572124	-0.0728077
0.9207500	0.0230493	0.2339556	0.1317675	0.0045281	-0.0152800	0.3694473	-0.0720984
0.9049440	0.0268976	0.2238535	0.1304911	0.0061615	-0.0177667	0.3818410	-0.0712717
0.8891618	0.0306313	0.2139469	0.1290232	0.0080452	-0.0202261	0.3943903	-0.0703236
0.8734075	0.0342686	0.2042382	0.1273677	0.0101786	-0.0226546	0.4070921	-0.0692504
0.8576852	0.0378258	0.1947297	0.1255293	0.0125611	-0.0250490	0.4199431	-0.0680487
0.8419986	0.0413169	0.1854240	0.1235135	0.0151923	-0.0274060	0.4329401	-0.0667154
0.8263518	0.0447544	0.1763234	0.1213267	0.0180713	-0.0297226	0.4460799	-0.0652476
0.8107488	0.0481488	0.1674301	0.1189759	0.0211976	-0.0319961	0.4593592	-0.0636432
0.7951933	0.0515087	0.1587465	0.1164691	0.0245702	-0.0342237	0.4727745	-0.0619005
0.7796895	0.0548412	0.1502746	0.1138147	0.0281884	-0.0364032	0.4863226	-0.0600187
0.7642411	0.0581517	0.1420166	0.1110219	0.0320513	-0.0385324	0.5000000	-0.0579974
0.7488520	0.0614441	0.1339746	0.1081005	0.0361578	-0.0406093	0.5138033	-0.0558375
0.7335262	0.0647210	0.1261506	0.1050606	0.0405070	-0.0426322	0.5277289	-0.0535405
0.7182674	0.0679833	0.1185466	0.1019130	0.0450978	-0.0445995	0.5417735	-0.0511093
0.7030796	0.0712312	0.1111646	0.0986687	0.0499289	-0.0465099	0.5559334	-0.0485478
0.6879666	0.0744632	0.1040062	0.0953388	0.0549992	-0.0483623	0.5702051	-0.0458612
0.6729320	0.0776772	0.0970735	0.0919350	0.0603074	-0.0501559	0.5845850	-0.0430563
0.6579799	0.0808700	0.0903680	0.0884686	0.0658521	-0.0518897	0.5990695	-0.0401411
0.6431138	0.0840375	0.0838915	0.0849512	0.0716321	-0.0535634	0.6136549	-0.0371254
0.6283375	0.0871749	0.0776457	0.0813940	0.0776457	-0.0551763	0.6283375	-0.0340208
0.6136549	0.0902767	0.0716321	0.0778082	0.0838915	-0.0567281	0.6431138	-0.0308405
0.5990695	0.0933370	0.0658521	0.0742044	0.0903680	-0.0582188	0.6579799	-0.0275998
0.5845850	0.0963492	0.0603074	0.0705930	0.0970735	-0.0596480	0.6729320	-0.0243160
0.5702051	0.0993064	0.0549992	0.0669838	0.1040062	-0.0610158	0.6879666	-0.0210086
0.5559334	0.1022012	0.0499289	0.0633858	0.1111646	-0.0623221	0.7030796	-0.0176990
0.5417735	0.1050261	0.0450978	0.0598075	0.1185466	-0.0635668	0.7182674	-0.0144111
0.5277289	0.1077734	0.0405070	0.0562566	0.1261506	-0.0647500	0.7335262	-0.0111714
0.5138033	0.1104350	0.0361578	0.0527396	0.1339746	-0.0658715	0.7488520	-0.0080083
0.5000000	0.1130032	0.0320513	0.0492626	0.1420166	-0.0669311	0.7642411	-0.0049532
0.4863226	0.1154697	0.0281884	0.0458304	0.1502746	-0.0679287	0.7796895	-0.0020398
0.4727745	0.1178266	0.0245702	0.0424468	0.1587465	-0.0688638	0.7951933	0.0006957
0.4593592	0.1200661	0.0211976	0.0391147	0.1674301	-0.0697359	0.8107488	0.0032140
0.4460799	0.1221802	0.0180713	0.0358359	0.1763234	-0.0705444	0.8263518	0.0054737
0.4329401	0.1241613	0.0151923	0.0326112	0.1854240	-0.0712883	0.8419986	0.0074305
0.4199431	0.1260021	0.0125611	0.0294402	0.1947297	-0.0719666	0.8576852	0.0090371
0.4070921	0.1276953	0.0101786	0.0263219	0.2042382	-0.0725780	0.8734075	0.0102441
0.3943903	0.1292340	0.0080452	0.0232539	0.2139469	-0.0731210	0.8891618	0.0109990
0.3818410	0.1306117	0.0061615	0.0202332	0.2238535	-0.0735938	0.9049440	0.0112469
0.3694473	0.1318223	0.0045281	0.0172558	0.2339556	-0.0739944	0.9207500	0.0109301
0.3572124	0.1328600	0.0031452	0.0143172	0.2442504	-0.0743204	0.9365761	0.0099886
0.3451393	0.1337195	0.0020133	0.0114119	0.2547356	-0.0745693	0.9524181	0.0083599
0.3332310	0.1343961	0.0011327	0.0085341	0.2654083	-0.0747384	0.9682721	0.0059791
0.3214906	0.1348855	0.0005035	0.0056773	0.2762660	-0.0748246	0.9841340	0.0027789
0.3099210	0.1351842	0.0001259	0.0028350	0.2873058	-0.0748245	1.0000000	-0.0013100
0.2985251	0.1352890	0.0000000	0.0000000	0.2985251	-0.0747348		

A.2. OSO-30-WT1 Coordinates

Table 3-2. A.2. OSO-30-WT1 Coordinates

1.0000000	0.0091400	0.2873058	0.1553606	0.0001259	-0.0036077	0.3099210	-0.1441964
0.9841340	0.0148232	0.2762660	0.1548064	0.0005035	-0.0072175	0.3214906	-0.1439459
0.9682721	0.0201982	0.2654083	0.1540472	0.0011327	-0.0108291	0.3332310	-0.1434553
0.9524181	0.0253076	0.2547356	0.1530851	0.0020133	-0.0144422	0.3451393	-0.1427218
0.9365761	0.0301887	0.2442504	0.1519231	0.0031452	-0.0180565	0.3572124	-0.1417435
0.9207500	0.0348737	0.2339556	0.1505647	0.0045281	-0.0216717	0.3694473	-0.1405192
0.9049440	0.0393908	0.2238535	0.1490141	0.0061615	-0.0252874	0.3818410	-0.1390491
0.8891618	0.0437639	0.2139469	0.1472763	0.0080452	-0.0289032	0.3943903	-0.1373340
0.8734075	0.0480141	0.2042382	0.1453567	0.0101786	-0.0325186	0.4070921	-0.1353758
0.8576852	0.0521592	0.1947297	0.1432615	0.0125611	-0.0361331	0.4199431	-0.1331773
0.8419986	0.0562144	0.1854240	0.1409972	0.0151923	-0.0397461	0.4329401	-0.1307424
0.8263518	0.0601928	0.1763234	0.1385709	0.0180713	-0.0433568	0.4460799	-0.1280758
0.8107488	0.0641050	0.1674301	0.1359900	0.0211976	-0.0469643	0.4593592	-0.1251832
0.7951933	0.0679601	0.1587465	0.1332625	0.0245702	-0.0505676	0.4727745	-0.1220713
0.7796895	0.0717652	0.1502746	0.1303964	0.0281884	-0.0541655	0.4863226	-0.1187474
0.7642411	0.0755260	0.1420166	0.1274003	0.0320513	-0.0577567	0.5000000	-0.1152201
0.7488520	0.0792466	0.1339746	0.1242826	0.0361578	-0.0613395	0.5138033	-0.1114986
0.7335262	0.0829299	0.1261506	0.1210523	0.0405070	-0.0649121	0.5277289	-0.1075931
0.7182674	0.0865774	0.1185466	0.1177182	0.0450978	-0.0684724	0.5417735	-0.1035145
0.7030796	0.0901895	0.1111646	0.1142891	0.0499289	-0.0720179	0.5559334	-0.0992748
0.6879666	0.0937654	0.1040062	0.1107740	0.0549992	-0.0755460	0.5702051	-0.0948869
0.6729320	0.0973033	0.0970735	0.1071816	0.0603074	-0.0790534	0.5845850	-0.0903646
0.6579799	0.1008005	0.0903680	0.1035205	0.0658521	-0.0825369	0.5990695	-0.0857229
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0.6283375	0.1076574	0.0776457	0.0960263	0.0776457	-0.0894159	0.6283375	-0.0761463
0.6136549	0.1110073	0.0716321	0.0922092	0.0838915	-0.0928025	0.6431138	-0.0712472
0.5990695	0.1142970	0.0658521	0.0883558	0.0903680	-0.0961472	0.6579799	-0.0663002
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0.5559334	0.1237366	0.0499289	0.0766476	0.1111646	-0.1058714	0.7030796	-0.0513952
0.5417735	0.1267146	0.0450978	0.0727167	0.1185466	-0.1089880	0.7182674	-0.0464888
0.5277289	0.1295949	0.0405070	0.0687811	0.1261506	-0.1120303	0.7335262	-0.0416598
0.5138033	0.1323688	0.0361578	0.0648457	0.1339746	-0.1149905	0.7488520	-0.0369395
0.5000000	0.1350277	0.0320513	0.0609146	0.1420166	-0.1178607	0.7642411	-0.0323611
0.4863226	0.1375631	0.0281884	0.0569917	0.1502746	-0.1206323	0.7796895	-0.0279602
0.4727745	0.1399662	0.0245702	0.0530800	0.1587465	-0.1232965	0.7951933	-0.0237750
0.4593592	0.1422287	0.0211976	0.0491822	0.1674301	-0.1258444	0.8107488	-0.0198456
0.4460799	0.1443424	0.0180713	0.0453003	0.1763234	-0.1282668	0.8263518	-0.0162144
0.4329401	0.1462992	0.0151923	0.0414356	0.1854240	-0.1305542	0.8419986	-0.0129260
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0.3572124	0.1543593	0.0031452	0.0186275	0.2442504	-0.1409223	0.9365761	-0.0030314
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0.3332310	0.1555120	0.0011327	0.0111498	0.2654083	-0.1428845	0.9682721	-0.0046023
0.3214906	0.1557836	0.0005035	0.0074267	0.2762660	-0.1435489	0.9841340	-0.0064860
0.3099210	0.1558494	0.0001259	0.0037109	0.2873058	-0.1439929	1.0000000	-0.0091400
0.2985251	0.1557085	0.0000000	0.0000000	0.2985251	-0.1442106		