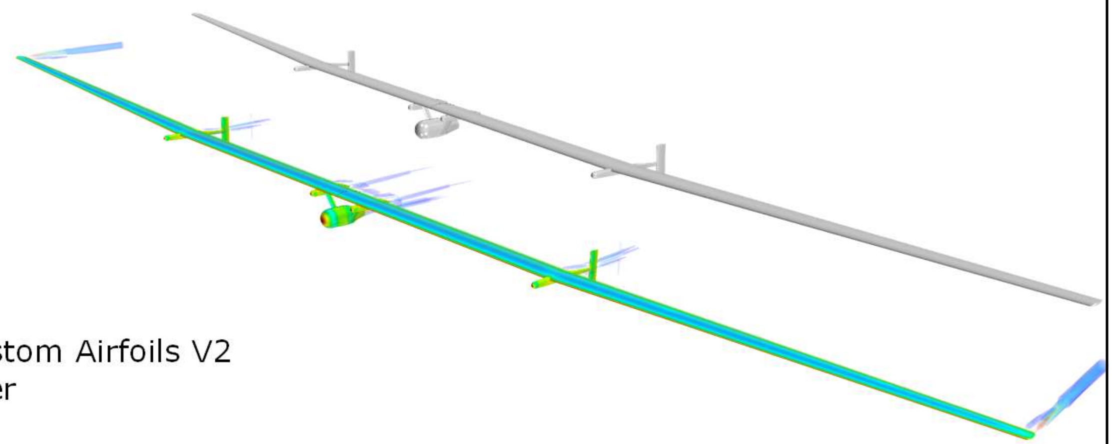
Raymer Mars Plane



Results – Custom Airfoils V2

D. Felix Finger

RMP Custom Airfoils

Approach to airfoil design V1

Analyzed airfoils for human powered flight. Unsuitable. All optimized for Re > 200,000

RMP Re < 150,000

Used optimization in Xfoil to find airfoil geometries for the Re-range of the RMP (Re# 100k…200k).

4 custom airfoils: 10%, 12%, 14%, 16% thickness ratio

Because of the low-Re conditions, less t/c significantly increases performance

Optimizer converged on “bumpy” airfoils, results didn’t look right at the first glance

Turns out, the bumps are used to limit the extend of the laminar separation bubbles

Because L/D from Xfoil is unreliable, airfoils were analyzed at 5 different angles of attack using a 2D RANS method (incl. transition modeling) at a fixed Re# = 147k

2D Results are presented on the next slides

RMP Custom Airfoils

Overview V1

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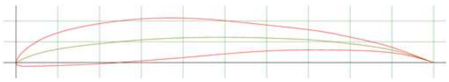
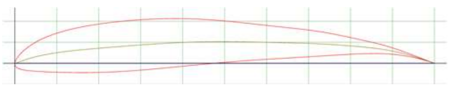
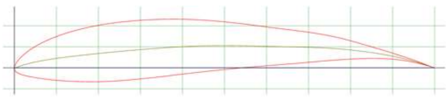


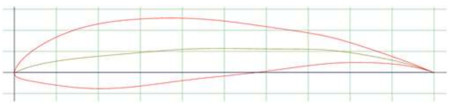
RMP 10
Max thickness 10.1% at 28.8% chord   Max camber 6% at 48.3% chord



RMP 12
Max thickness 12% at 28.5% chord   Max camber 5% at 48.2% chord



RMP 14
Max thickness 14% at 27.6% chord   Max camber 5.2% at 49.6% chord



RMP 16
Max thickness 16% at 27.1% chord   Max camber 5.6% at 49.1% chord

	10% t/c				12% t/c				14% t/c				16% t/c			
	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D
0,0	0,6700	0,01737	-0,1660	38,57	0,5883	0,01962	-0,1550	29,99	0,5917	0,02130	-0,1615	27,78	0,6149	0,02317	-0,1650	26,54
2,5	0,9795	0,01795	-0,1751	54,56	0,8556	0,01814	-0,1532	47,17	0,8384	0,02027	-0,1490	41,36	0,8795	0,02423	-0,1601	36,30
5,0	1,2326	0,02290	-0,1729	53,83	1,1391	0,02212	-0,1567	51,50	1,1174	0,02433	-0,1575	45,92	1,0876	0,02822	-0,1539	38,54
7,5	1,4221	0,02960	-0,1613	48,04	1,3285	0,02827	-0,1444	46,99	1,3046	0,03220	-0,1500	40,51	1,2803	0,03569	-0,1506	35,88
9,5	1,5103	0,03783	-0,1452	39,92	1,4182	0,03816	-0,1311	37,17	1,4224	0,03889	-0,1400	36,57	1,3859	0,04476	-0,1434	30,96

RMP Custom Airfoils

Overview V1

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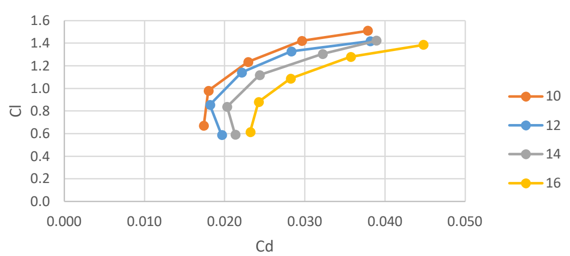
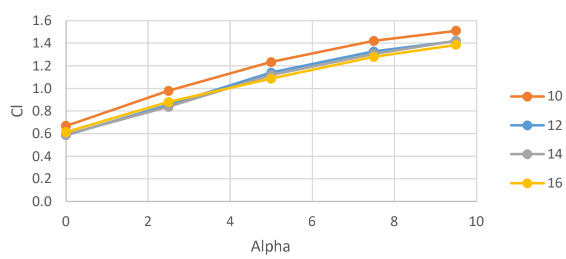
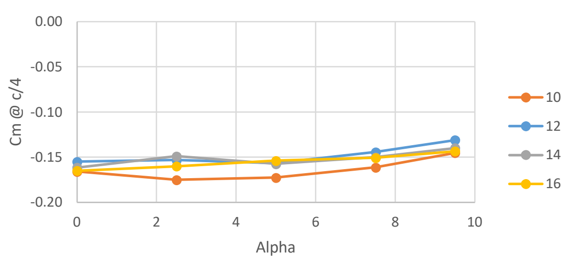
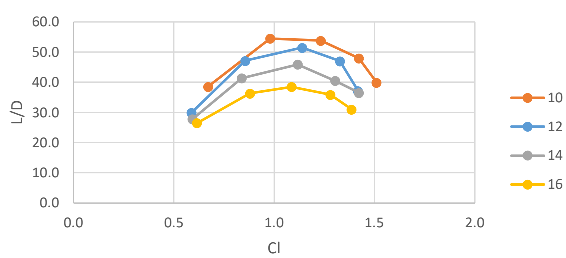








RMP Custom Airfoils

Comments on airfoil performance V1

Cl data looks promising. High Cl_{max} (>1.5) seems achievable for all airfoils (stall was not studied).
Compares positively to the initial RMP assumptions

High pitching moment is required to get that high lift performance.
$Cm_{c/4}$ varies between -0.15 and -0.17 Could be problematic for stability and control.

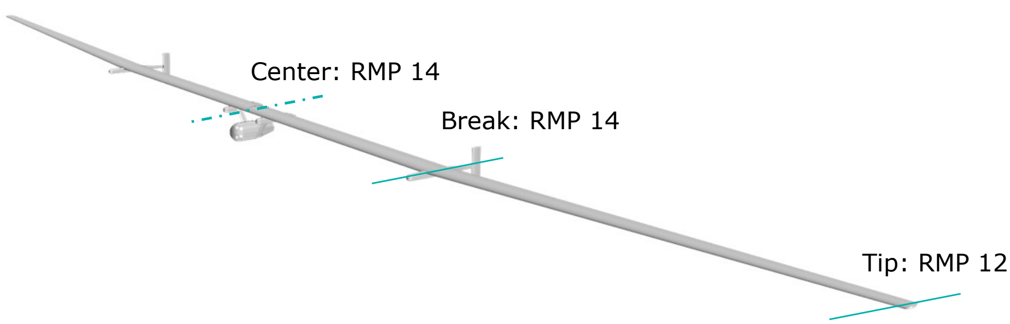
L/D data is not as good as expected. The low Re conditions take their toll.
L/D_{max} of the thinnest airfoil is 54. Very hard to get an aircraft L/D of 44 with such airfoil performance.

RMP Custom Airfoils

Complete aircraft analysis V1

To assess the 3D performance of a wing with the new airfoils an updated simulation was carried out.

New wing:



Very optimistic with respect to structural strength and stiffness

CFD Results

3D Data at 105k ft V1

AOA	2deg	4deg
CL	0,866	1,02
CD	0,02775	0,03265
L/D	31,21	31,24
CD Wing	0,02566	0,03034
CD Nacelle inner	0,00052	0,00062
CD Nacelle outer	0,00031	0,00048
CD Fuselage	0,00054	0,00047
CD Struts	0,00036	0,00038
CD Vertical Tails	0,00036	0,00036

Reference: NASA airfoil L/D: ~21
Invisicd + friction L/D: ~44

Got a 50% L/D improvement over NASA NLF1 airfoil from using the new airfoils. Higher benefit is obtainable by reducing t/c. Challenge: Structures.

RMP Custom Airfoils

Outlook V1

Doubling Re would bring the RMP into the human-powered aircraft Re-range

→ Much improved performance

Iterate design to get larger Re?

Higher Re could be obtained by smaller AR and/or lower W/S

Deeper wings could help to facilitate lower t/c

Trade study for AR is not straightforward because low-Re drag estimation is challenging

RMP Custom Airfoils

Approach to airfoil design V2

Raymer's Plan: "Dash-2 version of the design with Felix's airfoil and an untapered wing with lower aspect ratio. I'll also add horizontal tails since Felix's airfoils have a big cusp at the trailing edge which will make a lot of pitching moment." → *Felix' idea: put outboard horizontals to double use as ailerons.*
"Try designing an airfoil assuming chord lengths 25% and 50% more than the current version, then comparing it to the current version to see if the Reynolds # benefit is real."

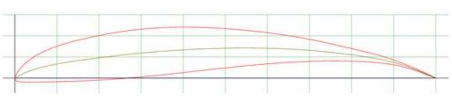
→ Worked the optimization pipeline in Xfoil again to find airfoils for 150% of the Re-range of the RMP (Re 150k … 300k).

4 custom airfoils: 11%, 12%, 14%, 16% thickness ratio (The 10% t/c constraint converged to an 11% thickness ratio)

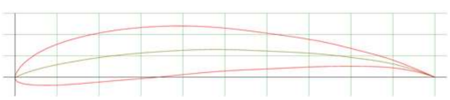
Again, the new 150% airfoils were analyzed at 5 different angles of attack using a 2D RANS method (incl. transition modeling) at a fixed Re# = 221k

RMP Custom Airfoils

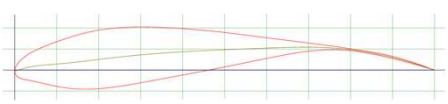
Overview V2



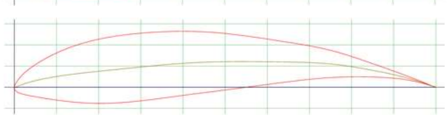
RMP 150 11
Max thickness 11.3% at 30.6% chord Max camber 7.1% at 55.2% chord



RMP 150 12
Max thickness 12% at 30.1% chord Max camber 6.5% at 48.4% chord



RMP 14
Max thickness 14% at 22.6% chord Max camber 5.4% at 68.7% chord

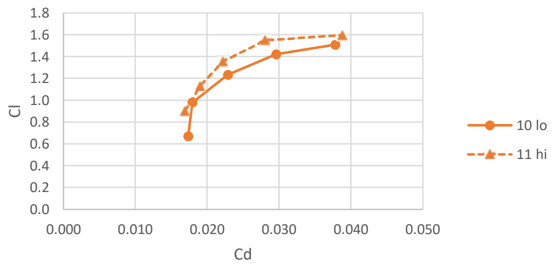


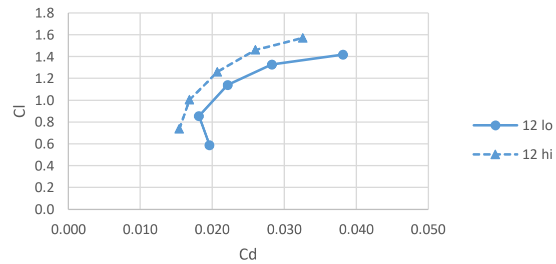
RMP 16
Max thickness 16% at 28.2% chord Max camber 6.1% at 43.7% chord

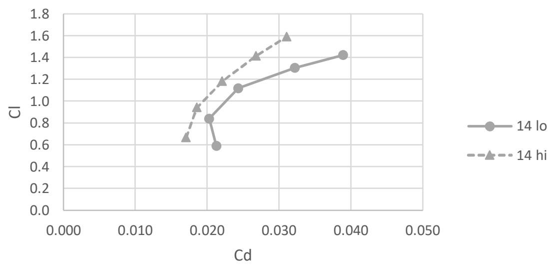
	11% t/c - Re 150%				12% t/c - Re 150%				14% t/c - Re 150%				16% t/c - Re 150%			
	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D
0,0	0,8980	0,01695	-0,2241	52,99	0,7366	0,01542	-0,1859	47,7830	0,66746	0,0171	-0,18	39,08	0,7020	0,01902	-0,1851	36,90
2,5	1,1301	0,01901	-0,2160	59,46	1,0046	0,01682	-0,1835	59,7234	0,94100	0,0186	-0,17	50,62	0,9604	0,02071	-0,1830	46,38
5,0	1,3563	0,02220	-0,2111	61,08	1,2603	0,02070	-0,1820	60,8905	1,18371	0,0221	-0,17	53,54	1,1892	0,02417	-0,1784	49,20
7,5	1,5493	0,02808	-0,2006	55,18	1,4625	0,02601	-0,1729	56,2217	1,41376	0,0268	-0,16	52,77	1,3694	0,03047	-0,1708	44,94
9,5	1,5976	0,03882	-0,1798	41,16	1,5713	0,03257	-0,1597	48,2368	1,59149	0,0311	-0,16	51,22	1,4702	0,03744	-0,1602	39,27

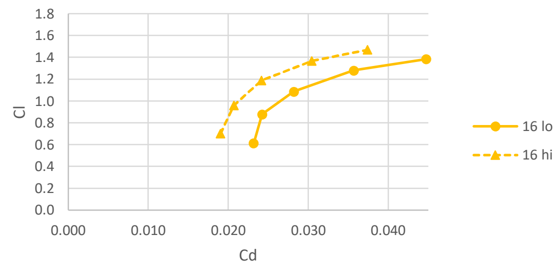
RMP Custom Airfoils

Overview low Re vs. high Re



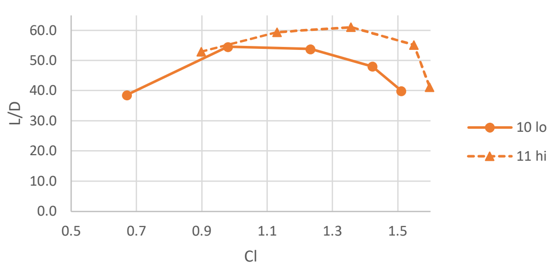


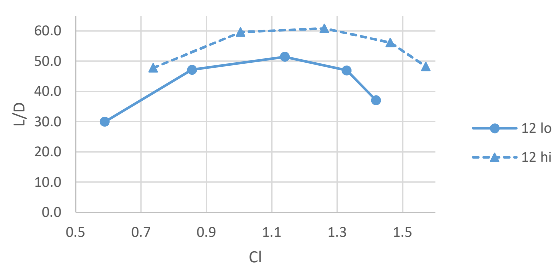


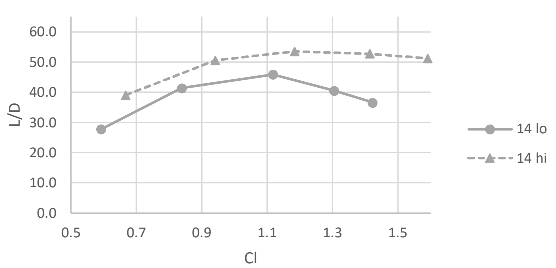


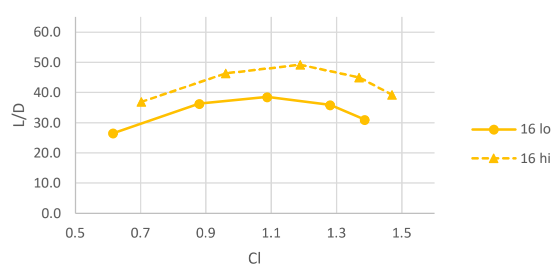
RMP Custom Airfoils

Overview low Re vs. high Re









RMP Custom Airfoils

Comments on airfoil performance V2

Higher Re allows higher Cl_{max}, so the target of Cl_{max} >1.5 seems reasonable for the 150% airfoils (stall was not studied).

$Cm_{c/4}$ for the high-Re airfoils is even higher than for the low-Re airfoils

Optimizer found a loophole for the 14% high-Re airfoil. Extremely thin trailing edge seems impractical for structures.

L/D is much improved. Still, the whole-aircraft L/D of 44 is challenging to reach for t/c > 12%.
AR - W/S – t/c trade studies necessary