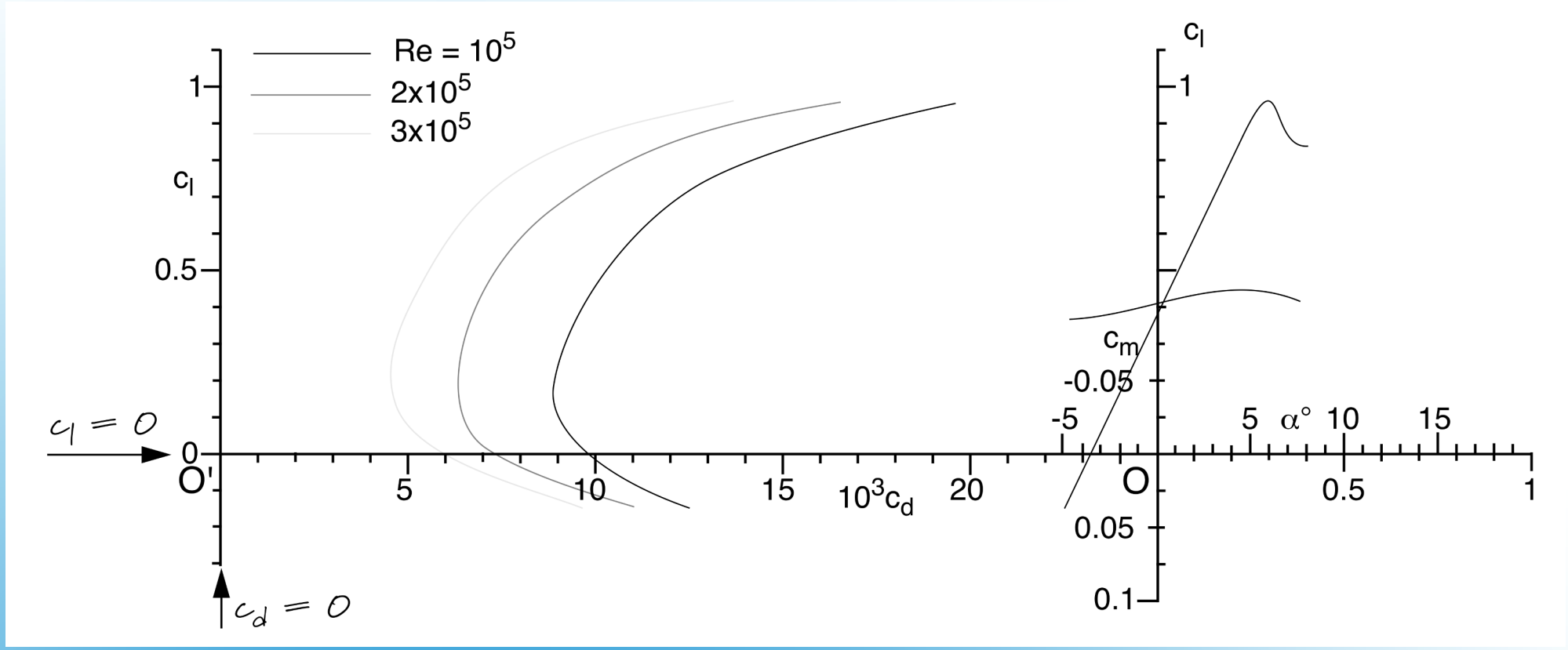

Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
O'
5
10
15
10^3c_d
20
c_l = 0
c_d = 0
c_l
1
c_m
-0.05
-5
5
α°
10
15
O
0.5
1
0.05
0.1

Understanding Polars Without Math Part 2

Bill Kuhlman

- Determining the Lift to Drag Ratio (c_l/c_d)

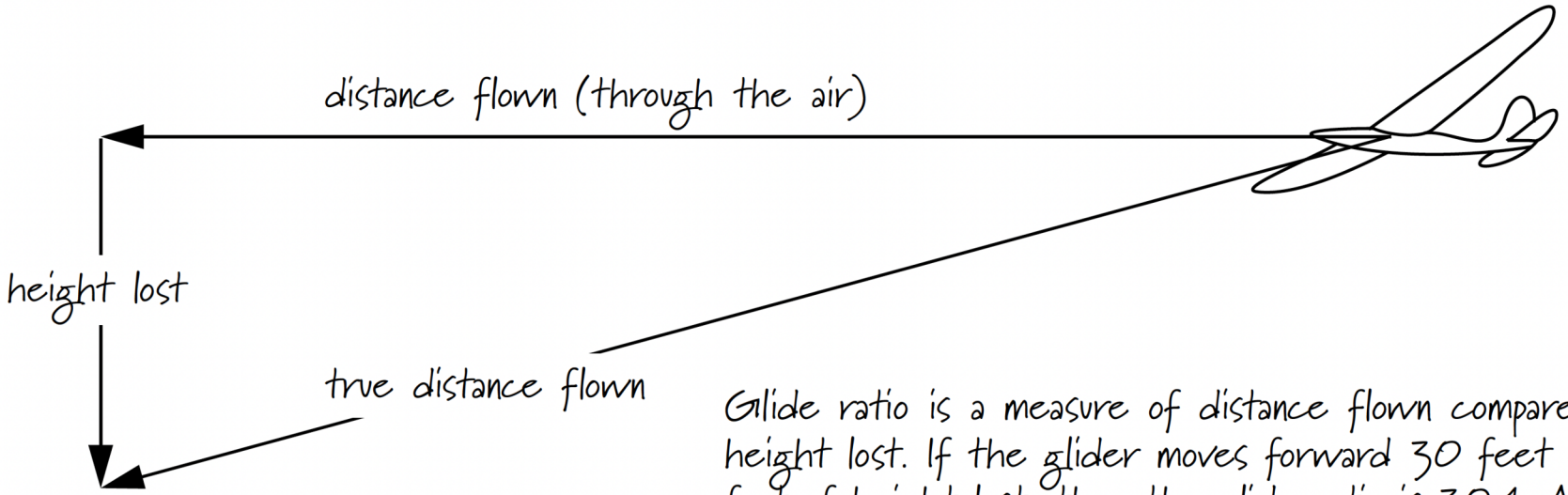
and Finding the Optimum Lift Coefficient ($c_{l,opt}$)

- Applying Section Characteristics

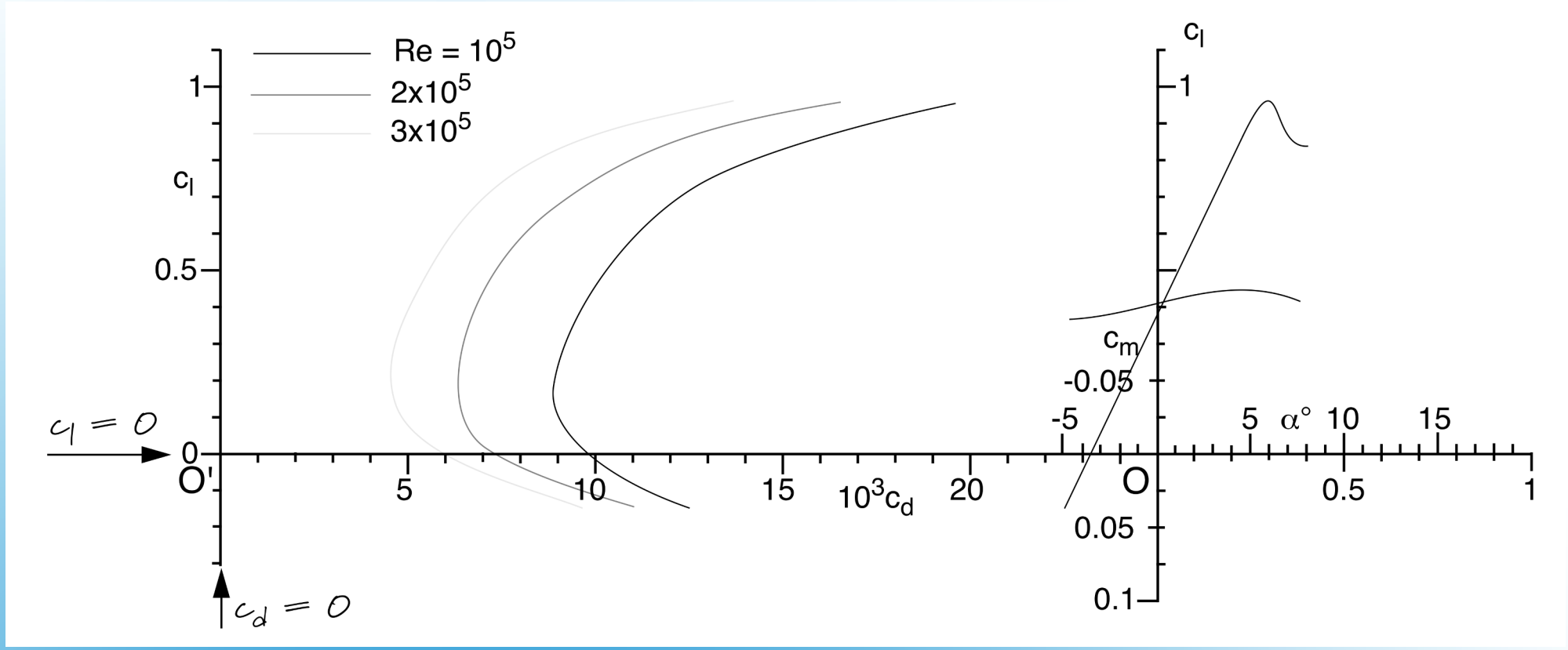
to a (planar) Wing

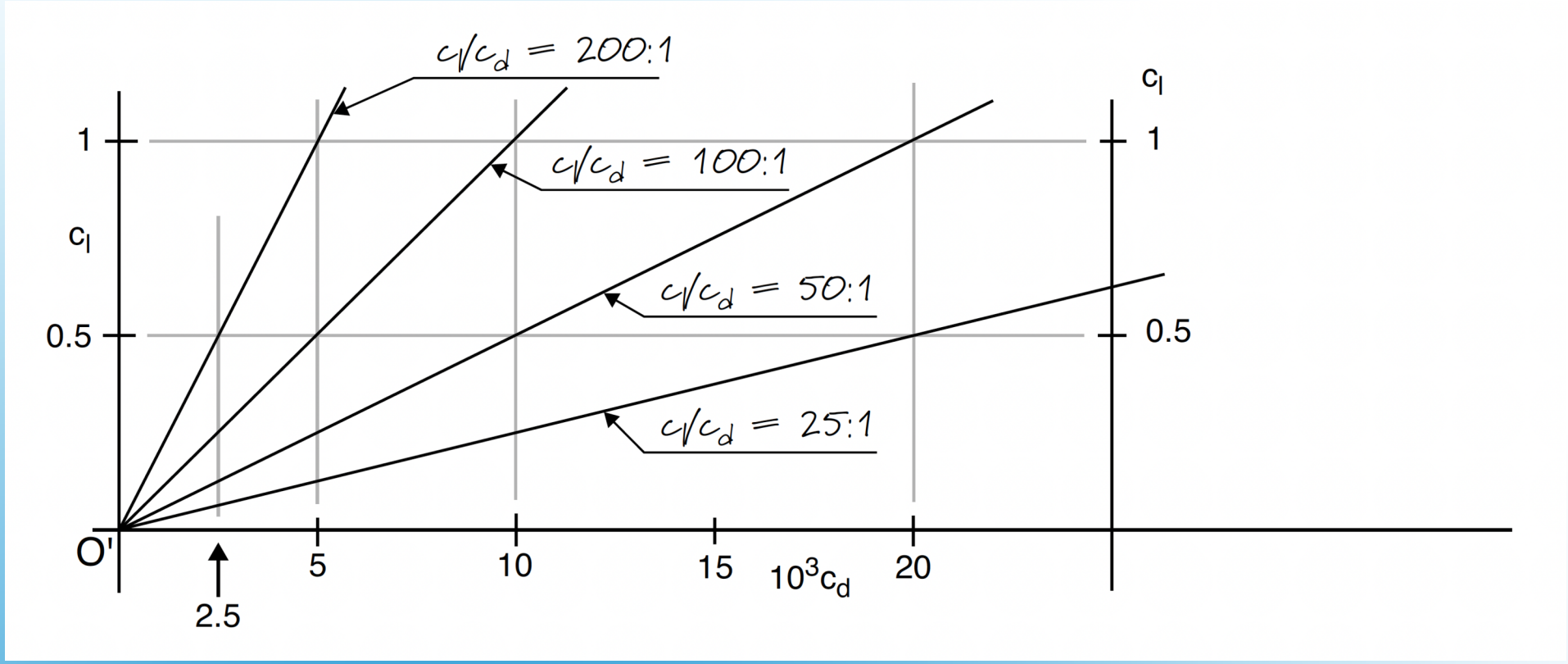
- Putting it All Together

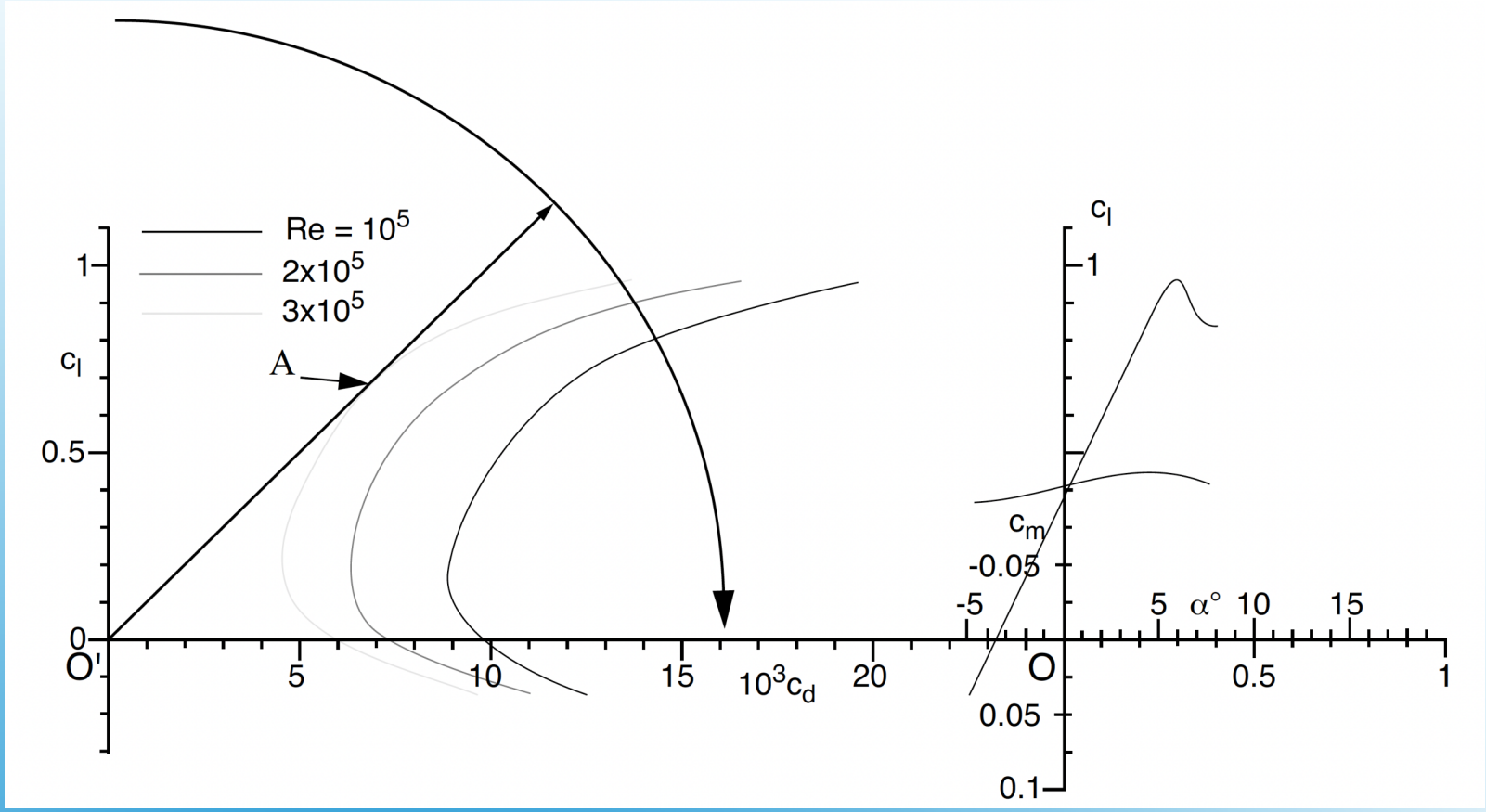
- Determining the Lift to Drag Ratio (c_l/c_d) and Finding the Optimum Lift Coefficient ($c_{l,opt}$)

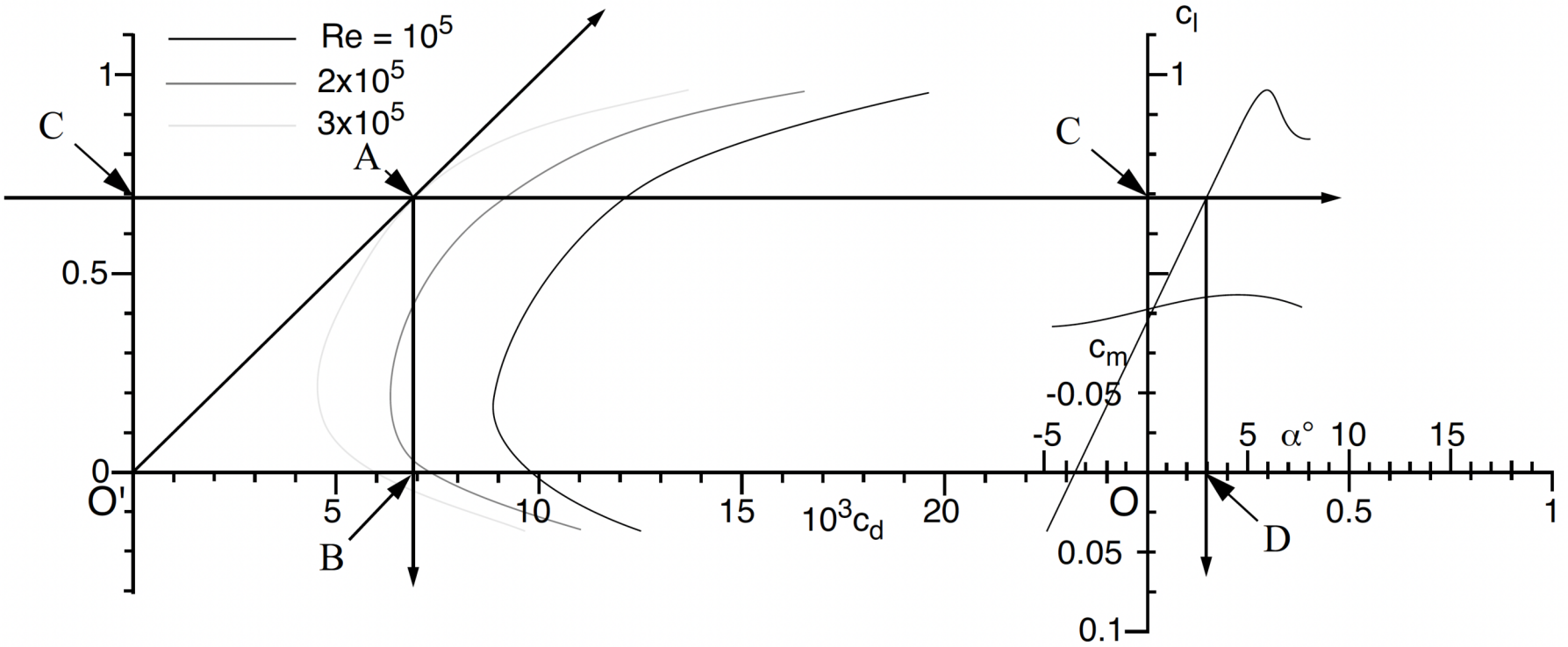


Glide ratio is a measure of distance flown compared to height lost. If the glider moves forward 30 feet for each foot of height lost, then the glide ratio is 30:1. A sailplane with a glide ratio of 25:1 would have a steeper glide. Height lost is normally made equivalent to 1; distance flown is based upon the same unit of measurement as height lost.


Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
O'
5
10
15
10^3c_d
20
c_l = 0
c_d = 0
c_l
1
c_m
-0.05
-5
5
α°
10
15
O
0.5
1
0.05
0.1

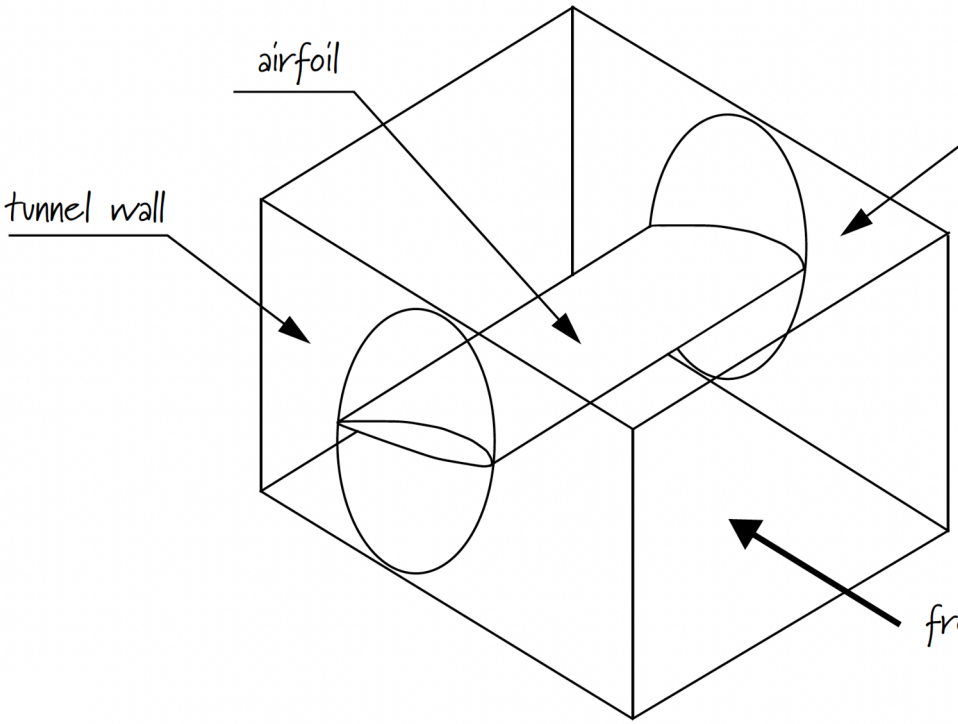

c_l/c_d = 200:1
c_l/c_d = 100:1
c_l/c_d = 50:1
c_l/c_d = 25:1
c_l
1
0.5
O'
2.5
5
10
15
20
$10^3 c_d$


Re = 10^5
2x10^5
3x10^5
A
c_l
1
0.5
0
O'
5
10
15
10^3c_d
20
c_l
1
c_m
-0.05
-5
5
α°
10
15
O
0.5
1
0.05
0.1


Re = 10^5
2x10^5
3x10^5
C
A
B
O'
1
0.5
0
5
10
15
10^3c_d
20
c_l
C
1
c_m
-0.05
-5
5
α°
10
15
O
0.5
1
D
0.05
0.1

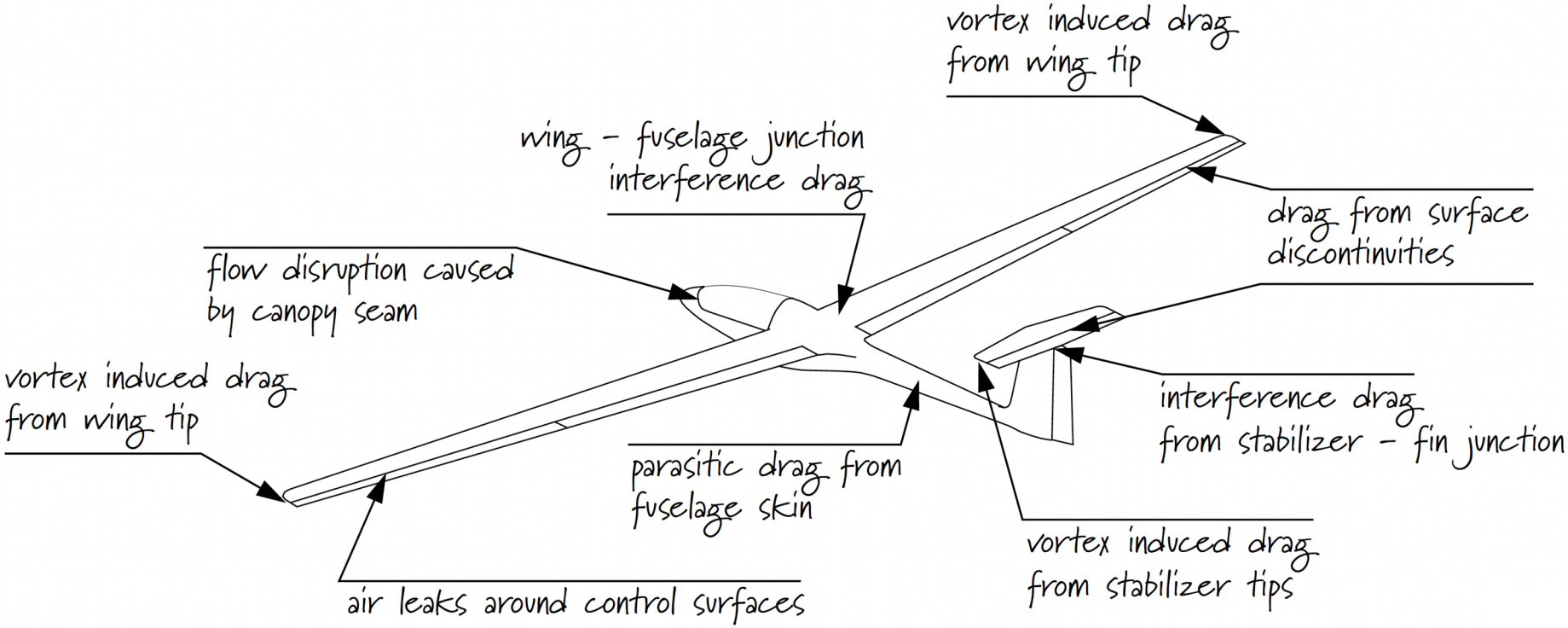
- Applying Section Characteristics to a (Planar) Wing

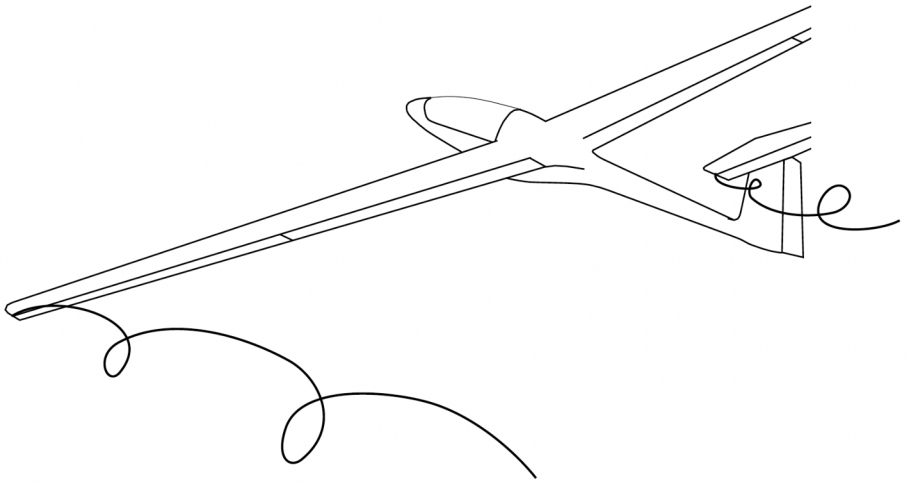
Non-planar wings include wings with end plates, winglets, or multi-element wing tips, C-wings, multi-wings (biplanes, triplanes, etc.), box-wings and joined wings. Turbine blades are also excluded as they operate within “cascade flow.”

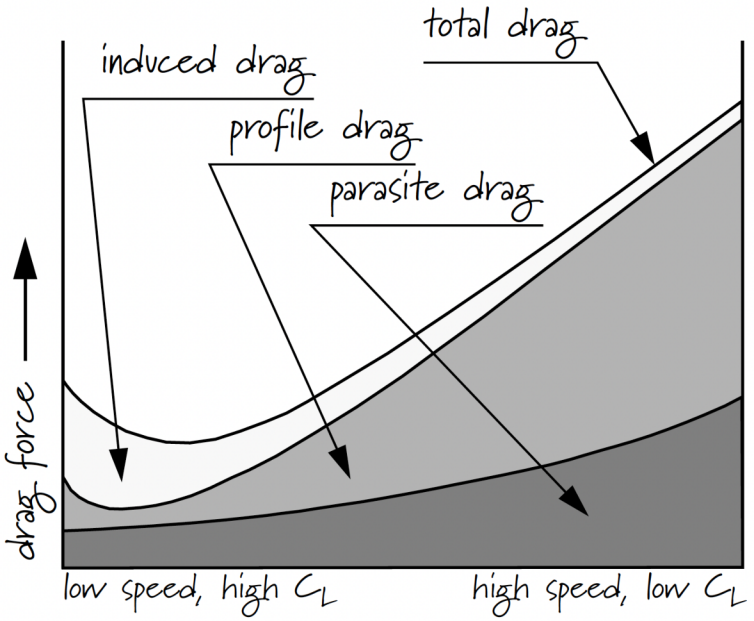


In a wind tunnel, the section being tested traverses the tunnel test section.

There are no wing tips to generate vortices.


vortex induced drag
from wing tip
wing - fuselage junction
interference drag
drag from surface
discontinuities
flow disruption caused
by canopy seam
vortex induced drag
from wing tip
interference drag
from stabilizer - fin junction
parasitic drag from
fuselage skin
vortex induced drag
from stabilizer tips
air leaks around control surfaces





At $L/D_{,max}$ induced drag = profile drag

Charts and Tables

Charts 1 - 6

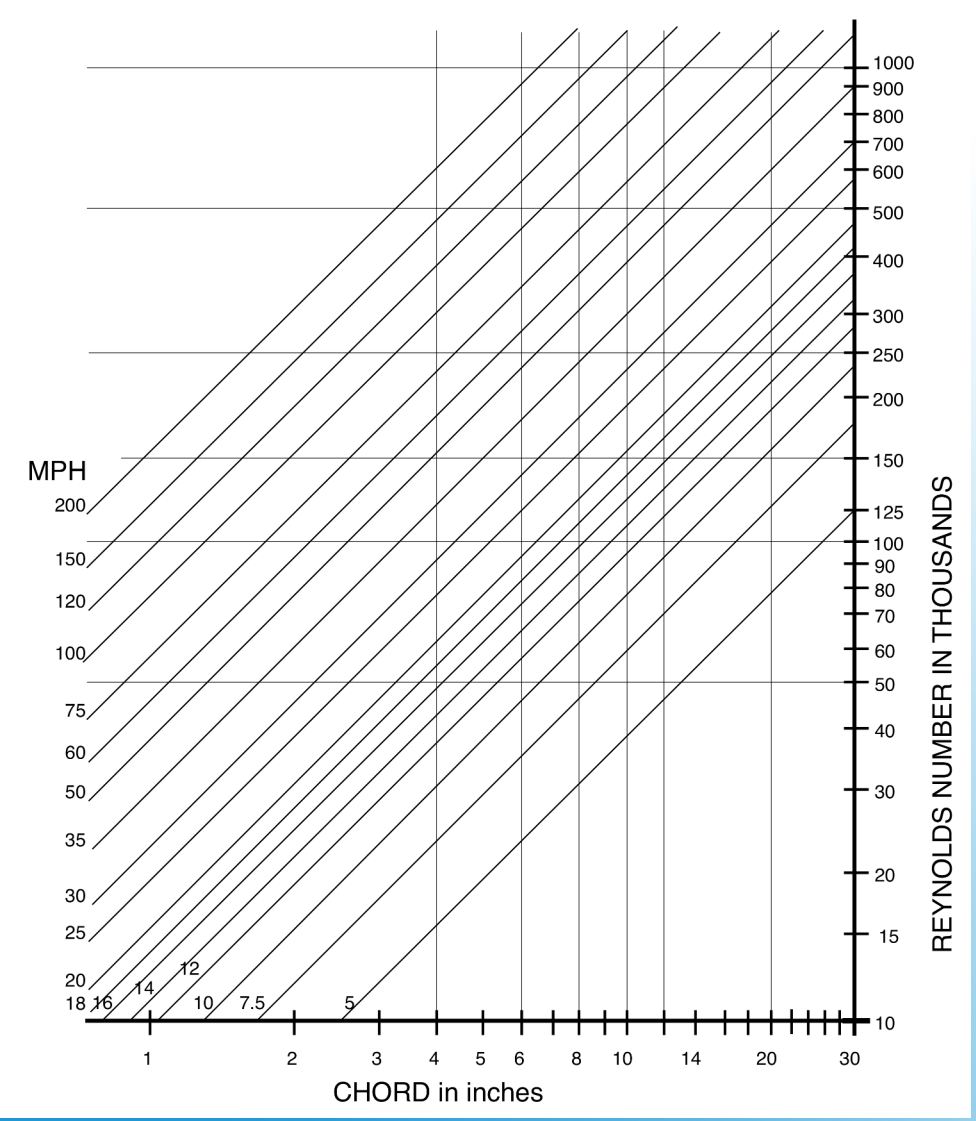
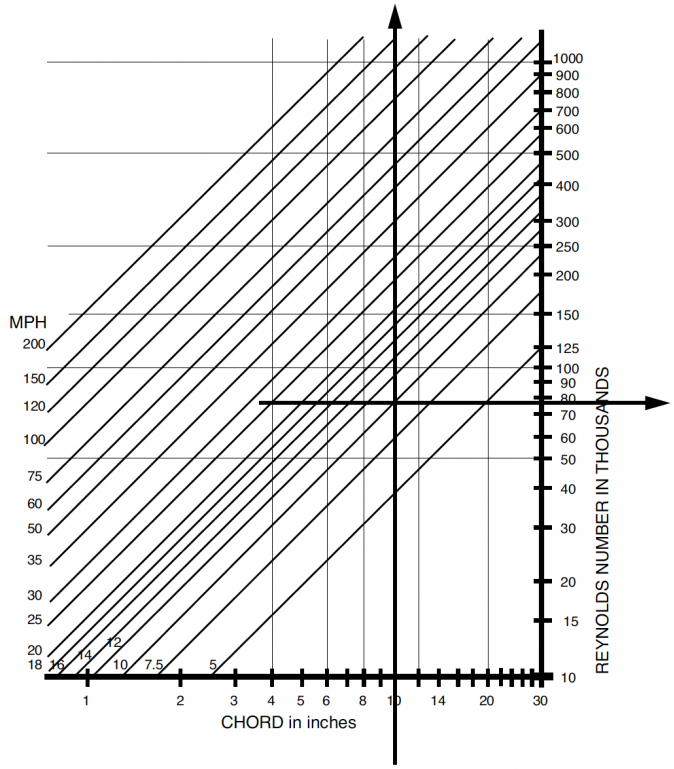
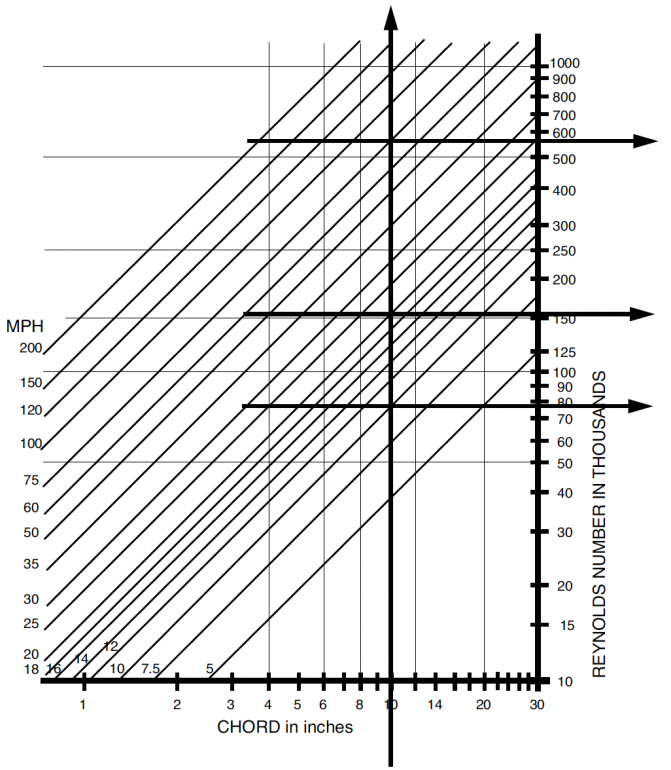


Chart 1 – Chord, V, and Re


MPH
200
150
120
100
75
60
50
35
30
25
20
18
16
14
12
10
7.5
5
1
2
3
4
5
6
8
10
14
20
30
CHORD in inches
1000
900
800
700
600
500
400
300
250
200
150
125
100
90
80
70
60
50
40
30
20
15
10
REYNOLDS NUMBER IN THOUSANDS


MPH
200
150
120
100
75
60
50
35
30
25
20
18
16
14
12
10
7.5
5
1
2
3
4
5
6
8
10
14
20
30
CHORD in inches
1000
900
800
700
600
500
400
300
250
200
150
125
100
90
80
70
60
50
40
30
20
15
10
REYNOLDS NUMBER IN THOUSANDS

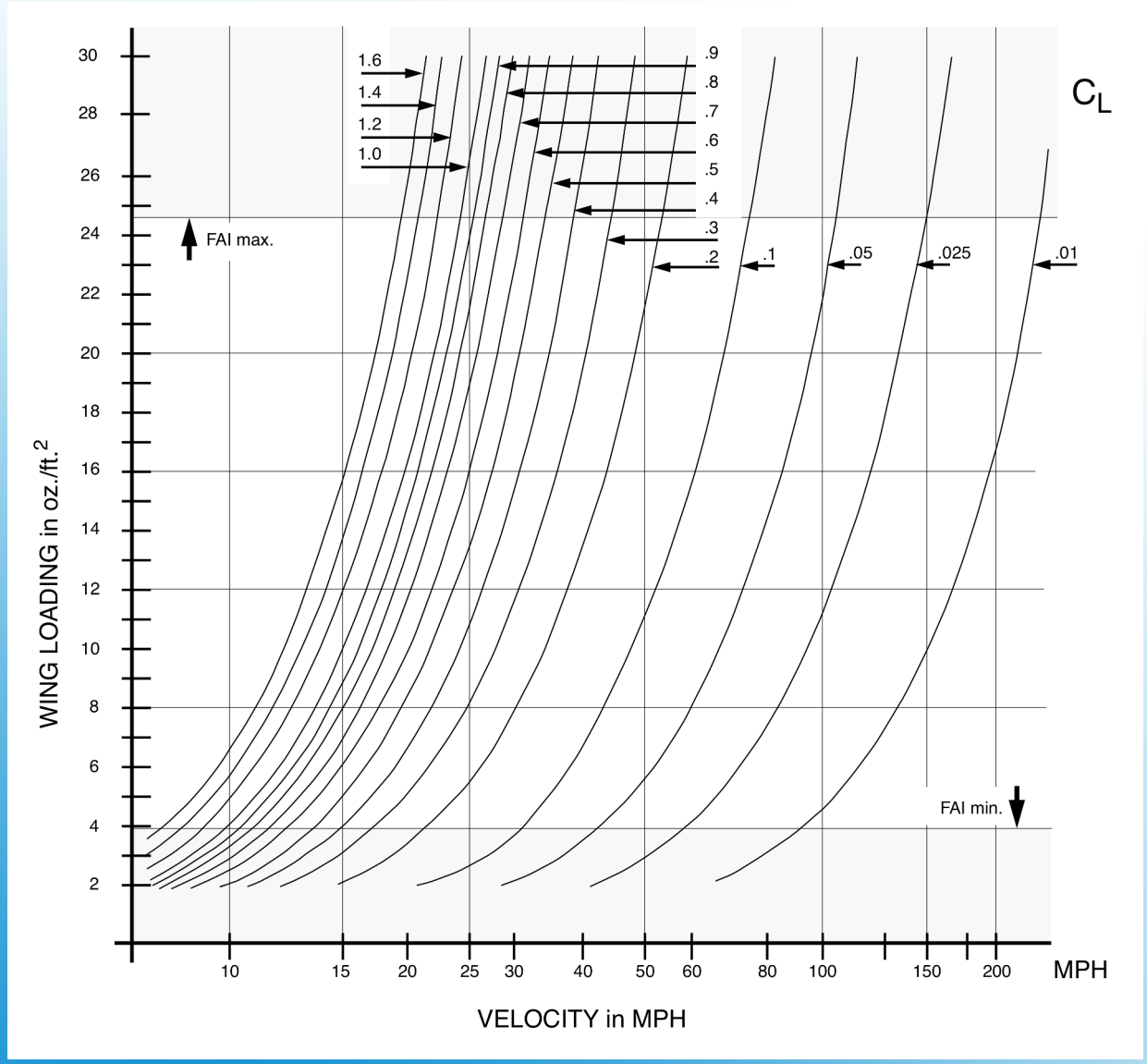
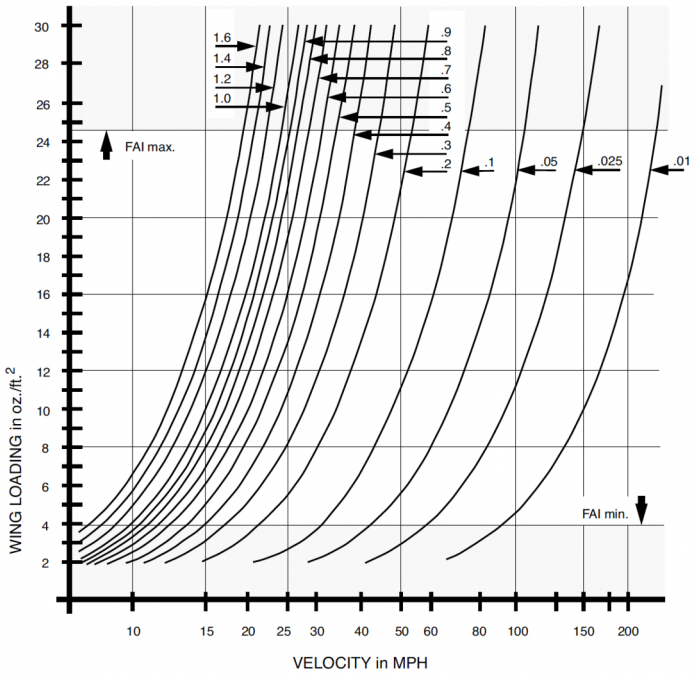
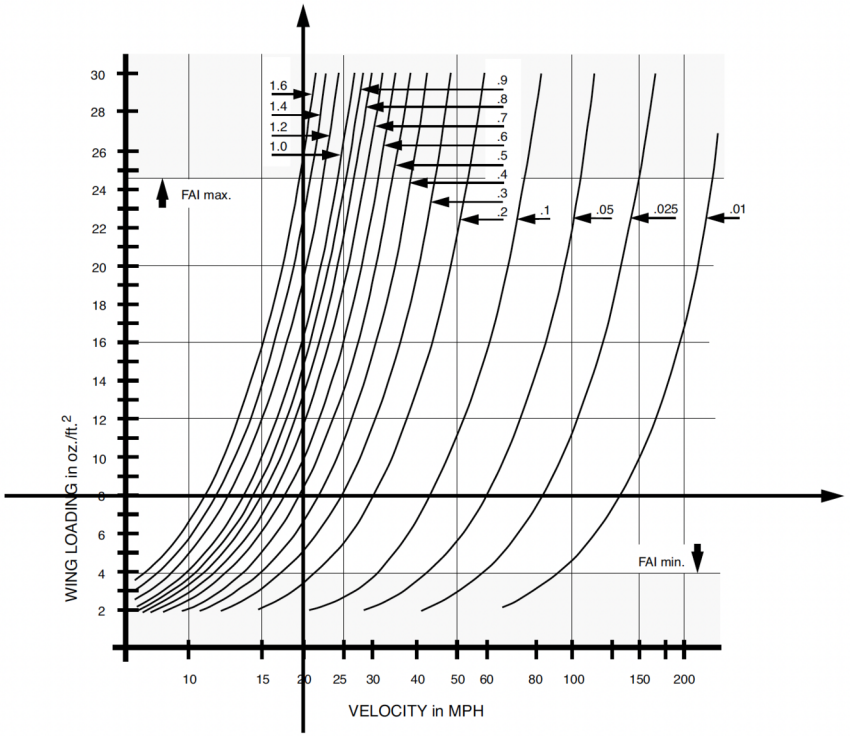


Chart 2 – Wing loading, V, and C_L


WING LOADING in oz./ft.2
VELOCITY in MPH
FAI max.
FAI min.
1.6
1.4
1.2
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.05
.025
.01
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
10
15
20
25
30
40
50
60
80
100
150
200


WING LOADING in oz./ft.2
VELOCITY in MPH
FAI max.
FAI min.
1.6
1.4
1.2
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.05
.025
.01
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
10
15
20
25
30
40
50
60
80
100
150
200

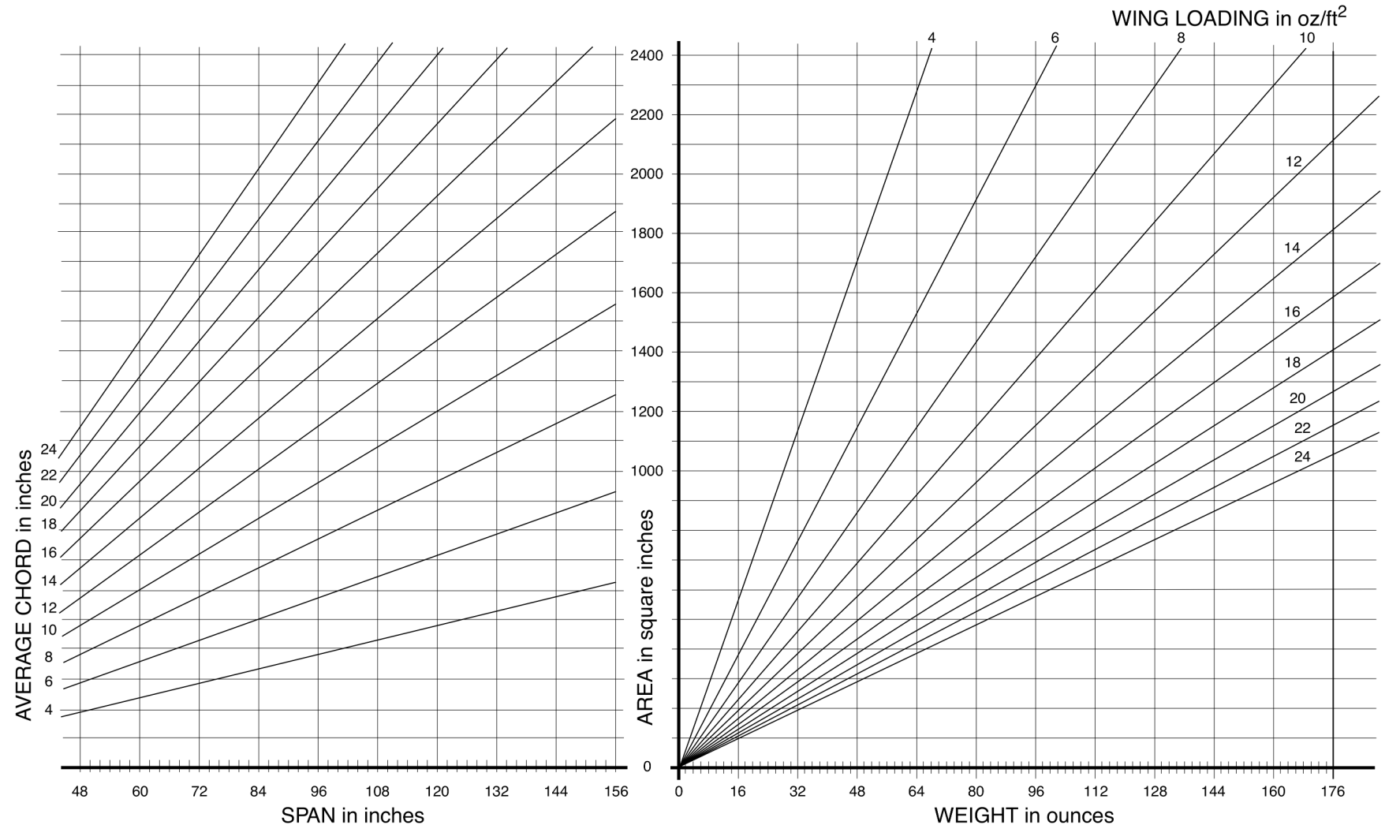


Chart 3 – Span, chord, and area
Area, weight, and wing loading

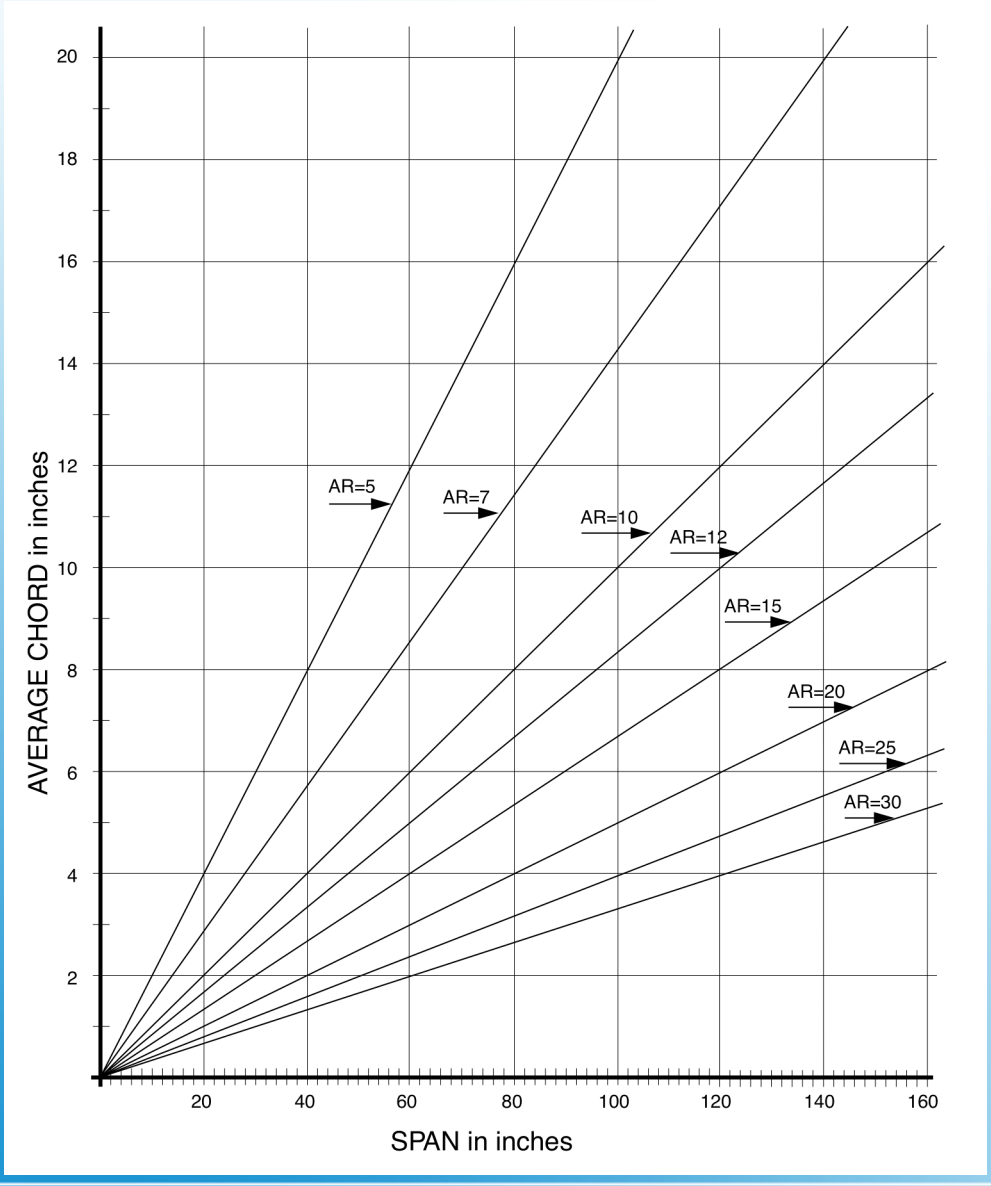


Chart 4 - Chord, span, and aspect ratio

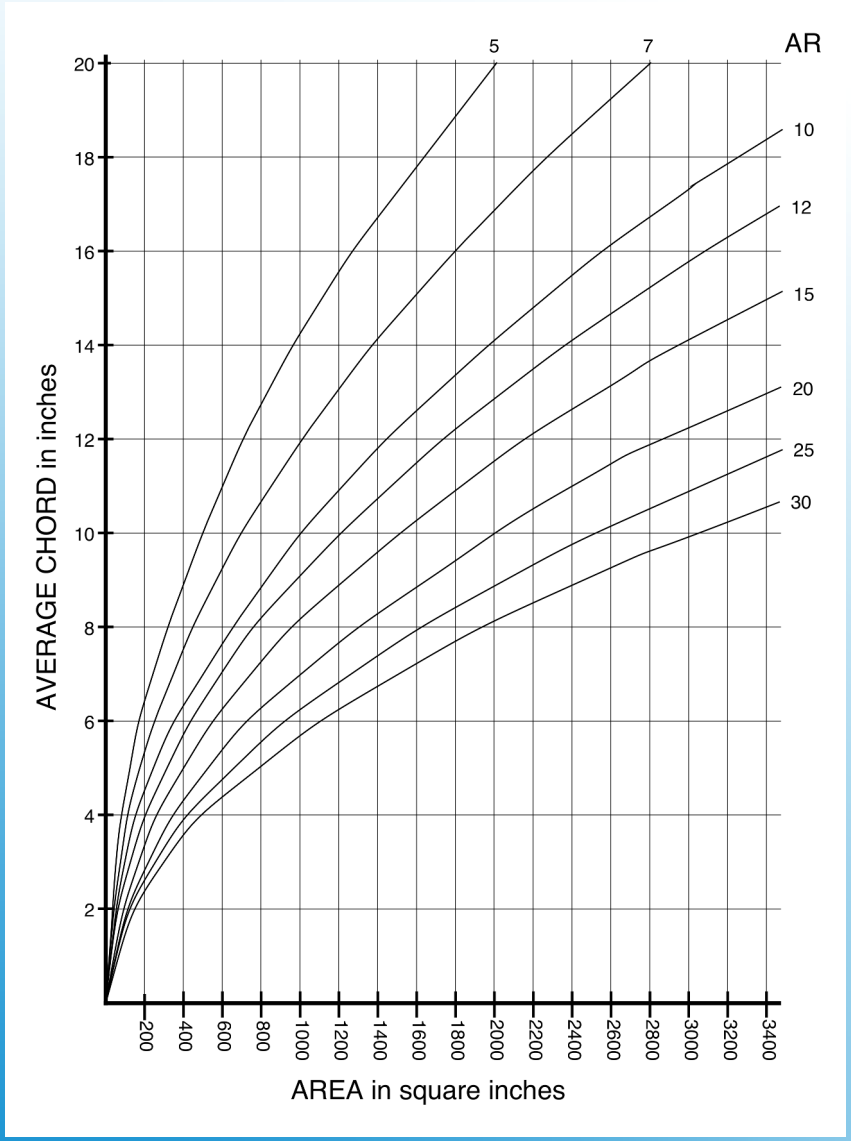


Chart 5 – Chord, area, and aspect ratio

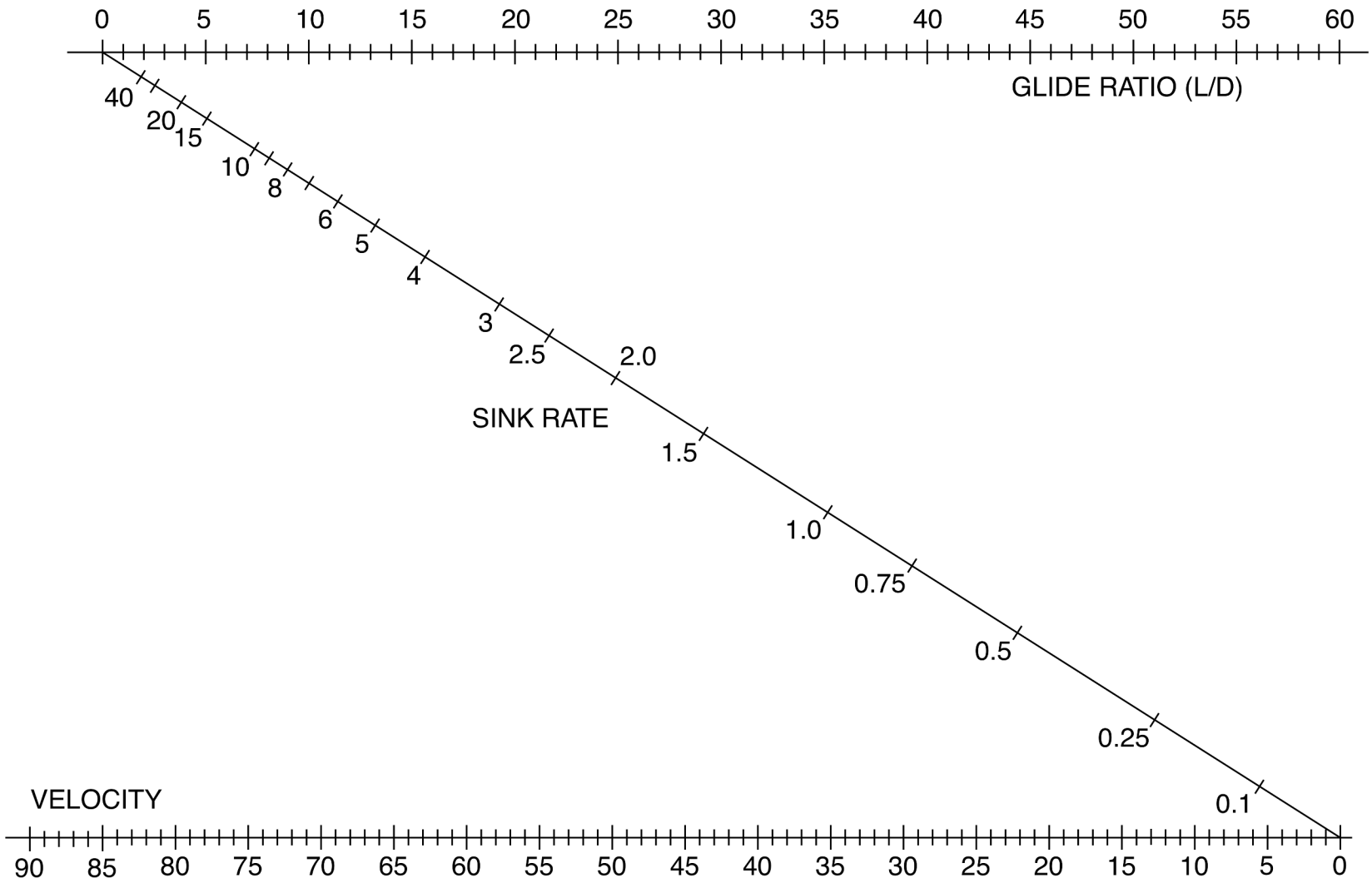


Chart 6 – Sink rate

Tables 1, 2, and 3.3

ASPECT RATIO	LIFT COEFFICIENT																	
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
5	.0006	.0025	.0057	.0102	.0159	.0229	.0312	.0407	.0516	.0637	.0770	.0917	.1076	.1248	.1432	.1630	.1840	.2063
7	.0005	.0018	.0041	.0073	.0114	.0164	.0223	.0291	.0368	.0455	.0550	.0655	.0768	.0891	.1023	.1164	.1314	.1473
10	.0003	.0013	.0029	.0051	.0080	.0115	.0156	.0204	.0258	.0318	.0385	.0458	.0538	.0624	.0716	.0815	.0920	.1031
12	.0003	.0011	.0024	.0042	.0066	.0095	.0130	.0170	.0215	.0265	.0321	.0382	.0448	.0520	.0597	.0679	.0767	.0859
15	.0002	.0008	.0019	.0034	.0053	.0076	.0104	.0136	.0172	.0212	.0257	.0306	.0359	.0416	.0477	.0543	.0613	.0688
20	.0002	.0006	.0014	.0025	.0040	.0057	.0078	.0102	.0129	.0159	.0193	.0229	.0269	.0312	.0358	.0407	.0460	.0516
25	.0001	.0005	.0011	.0020	.0032	.0046	.0062	.0081	.0103	.0127	.0154	.0183	.0215	.0250	.0286	.0326	.0368	.0413
30	.0001	.0004	.0010	.0017	.0027	.0038	.0052	.0068	.0086	.0106	.0128	.0153	.0179	.0208	.0239	.0272	.0307	.0344

INDUCED DRAG COEFFICIENT AS RELATED TO ASPECT RATIO AND LIFT COEFFICIENT

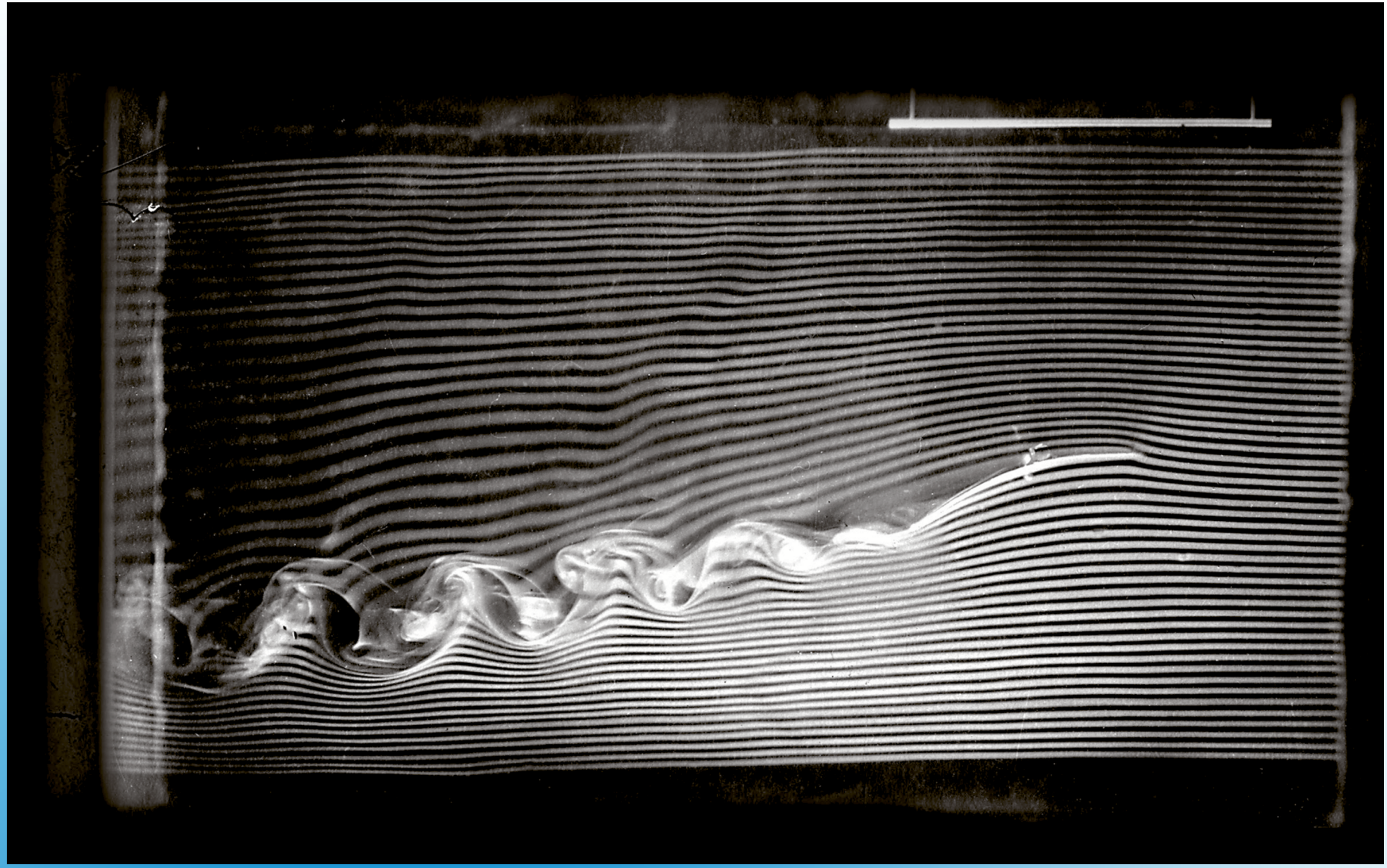
Table 1 – D_I vs. aspect ratio and C_L

LIFT COEFFICIENT

DRAG COEFFICIENT	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
0.001	100.0	200.0	300.0	400.0	500.0	600.0	700.0	800.0	900.0	1000	1100	1200	1300	1400	1500	1600	1700	1800
0.002	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0	550.0	600.0	650.0	700.0	750.0	800.0	850.0	900.0
0.003	33.3	66.7	100.0	133.3	166.7	200.0	233.3	266.7	300.0	333.3	366.7	400.0	433.3	466.7	500.0	533.3	566.7	600.0
0.004	25.0	50.0	75.0	100.0	125.0	150.0	175.0	200.0	225.0	250.0	275.0	300.0	325.0	350.0	375.0	400.0	425.0	450.0
0.005	20.0	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0	200.0	220.0	240.0	260.0	280.0	300.0	320.0	340.0	360.0
0.006	16.7	33.3	50.0	66.7	83.3	100.0	116.7	133.3	150.0	166.7	183.3	200.0	216.7	233.3	250.0	266.7	283.3	300.0
0.007	14.3	28.6	42.9	57.1	71.4	85.7	100.0	114.3	128.6	142.9	157.1	171.4	185.7	200.0	214.3	228.6	242.9	257.1
0.008	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100.0	112.5	125.0	137.5	150.0	162.5	175.0	187.5	200.0	212.5	225.0
0.009	11.1	22.2	33.3	44.4	55.6	66.7	77.8	88.9	100.0	111.1	122.2	133.3	144.4	155.6	166.7	177.8	188.9	200.0
0.010	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0	170.0	180.0
0.011	9.1	18.2	27.3	36.4	45.5	54.5	63.6	72.7	81.8	90.9	100.0	109.1	118.2	127.3	136.4	145.5	154.5	163.6
0.012	8.3	16.7	25.0	33.3	41.7	50.0	58.3	66.7	75.0	83.3	91.7	100.0	108.3	116.7	125.0	133.3	141.7	150.0
0.013	7.7	15.4	23.1	30.8	38.5	46.2	53.8	61.5	69.2	76.9	84.6	92.3	100.0	107.7	115.4	123.1	130.8	138.5
0.014	7.1	14.3	21.4	28.6	35.7	42.9	50.0	57.1	64.3	71.4	78.6	85.7	92.9	100.0	107.1	114.3	121.4	128.6
0.015	6.7	13.3	20.0	26.7	33.3	40.0	46.7	53.3	60.0	66.7	73.3	80.0	86.7	93.3	100.0	106.7	113.3	120.0
0.016	6.2	12.5	18.8	25.0	31.3	37.5	43.8	50.0	56.3	62.5	68.8	75.0	81.3	87.5	93.8	100.0	106.3	112.5
0.017	5.9	11.8	17.6	23.5	29.4	35.3	41.2	47.1	52.9	58.8	64.7	70.6	76.5	82.4	88.2	94.1	100.0	105.9
0.018	5.6	11.1	16.7	22.2	27.8	33.3	38.9	44.4	50.0	55.6	61.1	66.7	72.2	77.8	83.3	88.9	94.4	100.0
0.019	5.3	10.5	15.8	21.1	26.3	31.6	36.8	42.1	47.4	52.6	57.9	63.2	68.4	73.7	78.9	84.2	89.5	94.7
0.020	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0
0.021	4.8	9.5	14.3	19.0	23.8	28.6	33.3	38.1	42.9	47.6	52.4	57.1	61.9	66.7	71.4	76.2	81.0	85.7
0.022	4.5	9.1	13.6	18.2	22.7	27.3	31.8	36.4	40.9	45.5	50.0	54.5	59.1	63.6	68.2	72.7	77.3	81.8
0.023	4.4	8.7	13.0	17.4	21.7	26.1	30.4	34.8	39.1	43.5	47.8	52.2	56.5	60.9	65.2	69.6	73.9	78.3
0.024	4.2	8.3	12.5	16.7	20.8	25.0	29.2	33.3	37.5	41.7	45.8	50.0	54.2	58.3	62.5	66.7	70.8	75.0
0.025	4.0	8.0	12.0	16.0	19.2	24.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	56.0	60.0	64.0	68.0	72.0
0.026	3.8	7.7	11.5	15.4	18.5	23.1	26.9	30.8	34.6	38.5	42.3	46.2	50.0	53.8	57.7	61.5	65.4	69.2
0.027	3.7	7.4	11.1	14.8	18.5	22.2	25.9	29.6	33.3	37.0	40.7	44.4	48.1	51.8	55.5	59.3	63.0	66.7
0.028	3.6	7.1	10.7	14.3	17.2	21.4	25.0	28.6	32.1	35.7	39.3	42.9	46.4	50.0	53.6	57.1	60.7	64.3
0.029	3.5	6.9	10.3	13.8	16.7	20.7	24.1	27.6	31.0	34.5	37.9	41.4	44.8	48.3	51.7	55.2	58.6	62.1
0.030	3.3	6.7	10.0	13.3	16.1	20.0	23.3	26.7	30.0	33.3	36.7	40.0	43.3	46.7	50.0	53.3	56.7	60.0

LIFT TO DRAG RATIO

Table 2 – C_d, C_l, and C_l/C_d or C_D, C_L, and C_L/C_D

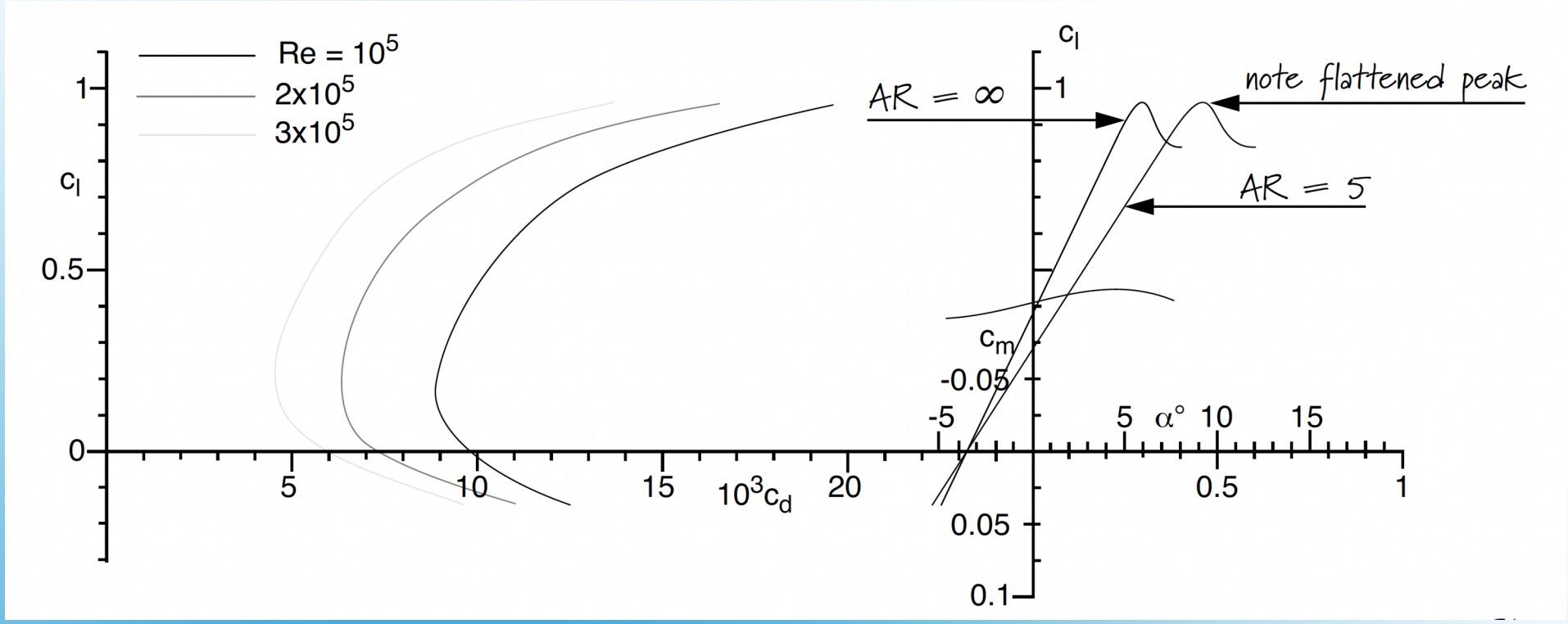


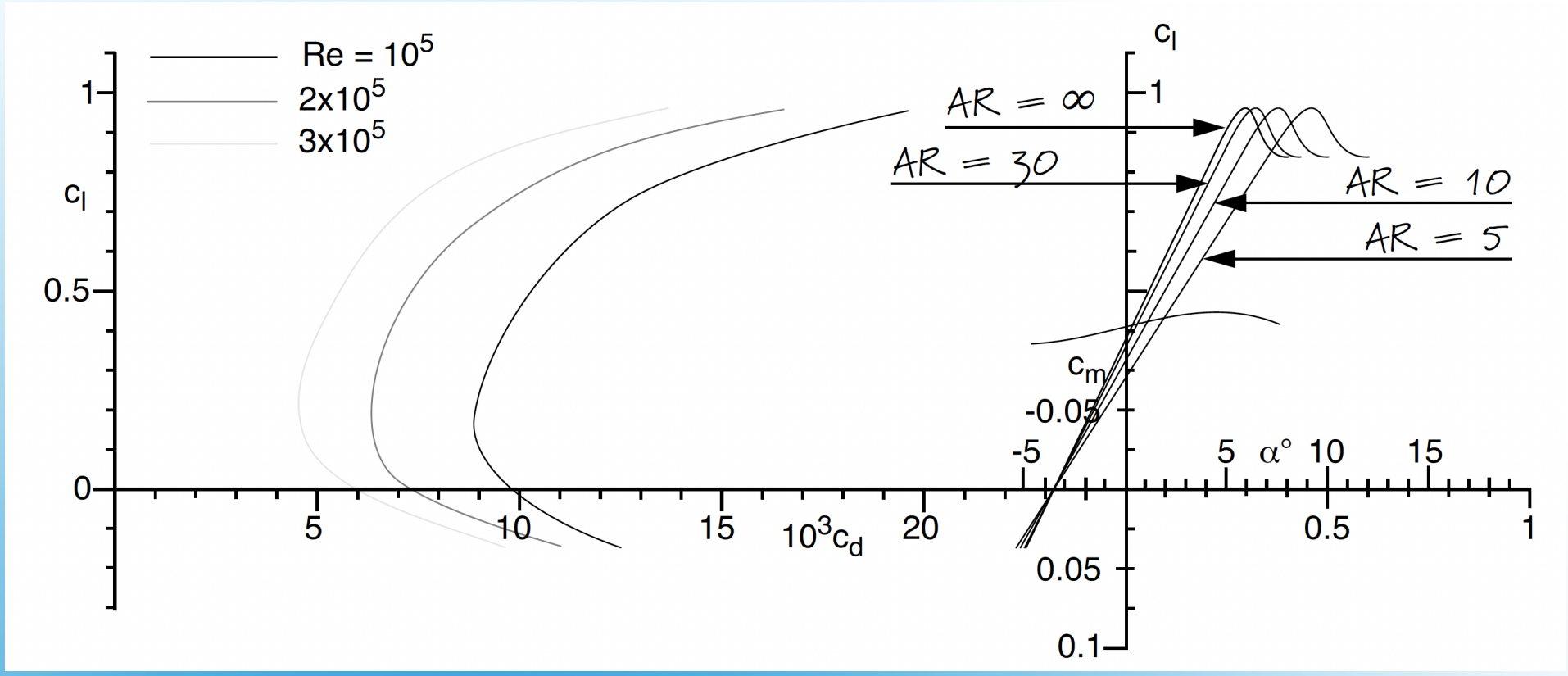
LIFT COEFFICIENT

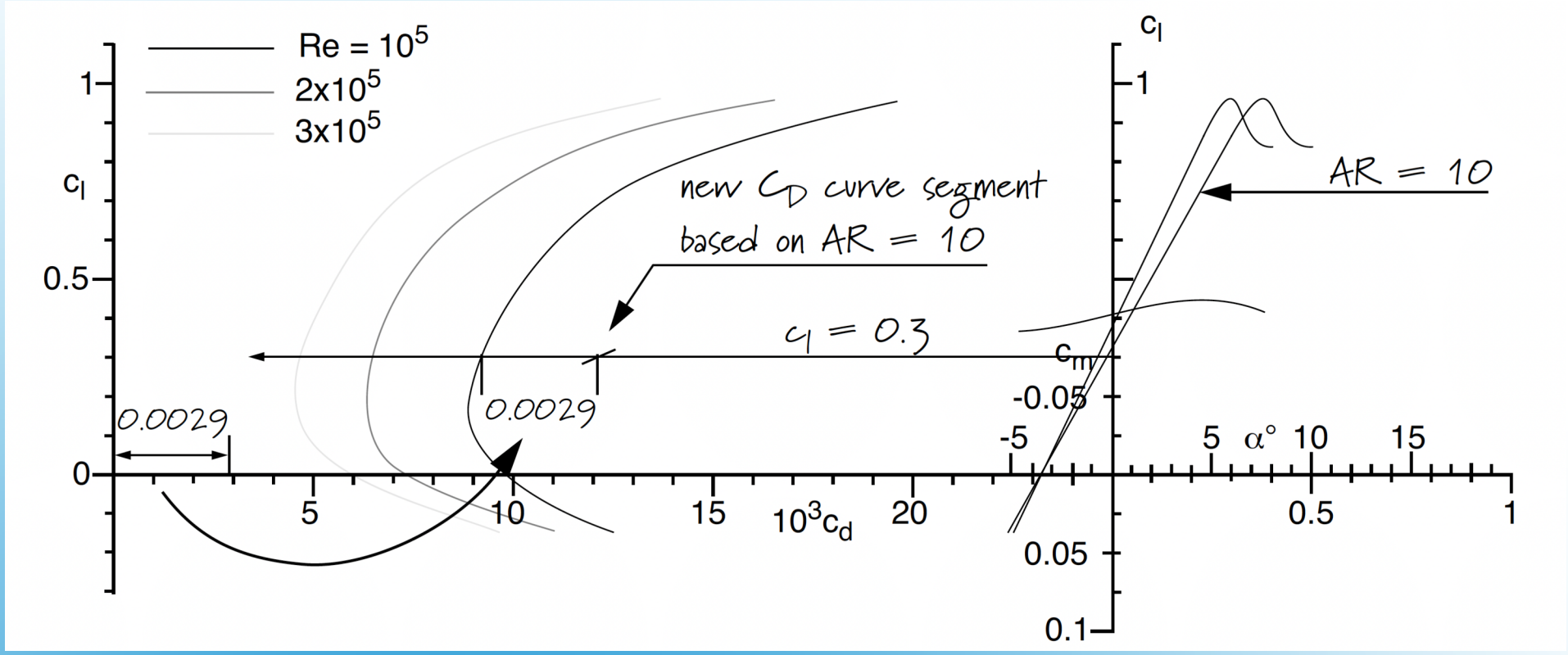
ANGLE OF ATTACK	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5
15	15.00	15.18	15.36	15.55	15.73	15.91	16.09	16.28	16.46	16.64	16.82	17.01	17.19	17.37	17.55	17.74
14.5	14.50	14.68	14.86	15.05	15.23	15.41	15 59	15.78	15.96	16.14	16.32	16.51	16.69	16.87	17.05	17 24
14	14.00	14.18	14.36	14.55	14.73	14.91	15 09	15.28	15.46	15.64	15.82	16.01	16.19	16.37	16.55	16 74
13.5	13.50	13.68	13.86	14.05	14.23	14.41	14 59	14.78	14.96	15.14	15.32	15.51	15.69	15.87	16.05	16 24
13	13.00	13.18	13.36	13.55	13.73	13.91	14 09	14.28	14.46	14.64	14.82	15.01	15.19	15.37	15.55	15 74
12.5	12.50	12.68	12.86	13.05	13.23	13.41	13 59	13.78	13.96	14.14	14.32	14.51	14.69	14.87	15.05	15.24
12	12.00	12.18	12.36	12.55	12.73	12.91	13 09	13.28	13.46	13.64	13.82	14.01	14.19	14.37	14.55	14.74
11.5	11.50	11.68	11.86	12.05	12.23	12.41	12 59	12.78	12.96	13.14	13.32	13.51	13.69	13.87	14.05	14.24
11	11.00	11.18	11.36	11.55	11.73	11.91	12.09	12.28	12.46	12.64	12.82	13.01	13.19	13.37	13.55	13.74
10.5	10.50	10.68	10.86	11.05	11.23	11.41	11.59	11.78	11.96	12.14	12.32	12.51	12.69	12.87	13.05	13.24
10	10.00	10.18	10.36	10.55	10.73	10.91	11.09	11.28	11.46	11.64	11.82	12.01	12.19	12.37	12.55	12.74
9.5	09.50	09.68	09.86	10.05	10.23	10.41	10.59	10.78	10.96	11.14	11.32	11.51	11.69	11.87	12.05	12 24
9	09.00	09.18	09.36	09.55	09.73	09.91	10.09	10.28	10.46	10.64	10.82	11.01	11.19	11.37	11.55	11.74
8.5	08.50	08.68	08.86	09.05	09.23	09.41	09.59	09.78	09.96	10.14	10.32	10.51	10.69	10.87	11.05	11 24
8	08.00	08.18	08.36	08.55	08.73	08.91	09.09	09.28	09.46	09.64	09.82	10.01	10.19	10.37	10.55	10.74
7.5	07.50	07.68	07.86	08.05	08.23	08.41	08.59	08.78	08.96	09.14	09.32	09.51	09.69	09.87	10.05	10.24
7	07.00	07.18	07.36	07.55	07.73	07.91	08.09	08.28	08.46	08.64	08.82	09.01	09.19	09.37	09.55	09.74
6.5	06.50	06.68	06.86	07.05	07.23	07.41	07.59	07.78	07.96	08.14	08.32	08.51	08.69	08.87	09.05	09.24
6	06.00	06.18	06.36	06.55	06.73	06.91	07.09	07.28	07.46	07.64	07.82	08.01	08.19	08.37	08.55	08.74
5.5	05.50	05.68	05.86	06.05	06.23	06.41	06.59	06.78	06.96	07.14	07.32	07.51	07.69	07.87	08.05	08.24
5	05.00	05.18	05.36	05.55	05.73	05.91	06.09	06.28	06.46	06.64	06.82	07.01	07.19	07.37	07.55	07.74
4.5	04.50	04.68	04.86	05.05	05.23	05.41	05.59	05.78	05.96	06.14	06.32	06.51	06.69	06.87	07.05	07.24
4	04.00	04.18	04.36	04.55	04.73	04.91	05.09	05.28	05.46	05.64	05.82	06.01	06.19	06 37	06.55	06.74
3.5	03.50	03.68	03.86	04.05	04.23	04.41	04.59	04.78	04.96	05.14	05.32	05.51	05.69	05 87	06.05	06.24
3	03.00	03.18	03.36	03.55	03.73	03.91	04.09	04.28	04.46	04.64	04.82	05.01	05.19	05 37	05.55	05.74
2.5	02.50	02.68	02.86	03.05	03.23	03.41	03.59	03.78	03.96	04.14	04.32	04.51	04.69	04 87	05.05	05.24
2	02.00	02.18	02.36	02.55	02.73	02.91	03.09	03.28	03.46	03.64	03.82	04.01	04.19	04 37	04.55	04.74
1.5	01.50	01.68	01.86	02.05	02.23	02.41	02.59	02.78	02.96	03.14	03.32	03.51	03.69	03 87	04.05	04.24
1	01.00	01.18	01.36	01.55	01.73	01.91	02.09	02.28	02.46	02.64	02.82	03.01	03.19	03 37	03.55	03.74
0.5	00.50	00.68	00.86	01.05	01.23	01.41	01.59	01.78	01.96	02.14	02.32	02.51	02.69	02.87	03.05	03.24
0	00.00	00.18	00.36	00.55	00.73	00.91	01.09	01.28	01.46	01.64	01.82	02.01	02.19	02.37	02.55	02.74
-0.5	-0.50	-0.32	-0.14	00.05	00.23	00.41	00.59	00.78	00.96	01.14	01.32	01.51	01.69	01.87	02.05	02.24
-1	-1.00	-0.82	-0.64	-0.45	-0.27	-0.09	00.09	00.28	00.46	00.64	00.82	01.01	01.19	01.37	01.55	01.74
-1.5	-1.50	-1.32	-1.14	-0.95	-0.77	-0.59	-0.41	-0.22	-0.04	00.14	00.32	00.51	00.69	00.87	01.05	01.24
-2	-2.00	-1.82	-1.64	-1.45	-1.27	-1.09	-0.91	-0.72	-0.54	-0.36	-0.18	00.01	00.19	00.37	00.55	00.74
-2.5	-2.50	-2.32	-2.14	-1.95	-1.77	-1.59	-1.41	-1.22	-1.04	-0.86	-0.68	-0.49	-0.31	-0.13	00.05	00.24
-3	-3.00	-2.82	-2.64	-2.45	-2.27	-2.09	-1.91	-1.72	-1.54	-1.36	-1.18	-0.99	-0.81	-0.63	-0.45	-0.26
-3.5	-3.50	-3.32	-3.14	-2.95	-2.77	-2.59	-2.41	-2.22	-2.04	-1.86	-1.68	-1.49	-1.31	-1.13	-0.95	-0.76
-4	-4.00	-3.82	-3.64	-3.45	-3.27	-3.09	-2.91	-2.72	-2.54	-2.36	-2.18	-1.99	-1.81	-1.63	-1.45	-1.26
-4.5	-4.50	-4.32	-4.14	-3.95	-3.77	-3.59	-3.41	-3.22	-3.04	-2.86	-2.68	-2.49	-2.31	-2.13	-1.95	-1.76
-5	-5.00	-4.82	-4.64	-4.45	-4.27	-4.09	-3.91	-3.72	-3.54	-3.36	-3.18	-2.99	-2.81	-2.63	-2.45	-2.26

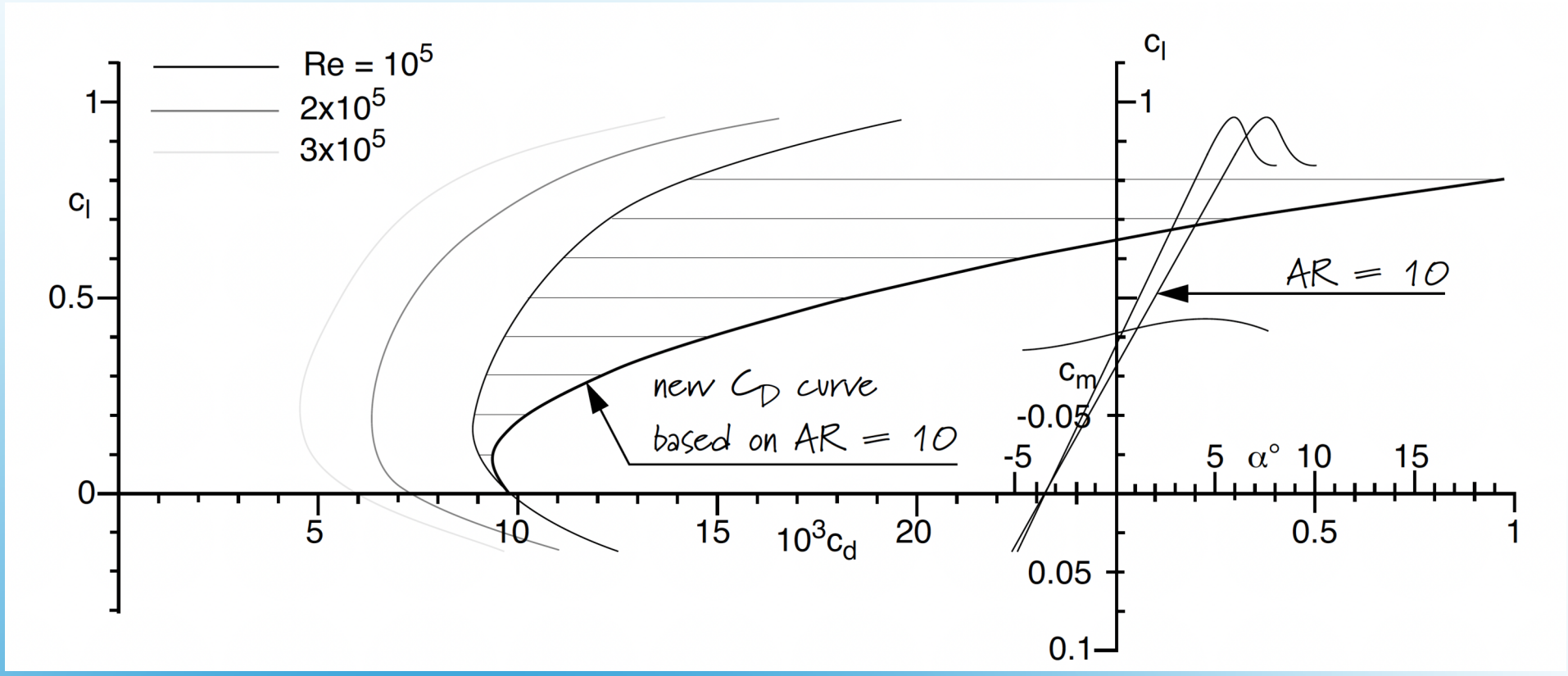
EQUIVALENT ANGLE OF ATTACK; ASPECT RATIO = 10

Table 3.3 – AoA, C_L, and AoA_{equiv} at AR=10


Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
5
10
15
10^3c_d
20
c_l
AR = ∞
1
note flattened peak
AR = 5
c_m
-0.05
-5
5
α°
10
15
0.5
1
0.05
0.1


Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
5
10
15
10^3c_d
20
AR = ∞
AR = 30
AR = 10
AR = 5
c_l
1
c_m
-0.05
-5
5
α°
10
15
0.5
1
0.05
0.1


Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
0.0029
0.0029
5
10
15
10^3c_d
20
new C_D curve segment
based on AR = 10
c_l = 0.3
c_l
1
AR = 10
c_m
-0.05
-5
5
α°
10
15
0.5
1
0.05
0.1


Re = 10^5
2x10^5
3x10^5
c_l
1
0.5
0
5
10
15
10^3c_d
20
new C_D curve
based on AR = 10
c_l
1
AR = 10
c_m
-0.05
0.05
0.1
-5
5
α°
10
15
0.5
1

Putting It All Together

- Exercise 1
- Exercise 2
- Exercise 3
- Exercise 4

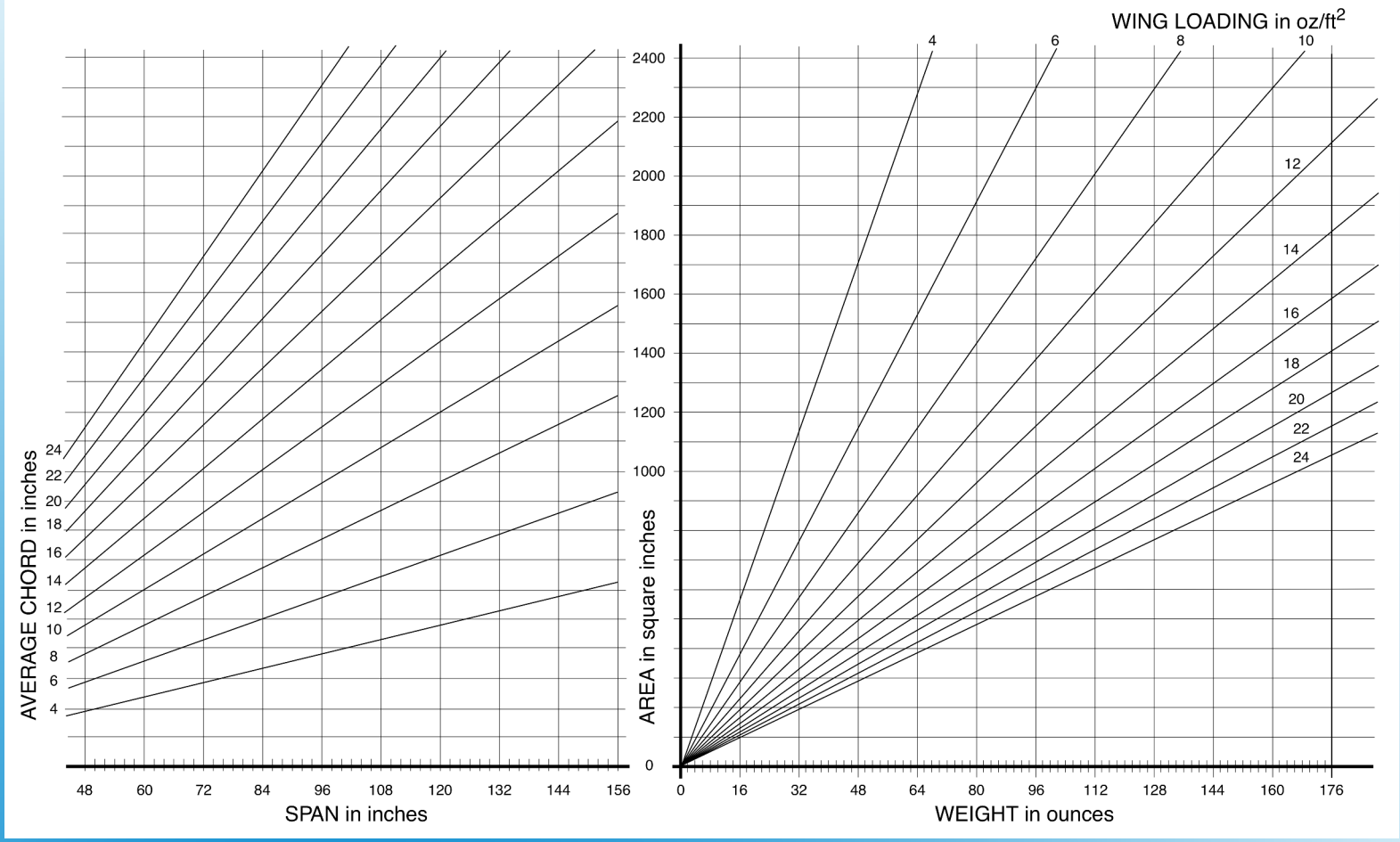
- **Exercise 1**

Find the stalling speed of a sailplane

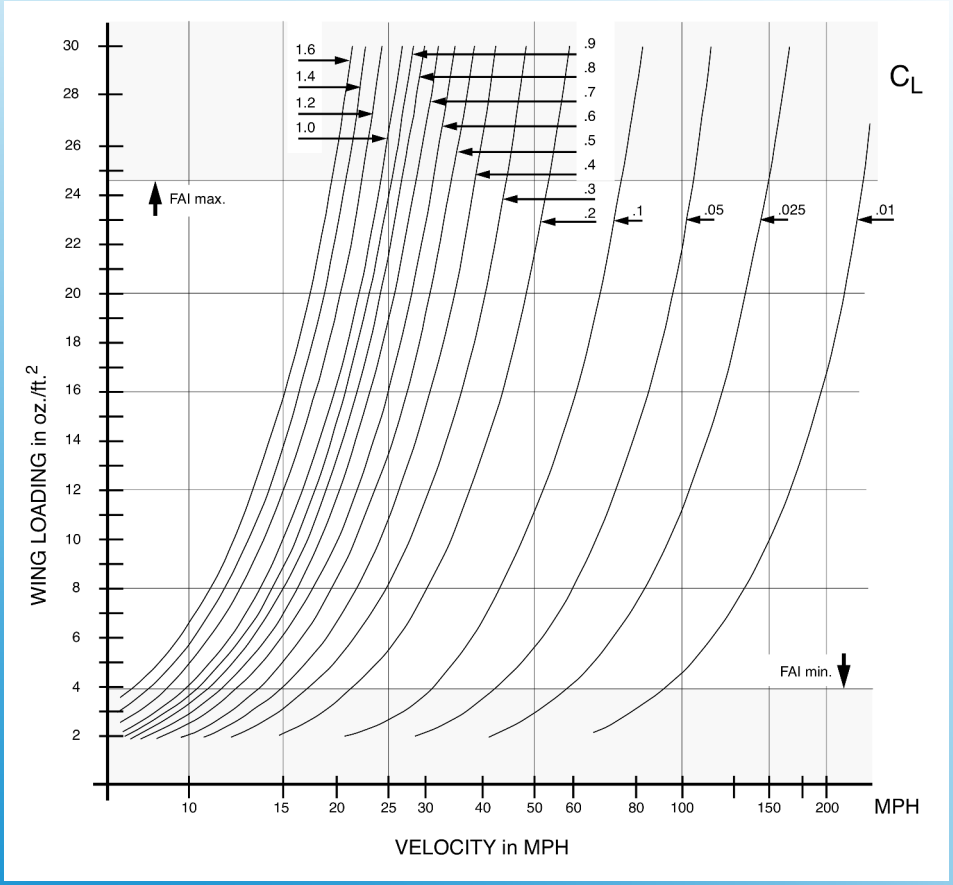
and the angle of attack and Reynolds number at which it occurs.

Then find the c_d and actual angle of attack of the sailplane wing section at a C_L of 0.5.

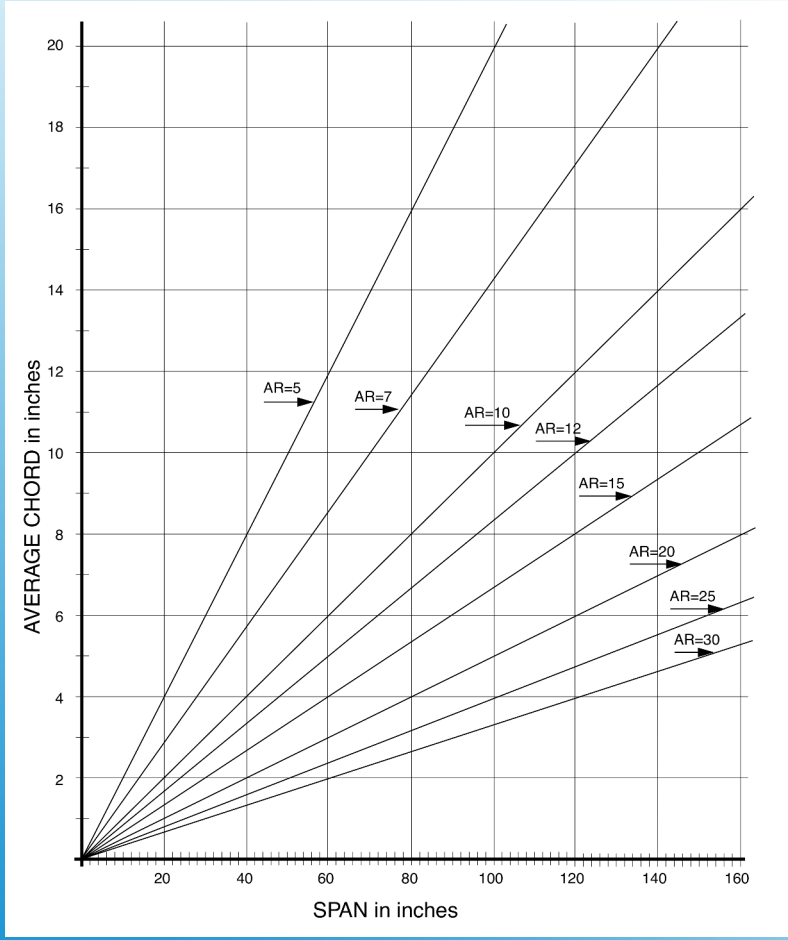
- Note the sailplane wing loading (using Chart 3 if necessary)



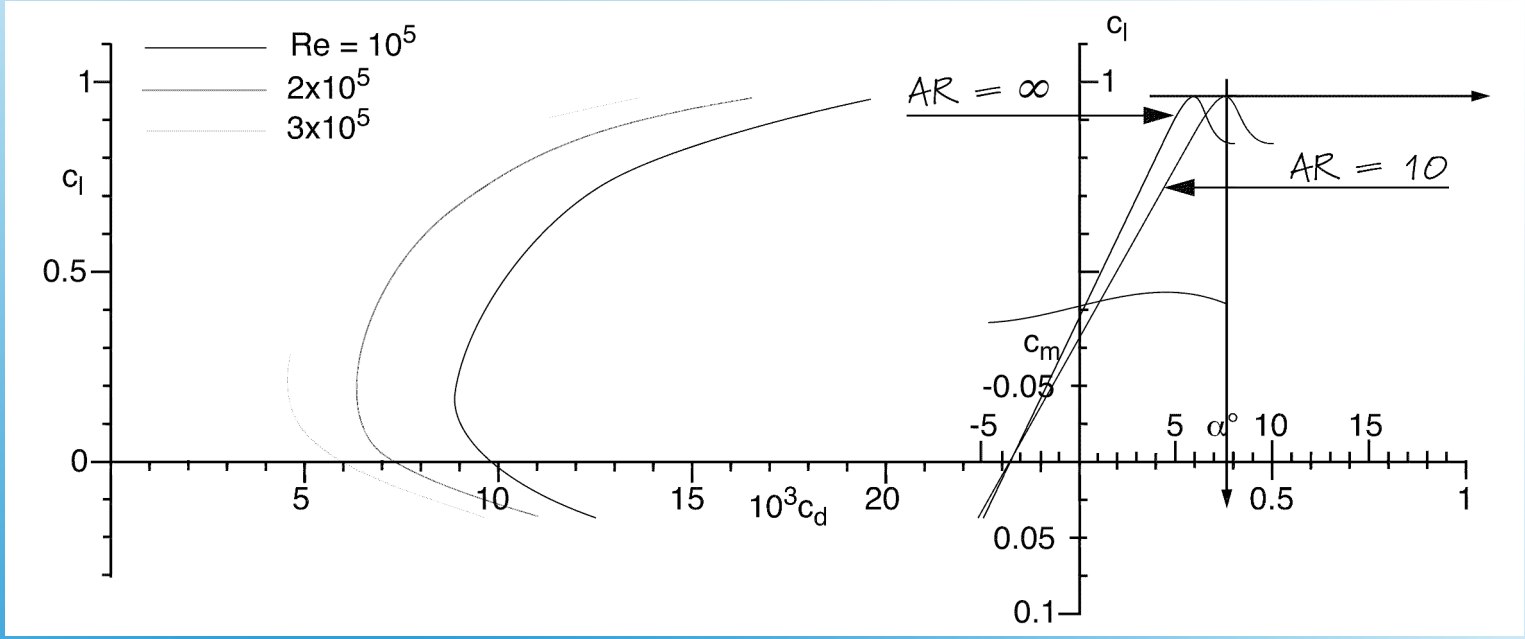
- Find the wing loading value on Chart 2 and draw a horizontal line across the chart



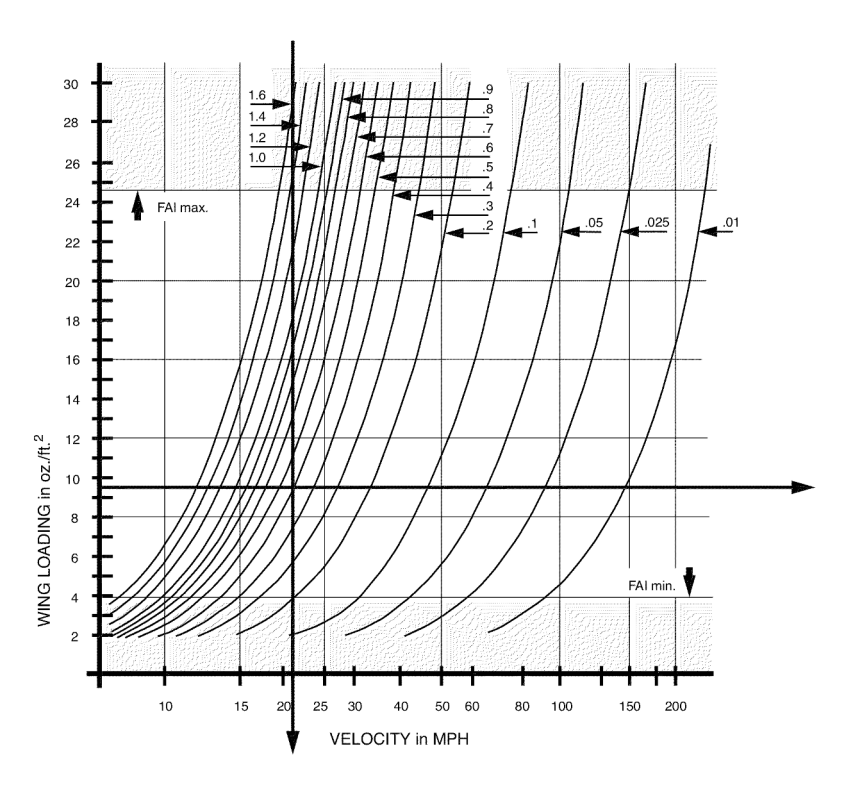
- Determine wing spect ratio (using Chart 4 if necessary)



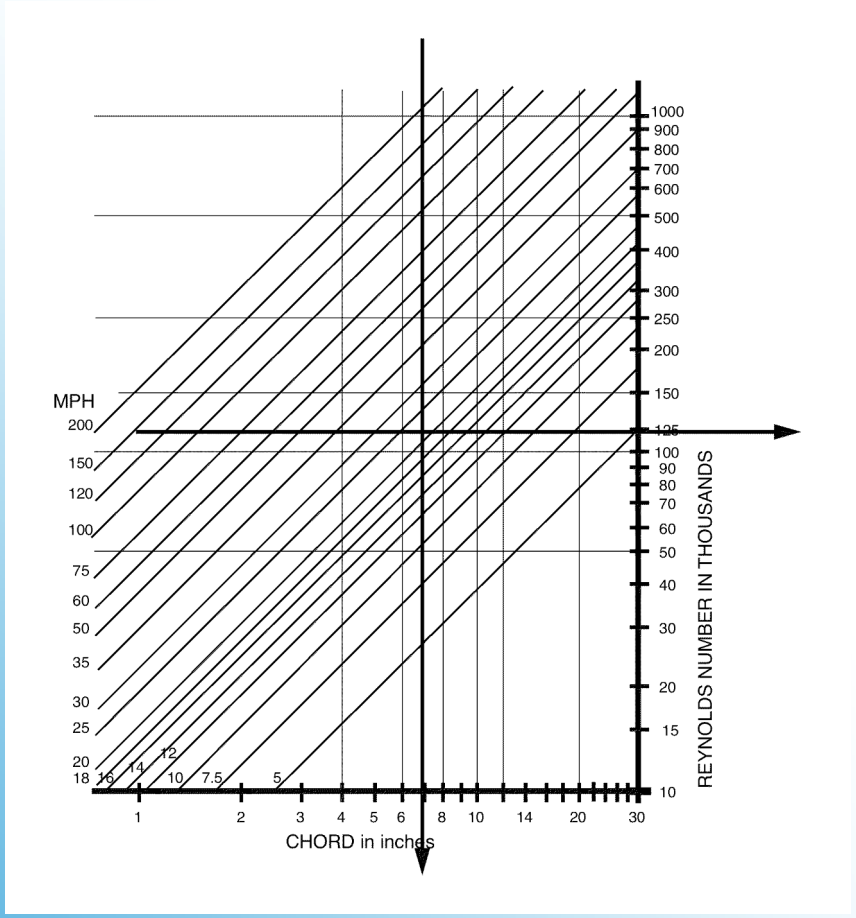
- Using the appropriate Table (aspect ratio 10) to find the new C_L curve.
- Find the angle of attack for $C_{L,max}$



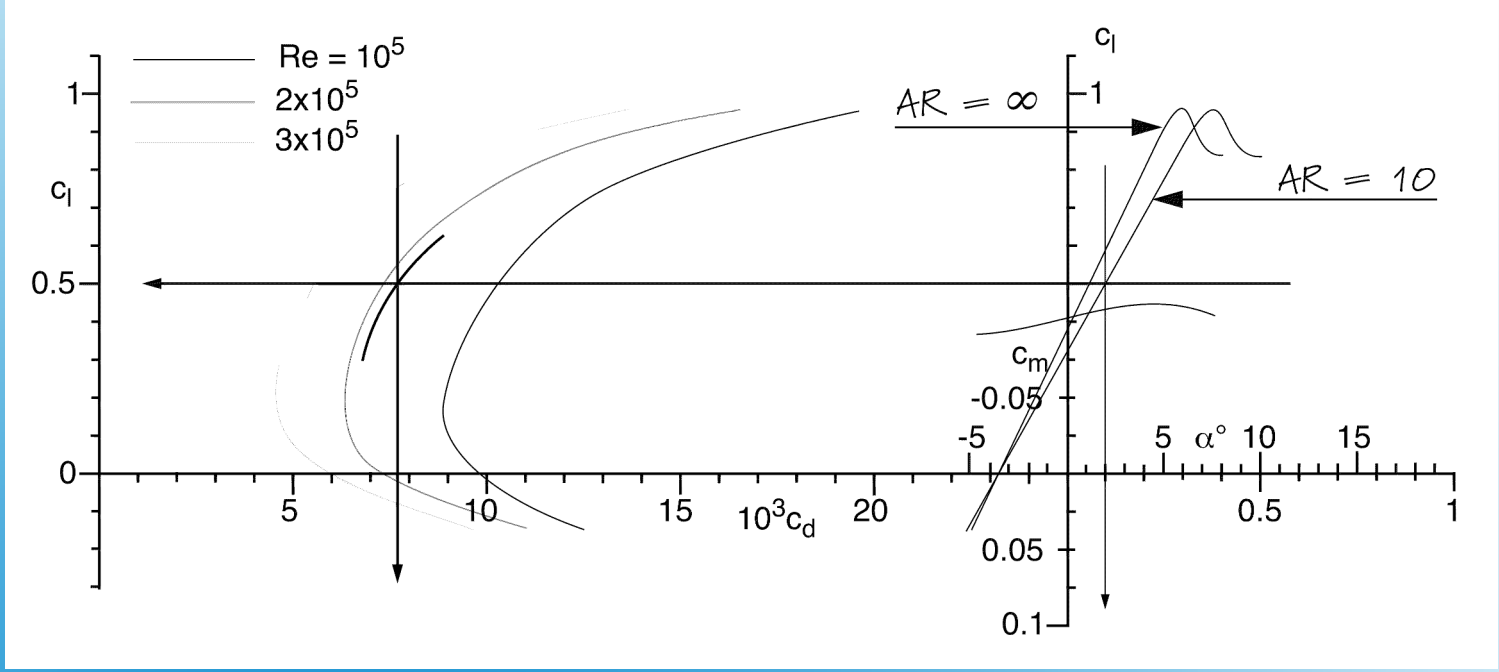
- Find the curve on Chart 2 that matches the wing section $C_{L,max}$
- Find the Velocity by dropping a vertical line



- Using Chart 1, draw a vertical line through the (average) chord axis note where it intersects stall speed.
- Draw a horizontal line through the intersection to determine Re at stall.



- Draw a horizontal line through c_l=0.5
- As previously for stall, find Re at C_L=0.5 (may have to interpolate). Does not account for D_l.
- Now find angle of attack at C_L=0.5



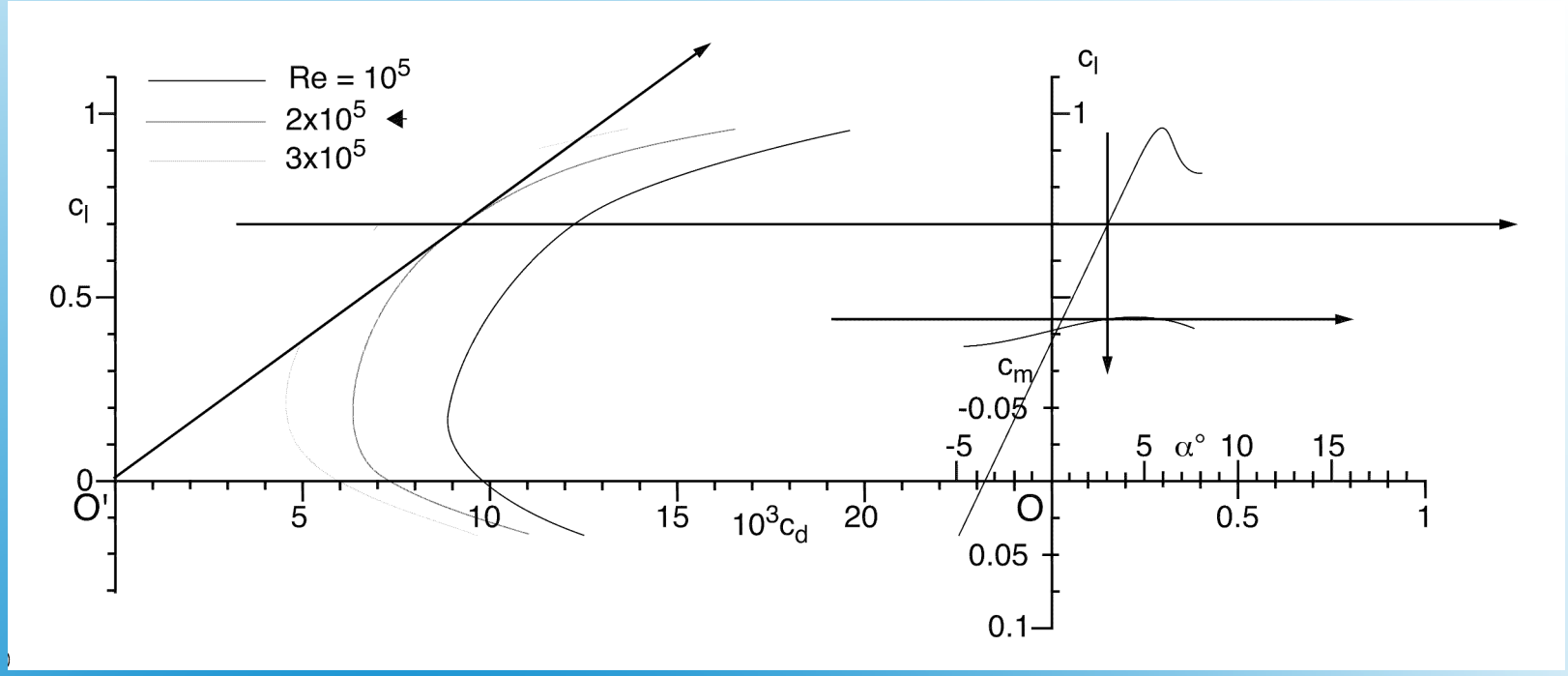
- **Exercise 2**

Find the moment coefficient ($c_{m,c/4}$) of the wing section at best c_l/c_d for a specific Reynolds number of your choosing.

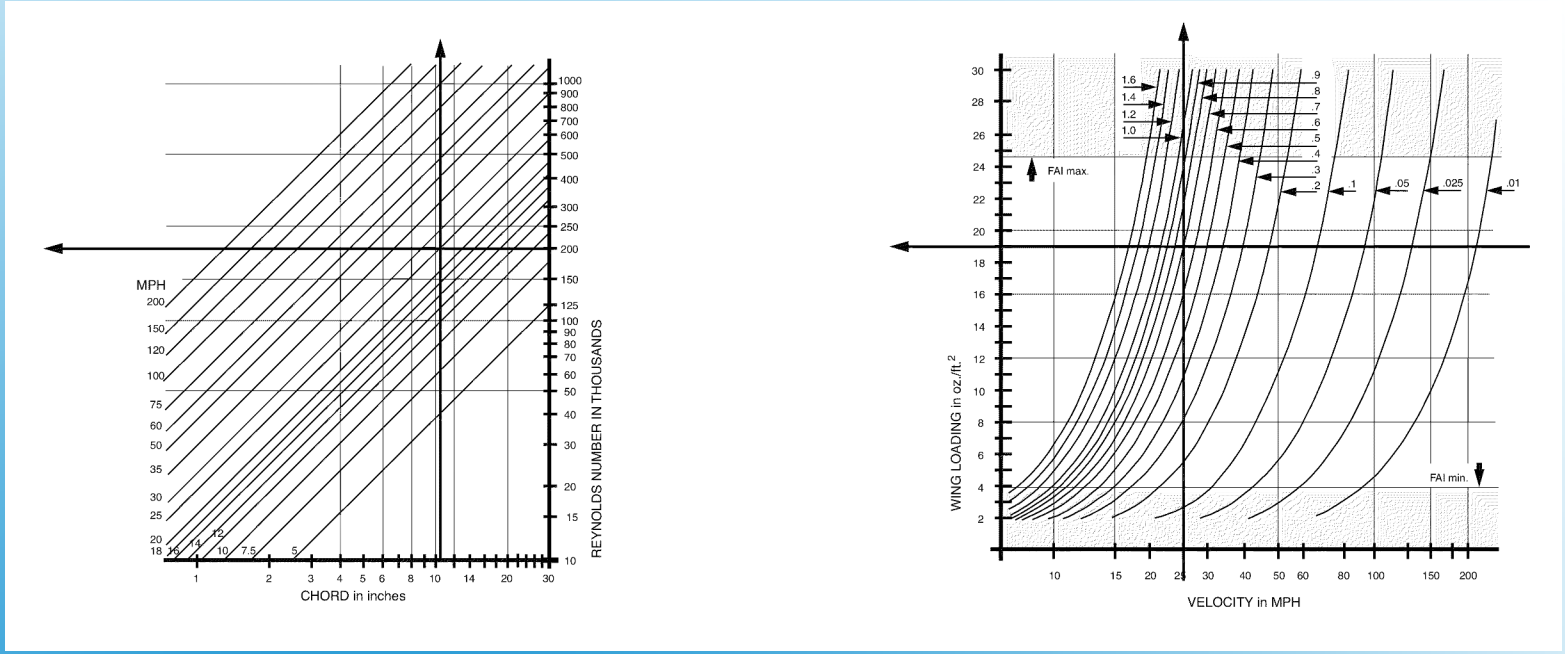
Determine the velocity for that Re.

Then find the wing loading needed to achieve this performance.

- Find best cl/cd for chosen Re
- Draw horizontal line through point
- Draw vertical line through cm,c/4 curve
- Draw horizontal line through intersection



- On Chart 1 find V based on chosen Re and (average) wing chord
- From Chart 2, with V and CL known, find the wing loading required for this V.



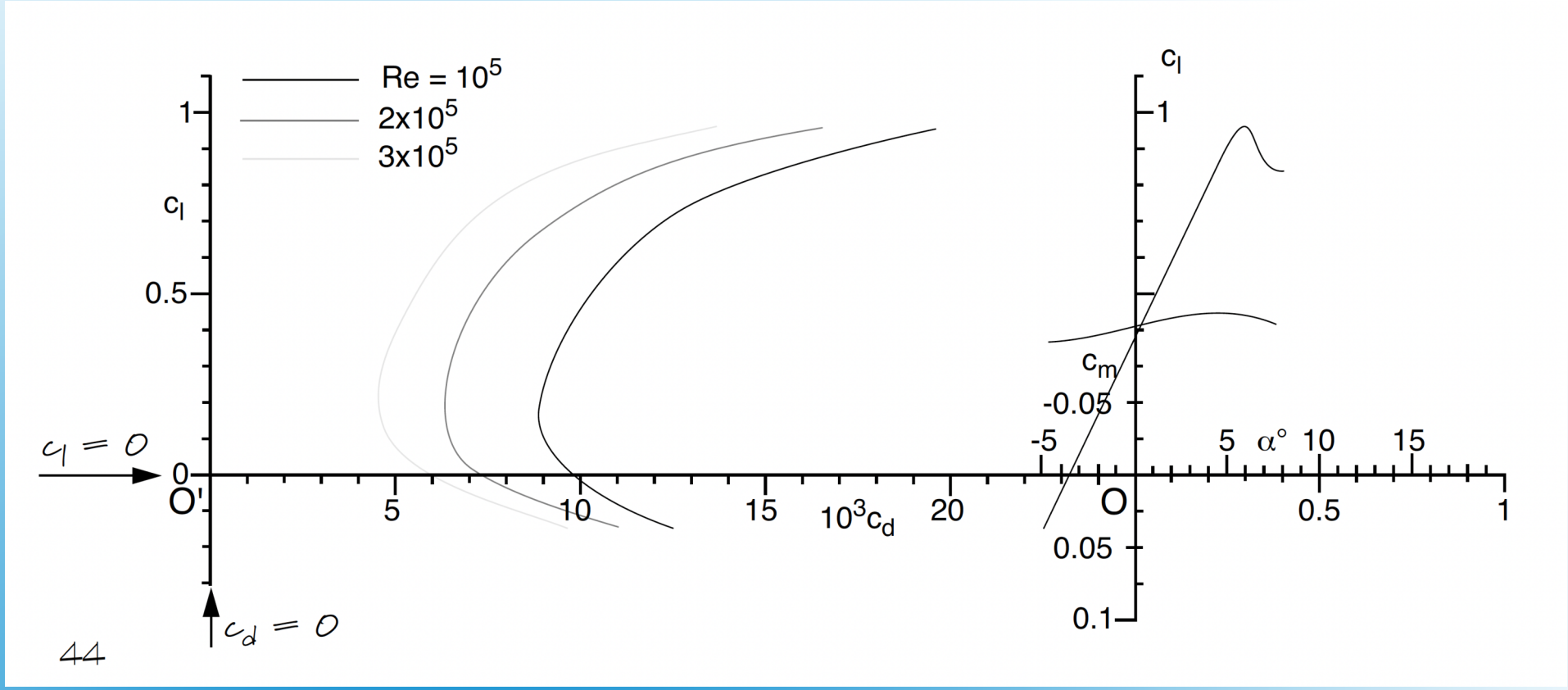
- **Exercise 3**

First, find the velocity of your sailplane for each of the polar c_d curves.

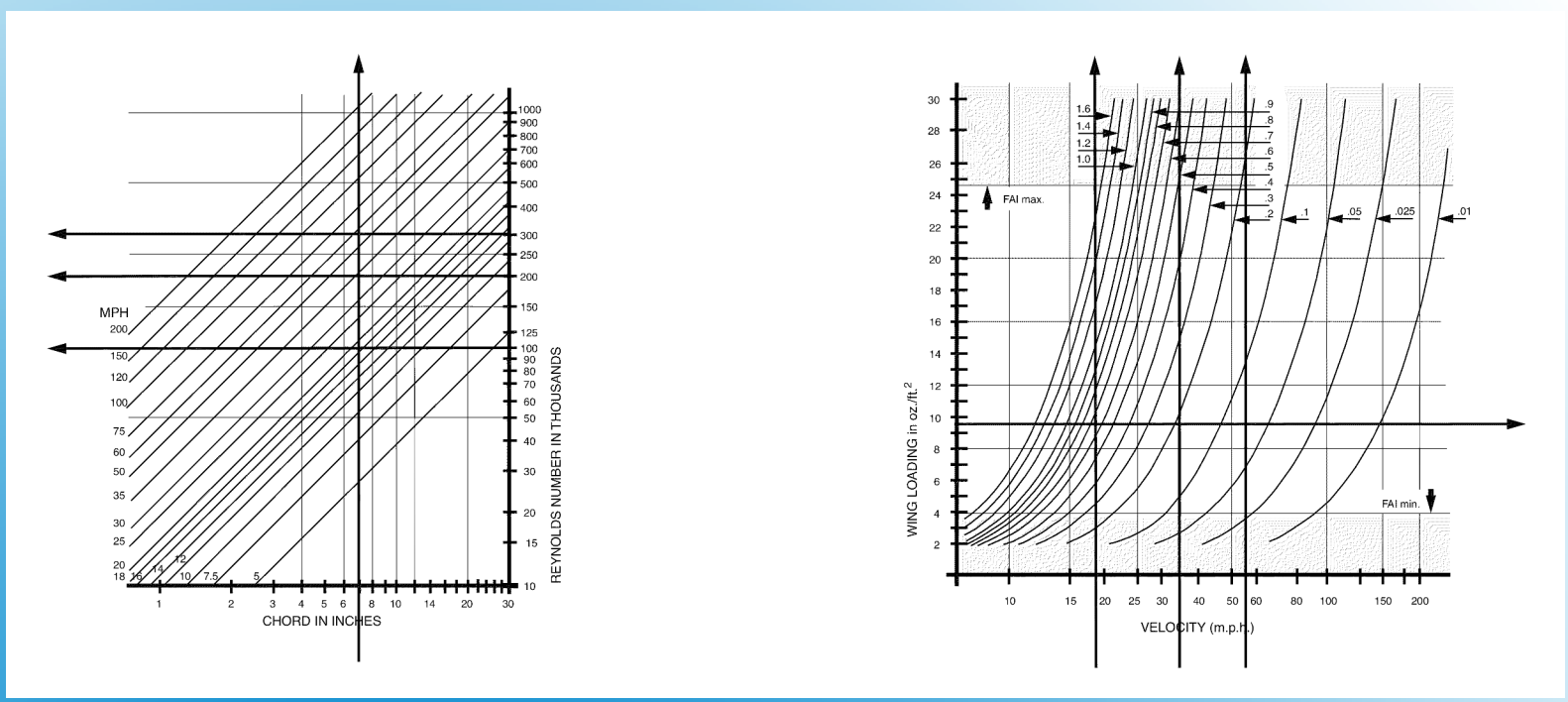
Then construct a polar diagram for your model which relates the section c_d to the sailplane C_L at each of these velocities.

Finally, construct another polar diagram which simply relates c_d to $c_{l,opt}$.

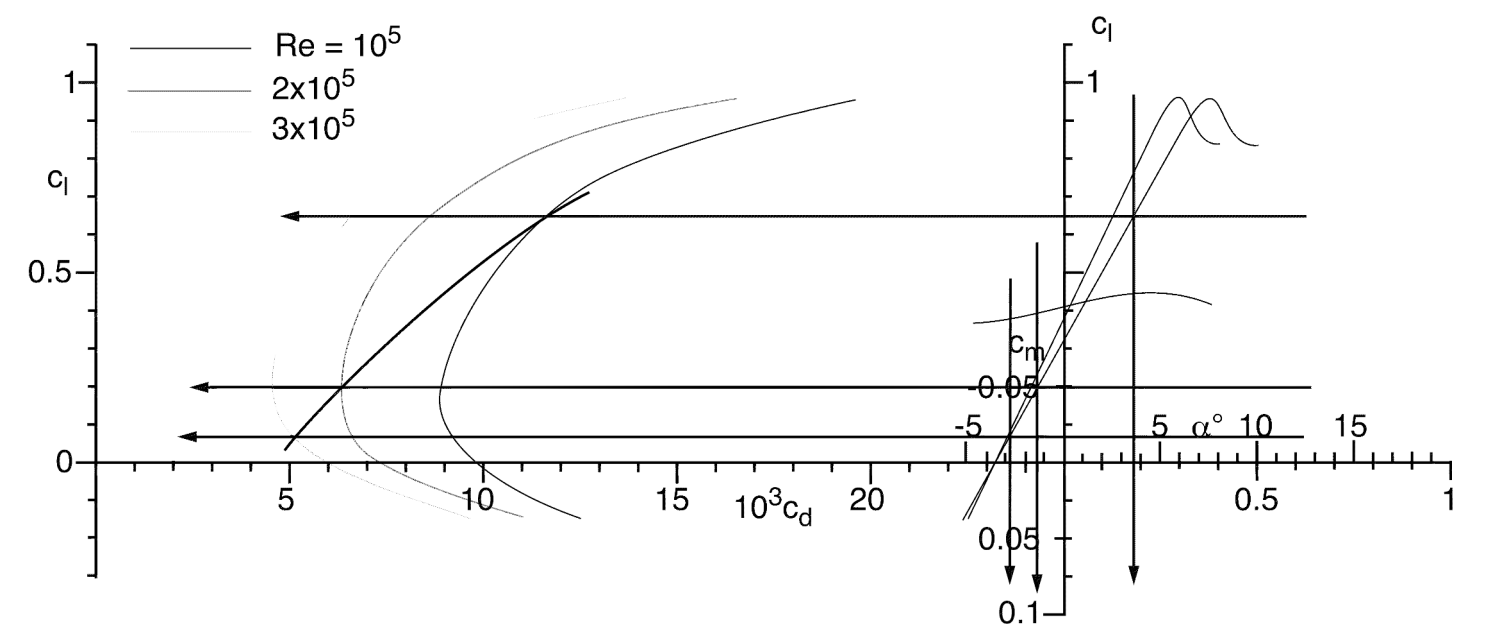
- Determine the Re values for each c_d curve



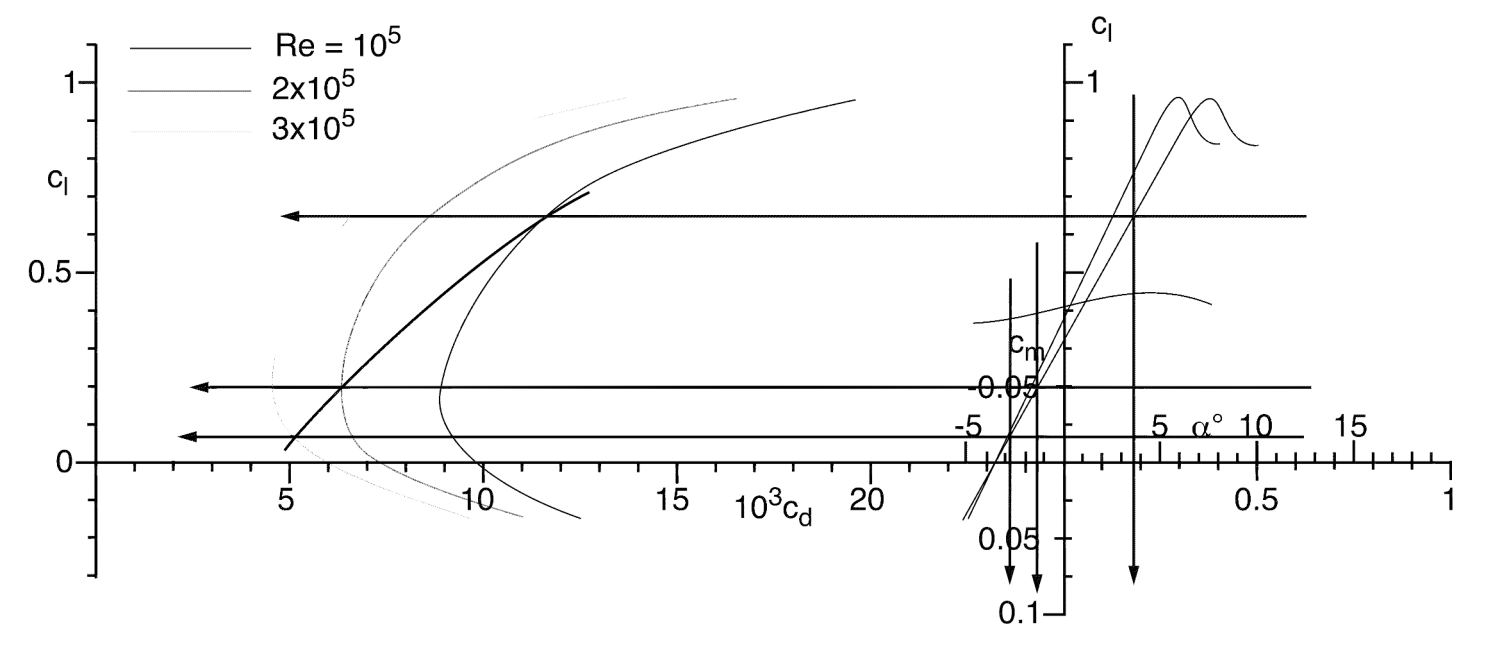
- Determine the V for each of these Re by using Chart 1
- Find the wing loading from Chart 3
- From Chart 2, and knowing the wing loading, find the sailplane C_L for each V



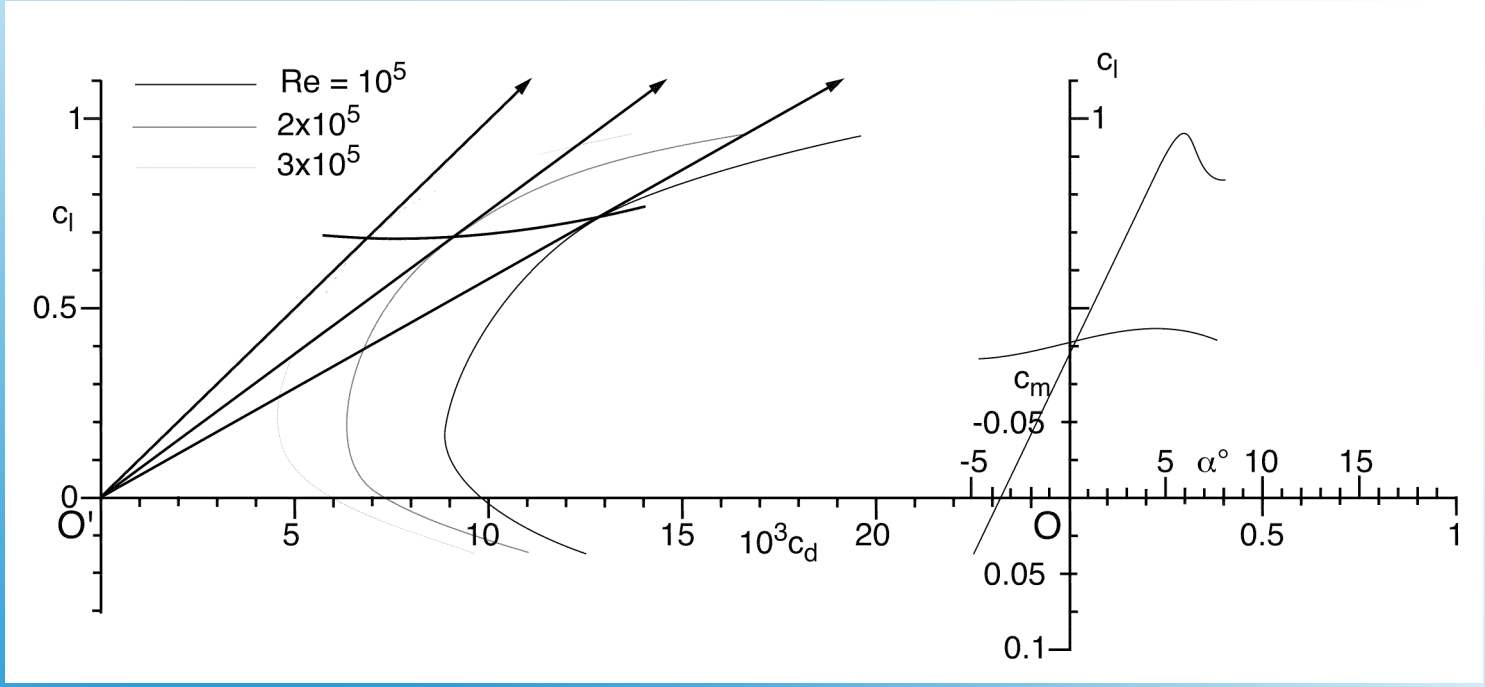
- Draw the C_L curve based on wing aspect ratio
- Draw a horizontal line through each C_L value and across the appropriate c_d curve
- Connect c_d intersections with a new curve



- Vertical lines from the intersections on the C_L curve give AoA for each Reynolds number



- Draw lines from O’ tangent to each c_d curve to determine $l/d_{,max}$
- A curve through each intersection will provide $c_{l,opt}$ for a range of Reynolds number



- **Exercise 4**

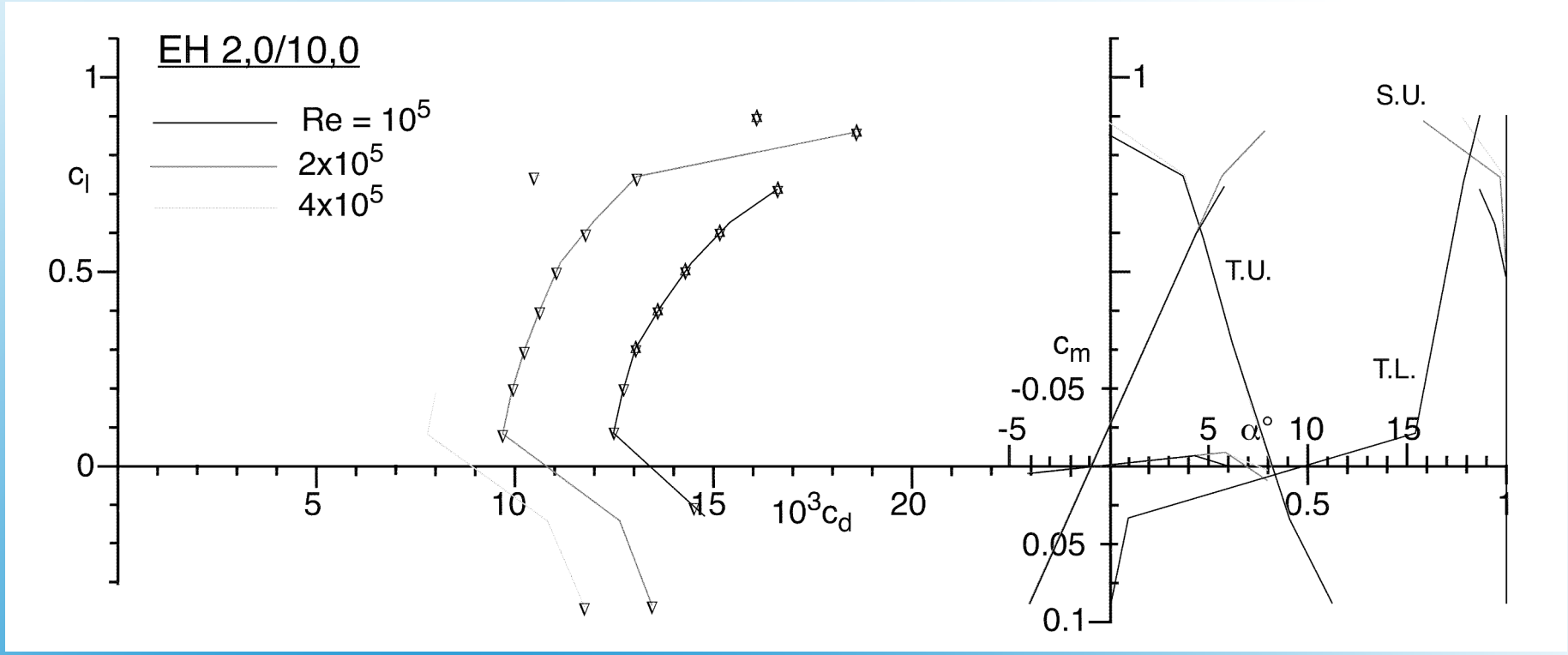
Assume a tailless sailplane using the EH 2,0/10,0 airfoil across the span.

The span is 100" and the chord is a constant 10".

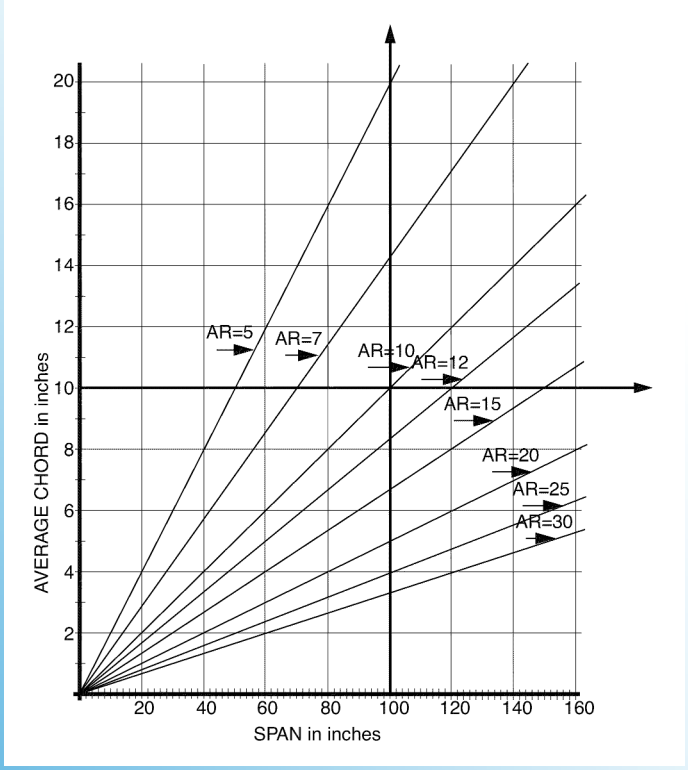
The fuselage has a constant c_d of 0.005.

The glider weighs 75 ounces.

Determine the aircraft maximum L/D.


EH 2,0/10,0
Re = 10^5
2x10^5
4x10^5
c_l
1
0.5
0
5
10
15
10^3c_d
20
c_m
-0.05
0.05
0.1
-5
5
α°
10
15
0.5
1
T.U.
T.L.
S.U.

Find the aspect ratio on Chart 4



Wing area (1000 in^2) is found on the left side of Chart 3, the wing loading is determined by using the right side of Chart 3

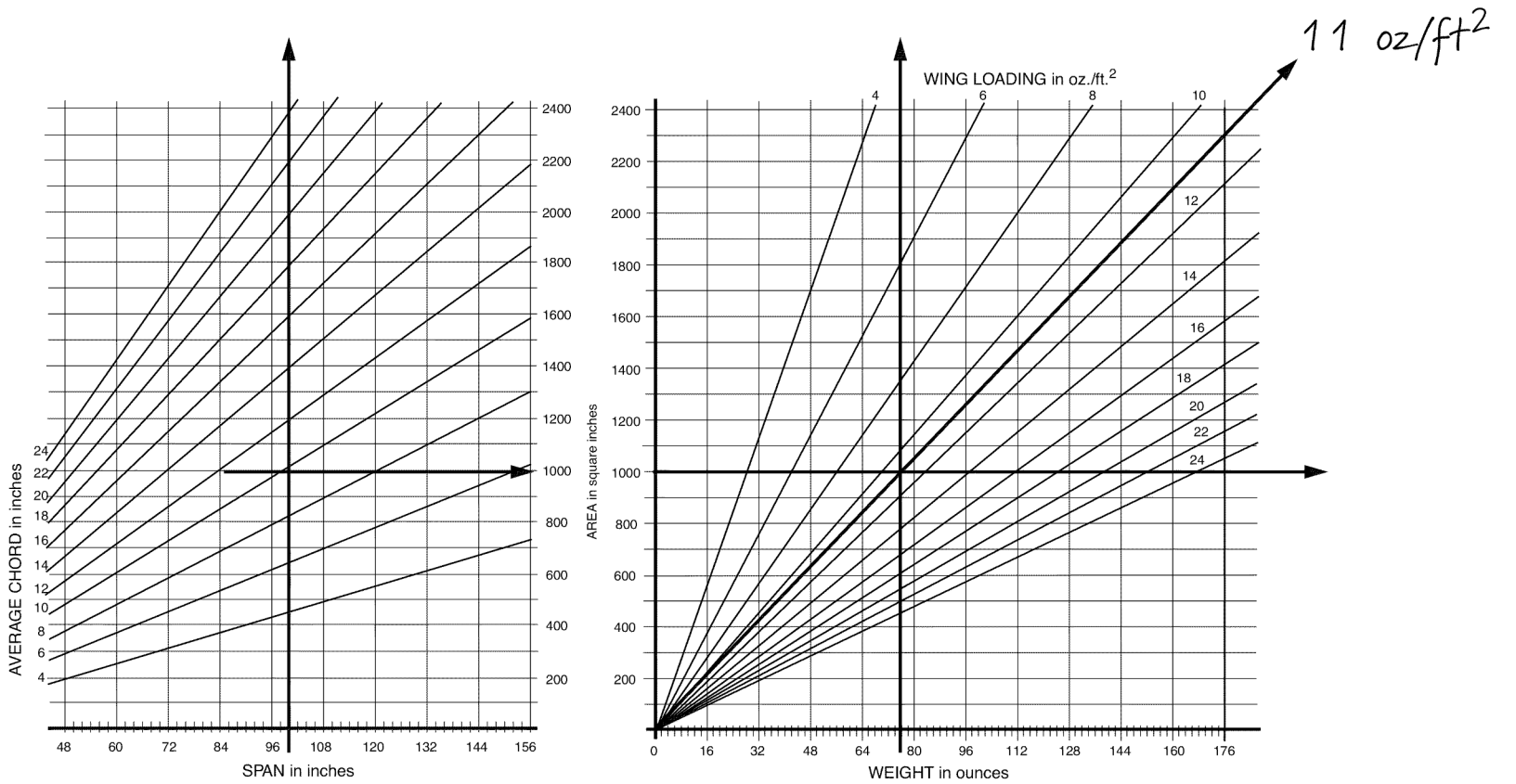
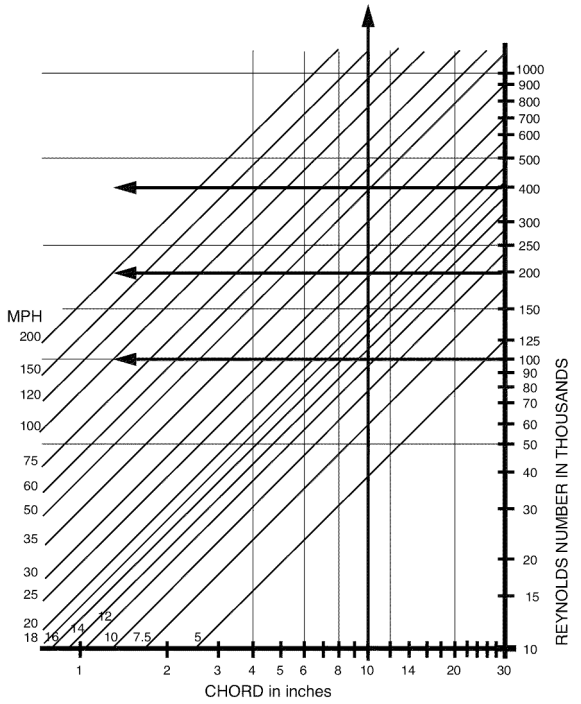
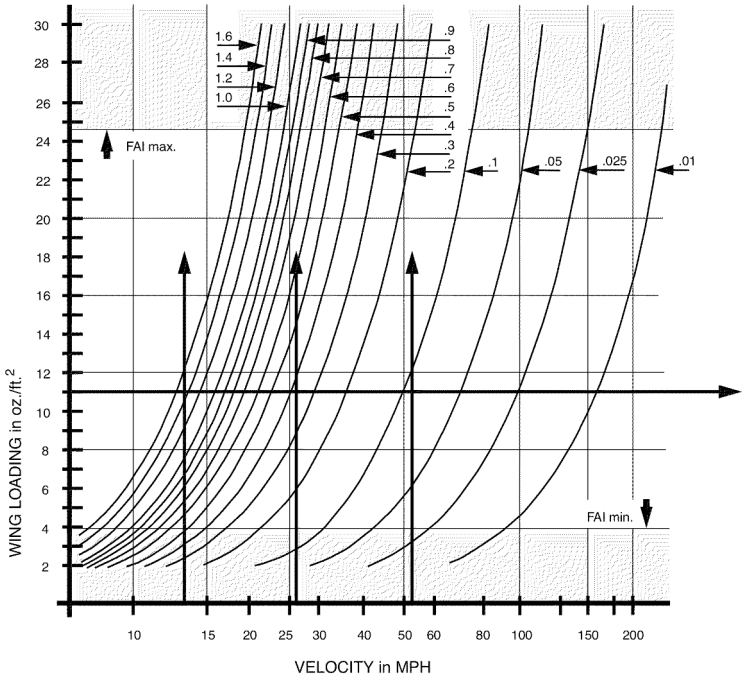


CHART 3

Use Chart 1 to find V for each of the c_d curves.
$Re = 10^5$, V = 13 mph
$Re = 2x10^5$, V = 26 mph
$Re = 3x10^5$, V = 52 mph

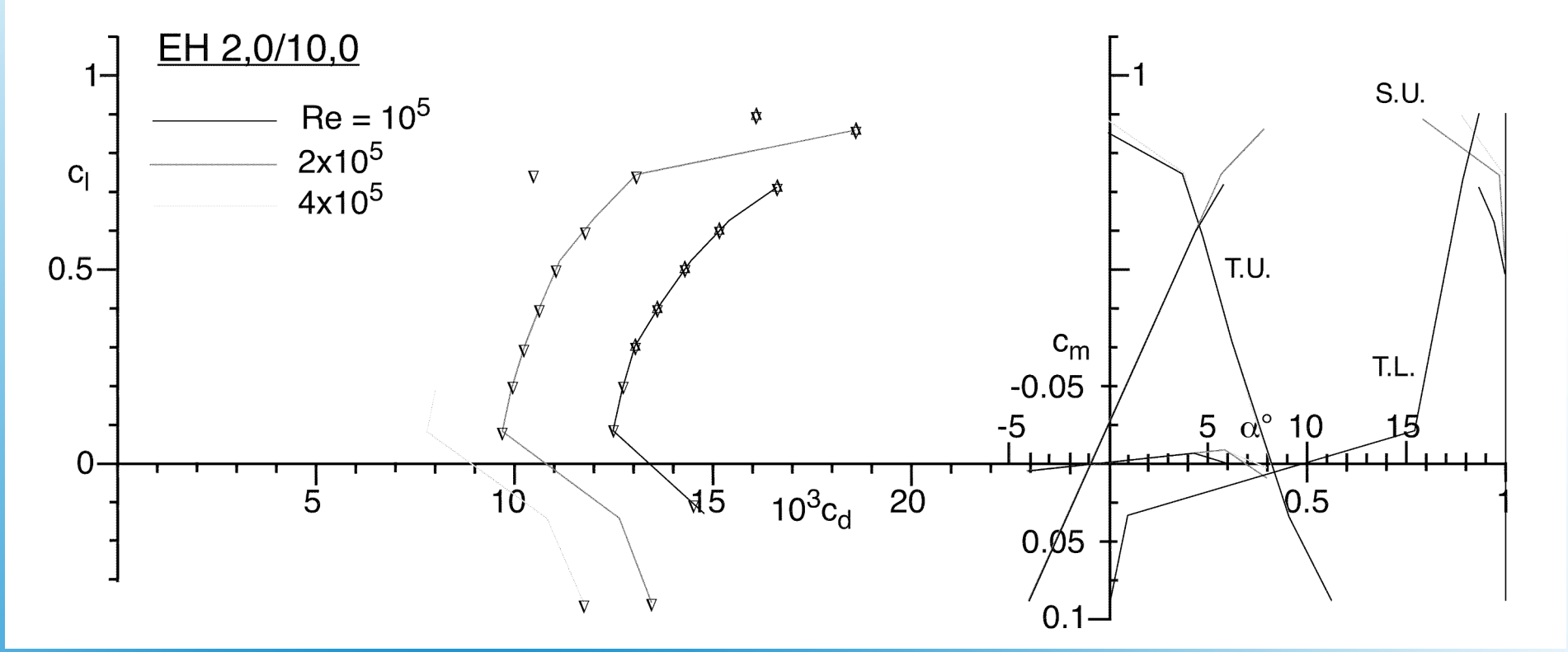
Use Chart 2 and 11 oz/ft^2 to determine the C_L for each of the Vs found.



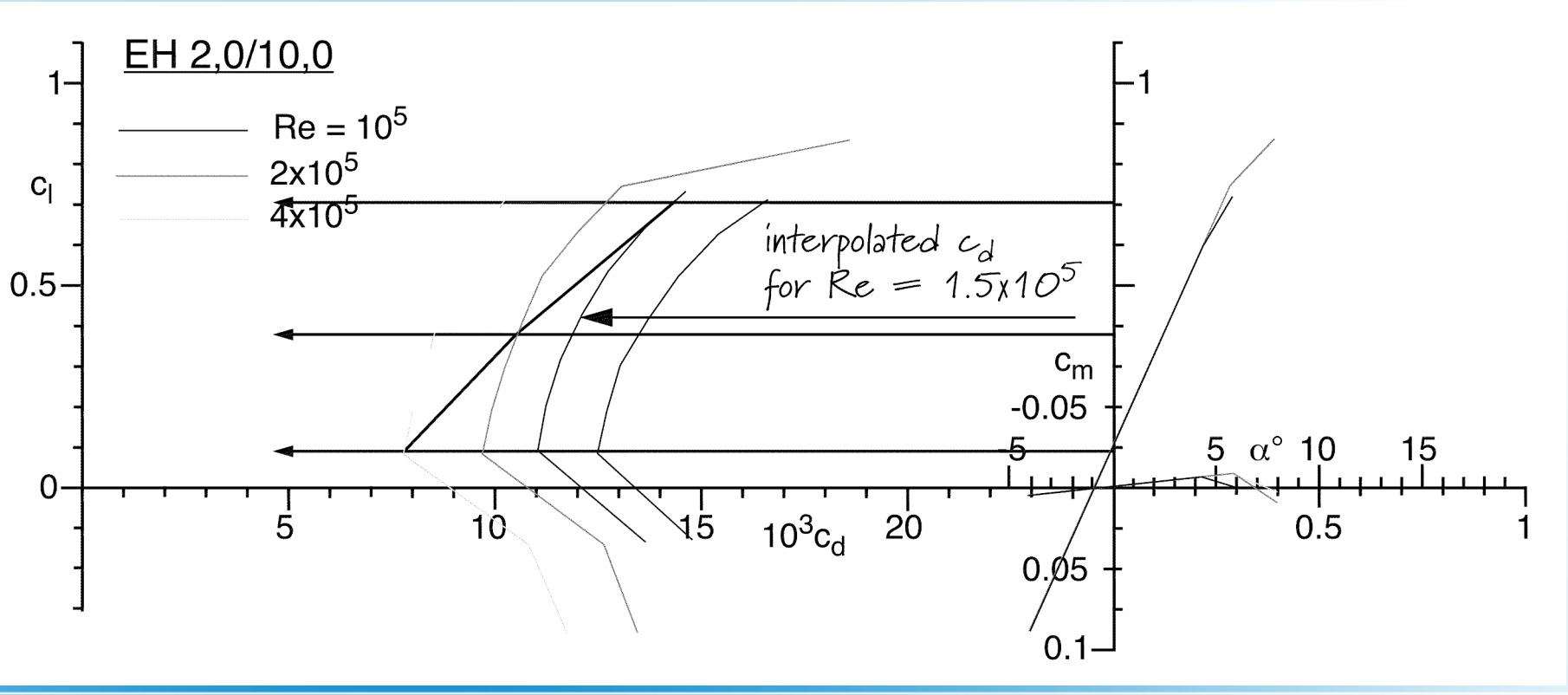


Polar for EH 2.0/10.0 (2% camber, 10% thickness)

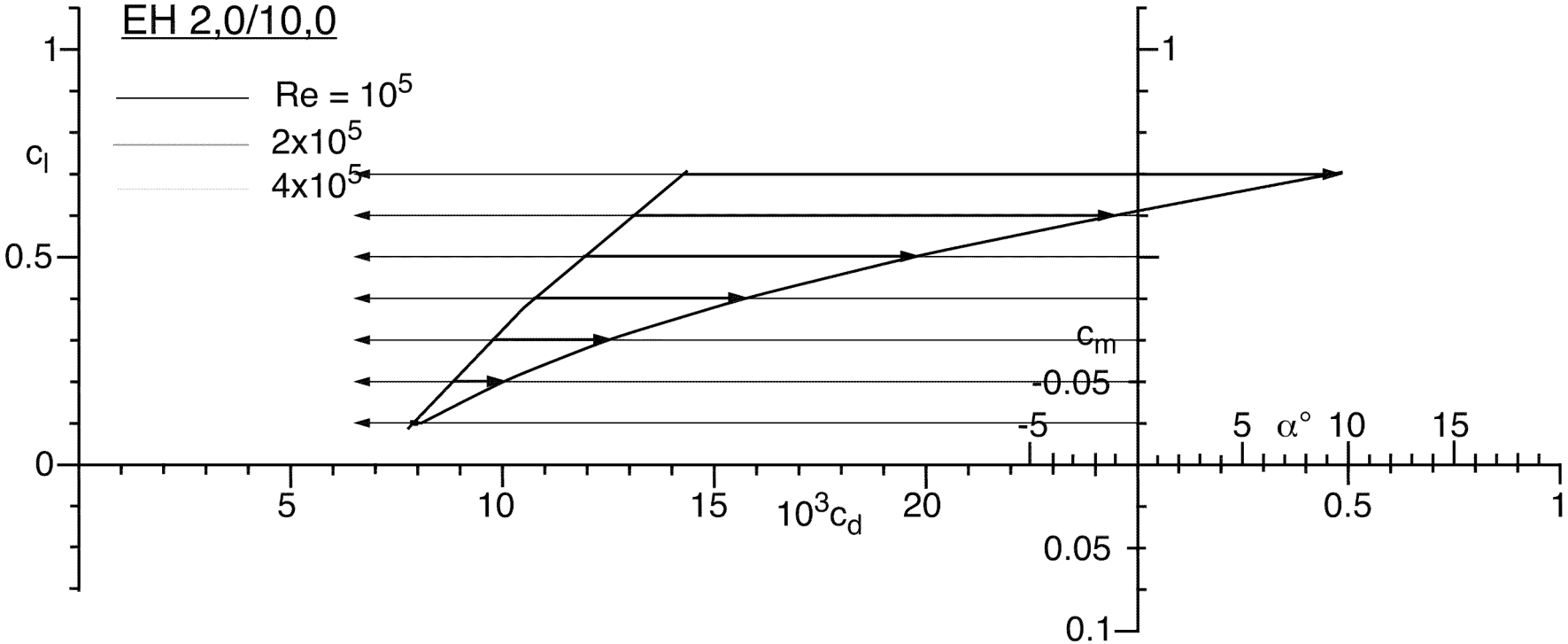
* C_d curves are not real curves, but connected straight line segments
* No clearly defined stall point on the c_l curve
* The c_m curve is superimposed over the AoA axis, so c_m = ~0.0 over entire range
* Note the S.U., T.U., and T.L. curves on the right side of the polar



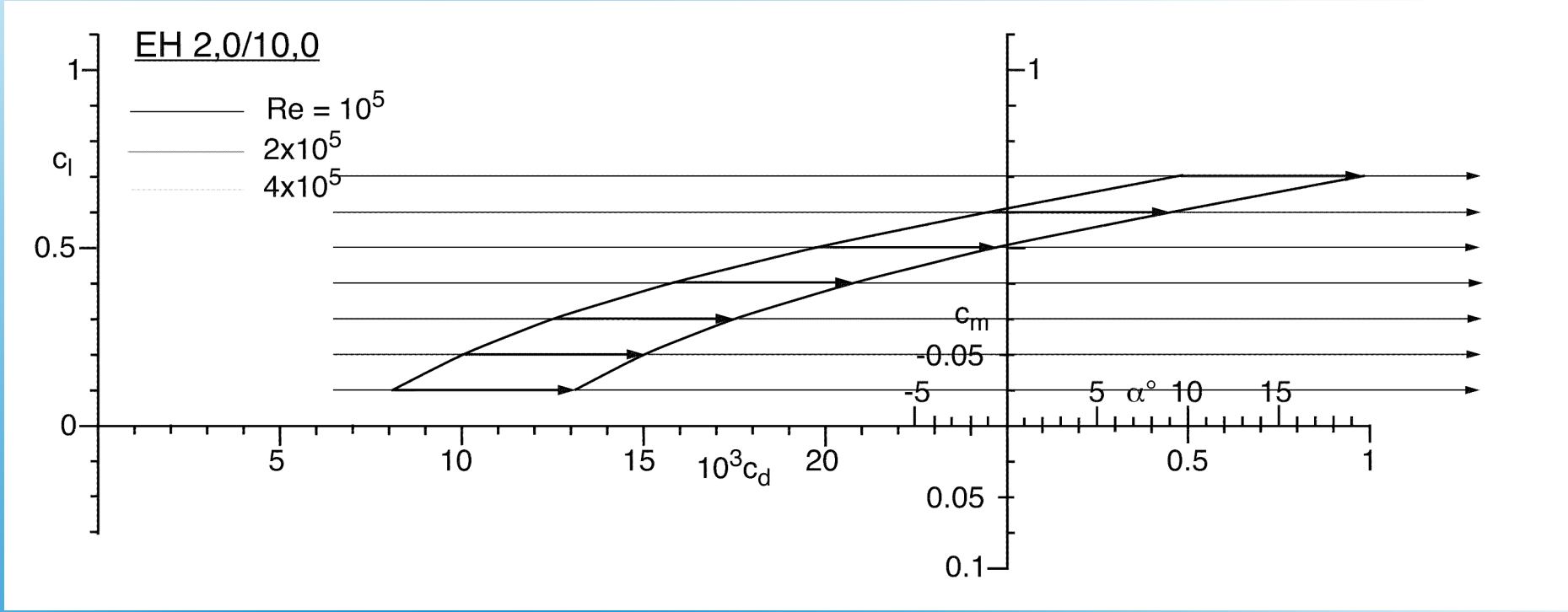
* Horizontal lines through each of the c_l values determined previously
* Note: The c_d curve for Re = 10^5 does not go past c_l = ~0.7, but CL required for 11 oz/ft^2 is over 1.4, so there's no intersection with the Re = 10^5 c_d curve
* Construct a c_d curve for Re = 1.5x10^5 through interpolation. V at Re = 1.5x10^5 is 19.5 mph and the required c_l is 0.7 (within c_d range depicted on polar)
* Now connect the three intersection points



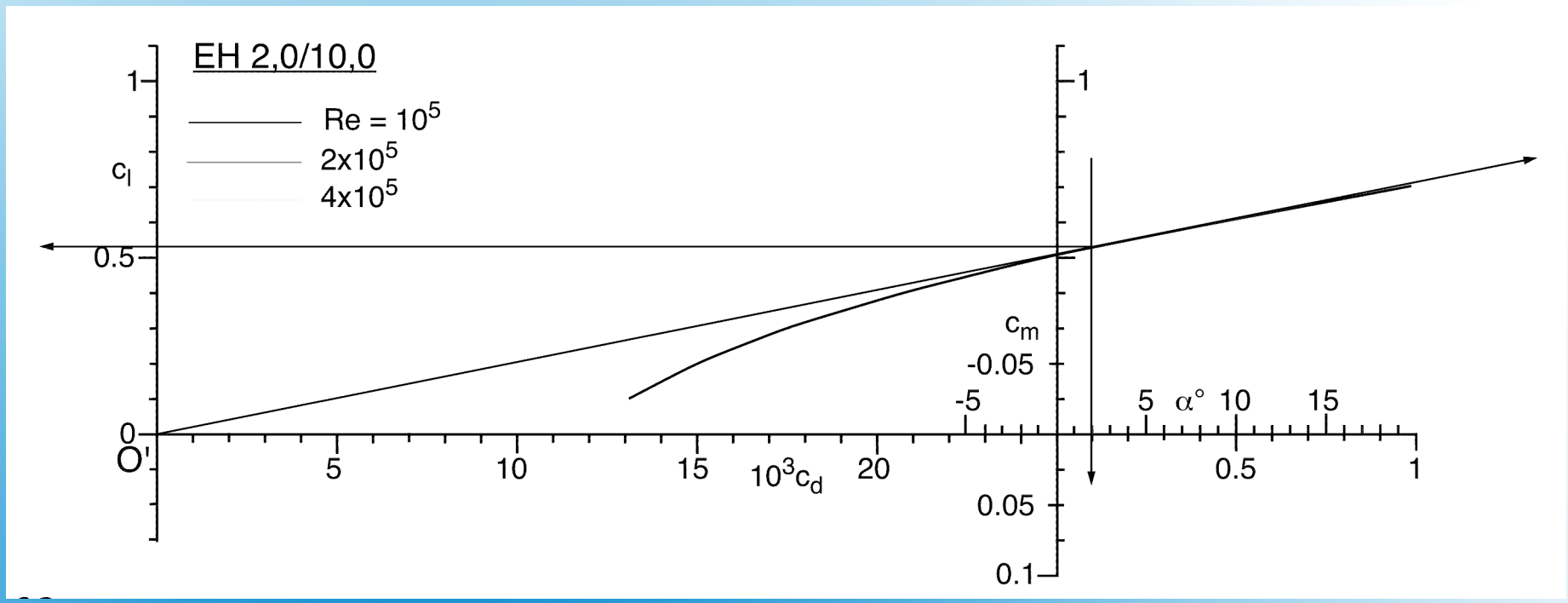
* From Table and using aspect ratio = 10, find the $C_{D,I}$ for each C_L value
* Add these induced drag values to the newly constructed c_d curve
* This results in a C_D curve because the effects of aspect ratio have been incorporated



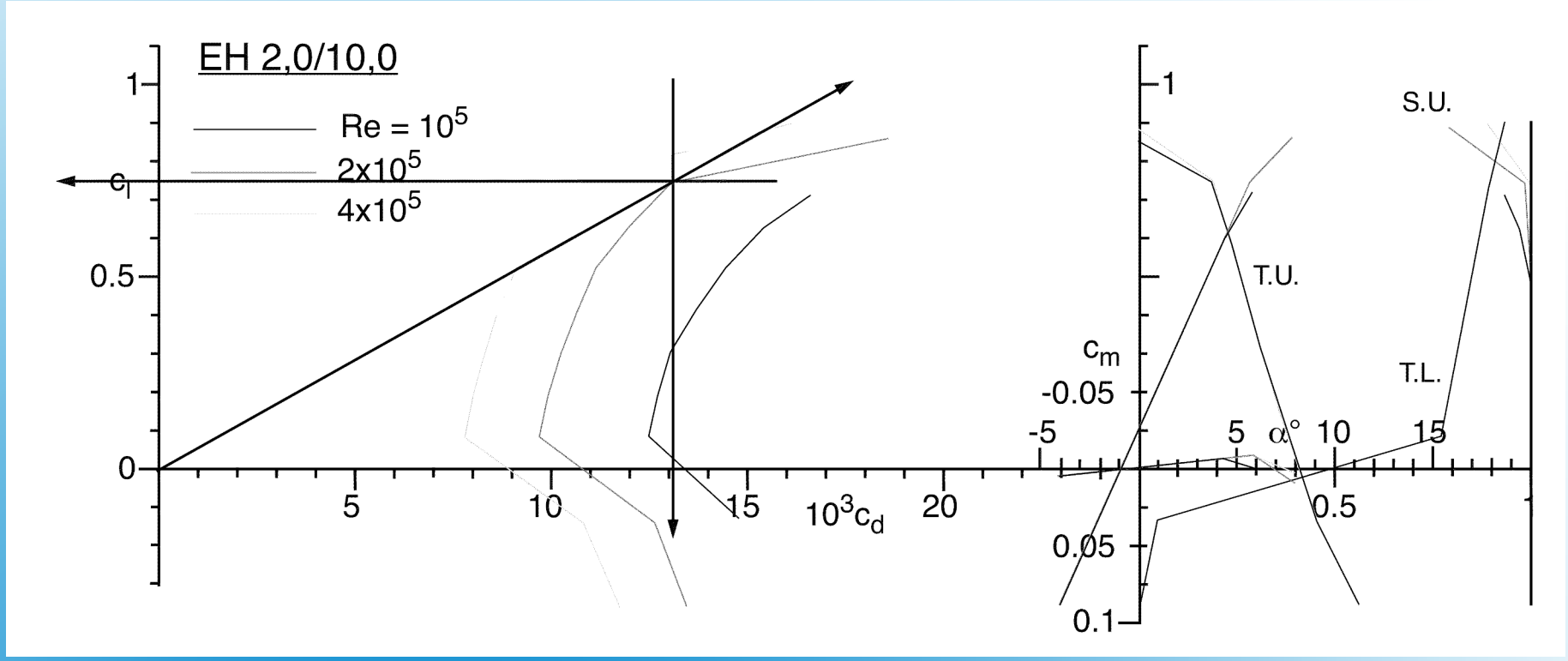
* Now add the fuselage drag, c_d = 0.005, to the last curve
* This last curve represents total aircraft drag, including wing profile drag ($c_{d,w}$), induced drag ($c_{d,i}$), and fuselage drag ($c_{d,f}$)



* Draw a straight line from the Origin O' tangent to the last curve to find L/D_{max}
* The best L/D occurs at $C_L = 0.53$, $C_D = 0.026$
* From Table 2, determine the L/D represented by that point.



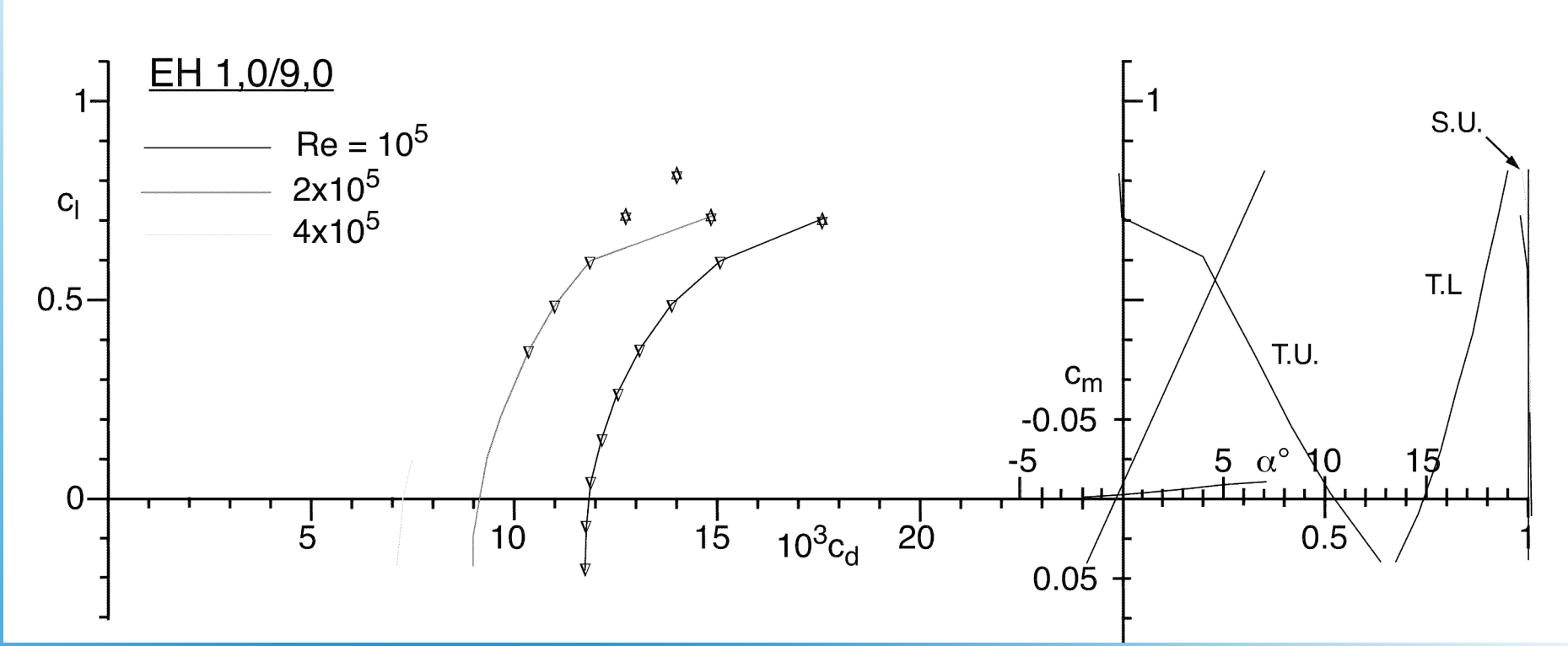
* The best L/D for this sailplane is 20.4 (The best l/d at Re = $2x10^5$ is 57.25 as shown in the polar below)
* Use Chart 6 to determine the sink rate



What performance improvements would you expect to find if

* Span is increased to 120”?
* Aircraft weight is lowered to 60 ounces?
* The fuselage is eliminated?

Here’s the polar for the EH 1,0/9,0 (Camber = 1.0%, thickness = 9.0%). It has half the camber and is 1.0% thinner than the EH 2,0/10,0. Compute the best L/D.



The End
of Part 2

