AEROPROFILI

1. Dani su dijagrami aerodinamičkih karakteristika za aeroprofil NACA 65_2-415 koji se ispituje pri uvjetima standardne atmosfere na razini mora i brzini 150 m/s. Odredi:

a) napadni kut nultog uzgona,
b) sile uzgona i otpora pri napadnom kutu 6˚,
c) kritični napadni kut i odgovarajuće brzine pri Reynoldsovima brojevima $3\cdot10^6$, $6\cdot10^6$ i $9\cdot10^6$,
d) ovisnost pozicije centra potiska u odnosu na napadni kut za napadne kutove od -4 do +8, prikazati tablično i grafički.

Rješenje:

a) $\alpha_{z0} = -2.5° \rightarrow$ očitano iz dijagrama

b) $\alpha = 6° \Rightarrow c_z = 0.9 \Rightarrow c_x = 0.0088 \rightarrow$ očitano iz dijagrama

$$\text{ISA /SL} \rightarrow \mu = 1.7894 \cdot 10^{-5} \quad Pas$$

$$\text{Re} = \frac{\rho V c}{\mu} = \frac{1.225 \cdot 150 \cdot 1}{1.7894 \cdot 10^{-5}} = 10.269 \cdot 10^6$$

$$Z' = c_z \frac{1}{2} \rho V^2 \cdot c \cdot 1 = 0.9 \cdot \frac{1}{2} \cdot 1.225 \cdot 150^2 \cdot 1 = 12403 \quad N$$

$$X' = c_x \frac{1}{2} \rho V^2 \cdot c \cdot 1 = 0.0088 \cdot \frac{1}{2} \cdot 1.225 \cdot 150^2 \cdot 1 = 121.3 \quad N$$

c)

$$V = \frac{\mu \,\text{Re}}{\rho \cdot c} = \frac{1.7894 \cdot 10^{-5} \cdot \text{Re}}{1.225 \cdot 1} = 1.4607 \cdot 10^{-5}\,\text{Re}$$

Re	V [m/s]	α_{kr} [°]
$3\cdot10^6$	43.82	16
$6\cdot10^6$	87.64	17.5
$9\cdot10^6$	131.47	17

d)

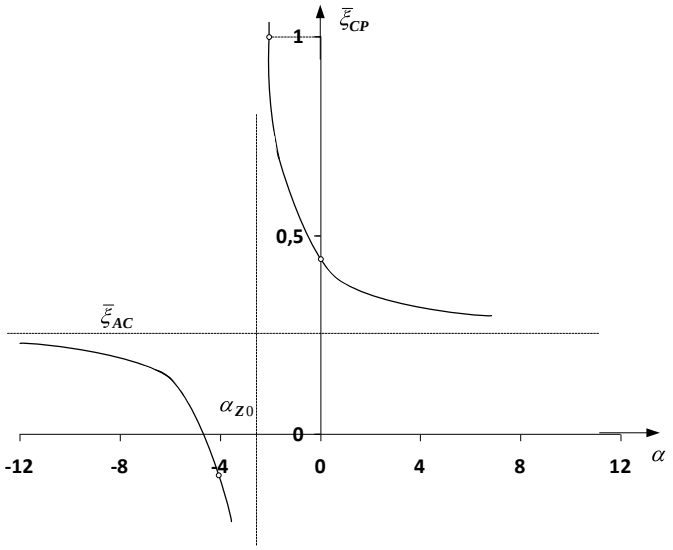
$$c_{M_{CP}} = c_{M_{AC}} + c_z(\bar{\xi}_{CP} - \bar{\xi}_{AC})$$

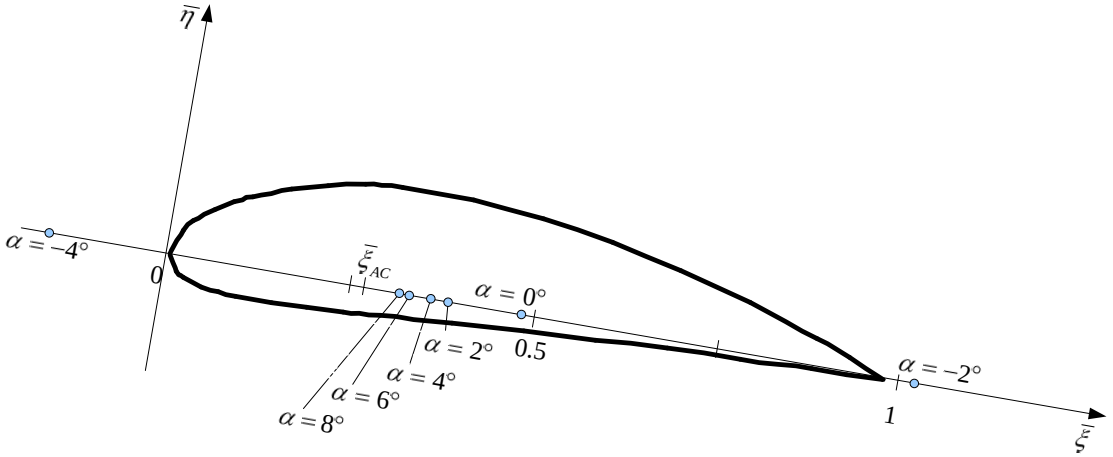
$$c_{M_{CP}} = 0 \rightarrow c_{M_{AC}} + c_z(\bar{\xi}_{CP} - \bar{\xi}_{AC}) = 0 \Rightarrow \bar{\xi}_{CP} = \bar{\xi}_{AC} - \frac{c_{M_{AC}}}{c_z}$$

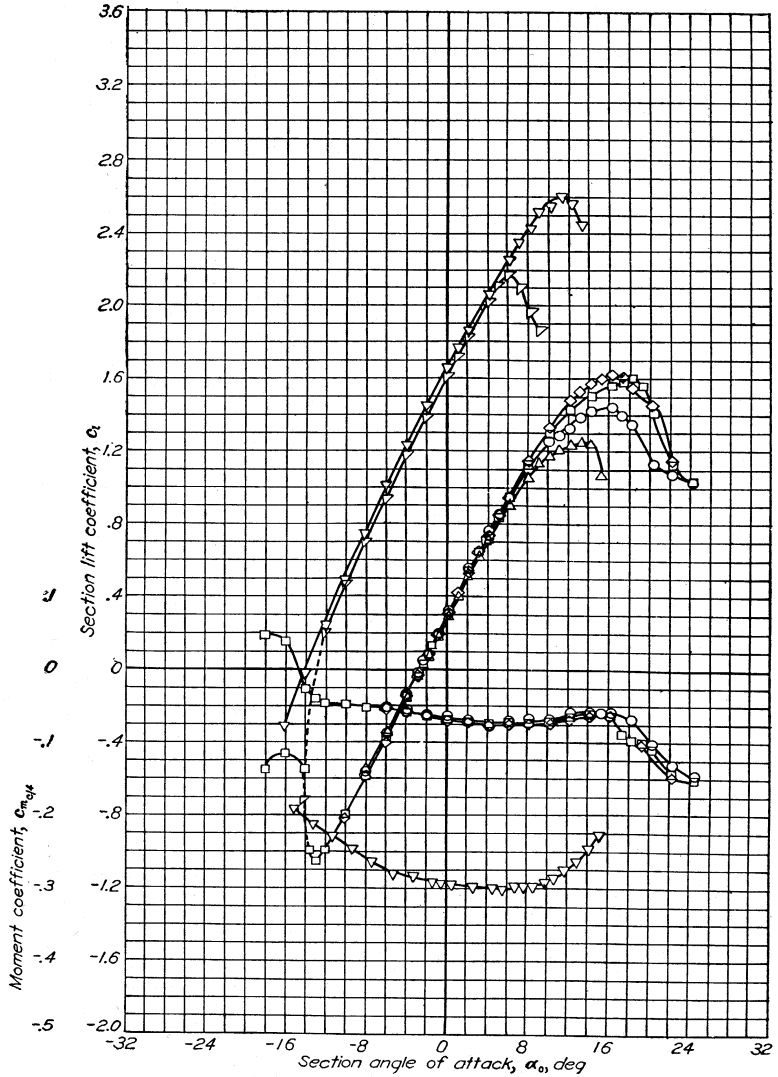
$$\bar{\xi}_{AC} = 0.268 \quad \Rightarrow \quad iz \quad dijagrama$$

α [°]	c_z	c_{Mac}	ξ_{CP}
-4	-0,14	-0,06	-0,161
-2	0,08	-0,06	1,018
0	0,28	-0,06	0,482
2	0,52	-0,06	0,383
4	0,72	-0,06	0,351
6	0,9	-0,06	0,335
8	1,1	-0,06	0,323

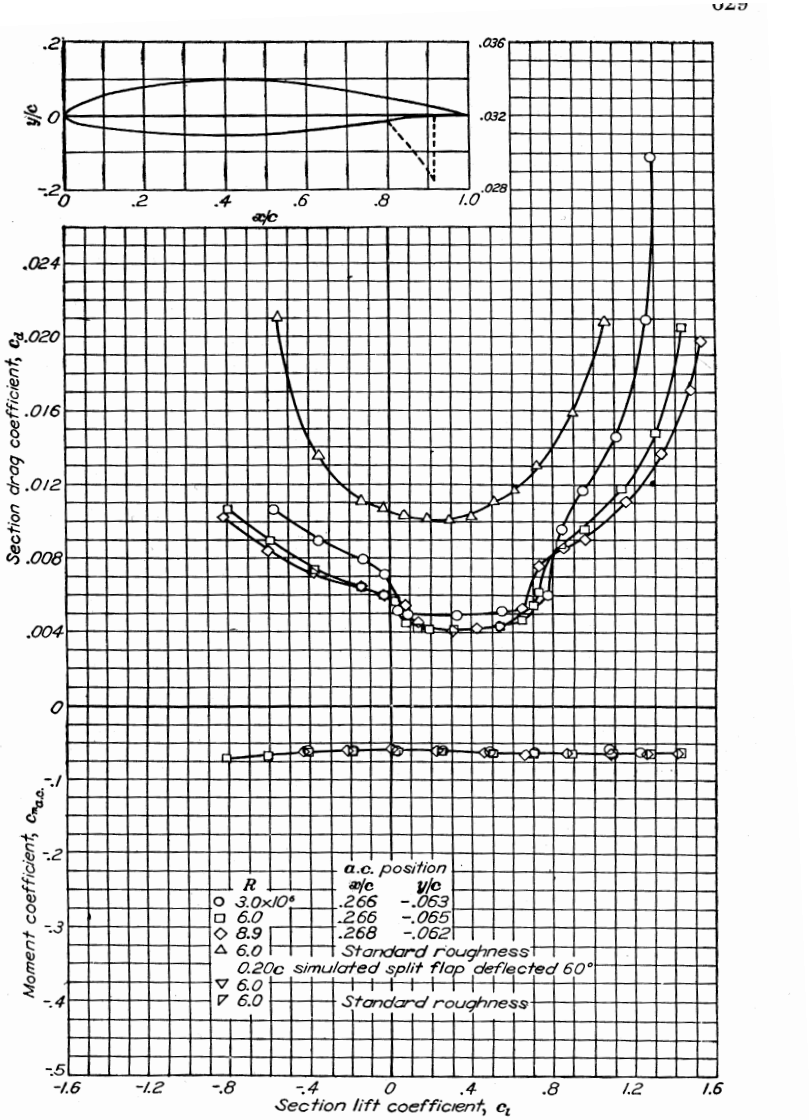
Položaj CP ovisno o napadnom kutu







NACA 65$_2$-415 Wing Section



NACA 65$_2$-415 Wing Section (*Continued*)

2. Promatramo let krila beskonačnog raspona izrađenog od aeroprofila NACA 2415 s tetivom duljine c = 1060 mm na visini H = 10 000 m u uvjetima standardne atmosfere brzinom V = 100 m/s. Odrediti:

a) sile uzgona i otpora po jedinici raspona krila kod nultog napadnog kuta,
b) srednju razliku tlaka na krilu u uvjetima pod a)
c) kut nultog uzgona,
d) kritični napadni kut kod brzine 100 m/s,
e) koliko kritični napadni kut ovisi o brzini.

Rješenje:

H = 10 000 m

$$\rho = \rho_n (1 - 2.256 \cdot 10^{-5} \cdot H)^{4.256} = 1.225 \cdot (1 - 2.256 \cdot 10^{-5} \cdot 10000)^{4.256} = 0.4126 \quad kg/m^3$$

$$T = T_n - \beta \cdot H = 288.15 - 6.5 \cdot 10^{-3} \cdot 1000 = 223.15 \quad K$$

$$p = \rho \cdot R \cdot T = 0.4126 \cdot 287.053 \cdot 223.15 = 26429.5 \quad Pa$$

$$\mu = 14.577 \cdot 10^{-6} \quad Pas \rightarrow iz \quad tablice$$

$$\mathrm{Re} = \frac{\rho V c}{\mu} = \frac{0.4126 \cdot 100 \cdot 1.06}{14.577 \cdot 10^{-6}} = 3 \cdot 10^6$$

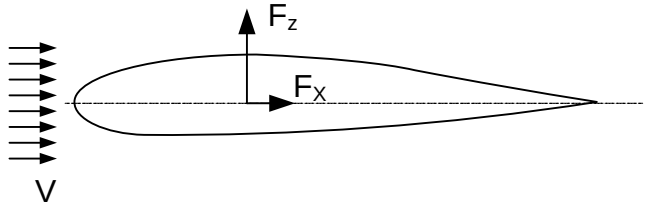
a)

$\alpha = 0° \Rightarrow c_z = 0.19 \Rightarrow c_x = 0.0065 \rightarrow$ očitano iz dijagrama

$$F_Z = C_z \frac{1}{2} \rho V^2 S = 0.19 \cdot \frac{1}{2} \cdot 0.4126 \cdot 100^2 \cdot 1.06 \cdot 1 = 415.5 \quad N/m$$

$$F_X = C_x \frac{1}{2} \rho V^2 S = 0.0065 \cdot \frac{1}{2} \cdot 0.4126 \cdot 100^2 \cdot 1.06 \cdot 1 = 14.2 \quad N/m$$

b)



$$p_d - p_g = \frac{F_Z}{S} = \frac{F_Z}{b \cdot c} = \frac{415.5}{1.06} = 392 \quad Pa$$

c) $C_z = 0 \Rightarrow \alpha = -2.5° \rightarrow iz \quad dijagrama$

d) $C_{z\max} \Rightarrow \alpha_{kr} = 14° \rightarrow iz \quad dijagrama$

e) $\text{Re} = 3 \cdot 10^6 \Rightarrow V = 100 \quad m/s \Rightarrow \alpha_{kr} = 14°$

$$\text{Re} = 6 \cdot 10^6 \Rightarrow V = \frac{\text{Re} \cdot \mu}{\rho \cdot c} = \frac{6 \cdot 10^6 \cdot 14.577 \cdot 10^{-6}}{0.4126 \cdot 1.06} = 200 \quad m/s$$
$$\Rightarrow \alpha_{kr} = 16°$$

$$\text{Re} = 9 \cdot 10^6 \Rightarrow V = \frac{\text{Re} \cdot \mu}{\rho \cdot c} = \frac{9 \cdot 10^6 \cdot 14.577 \cdot 10^{-6}}{0.4126 \cdot 1.06} = 300 \quad m/s$$
$$\Rightarrow \alpha_{kr} = 16°$$

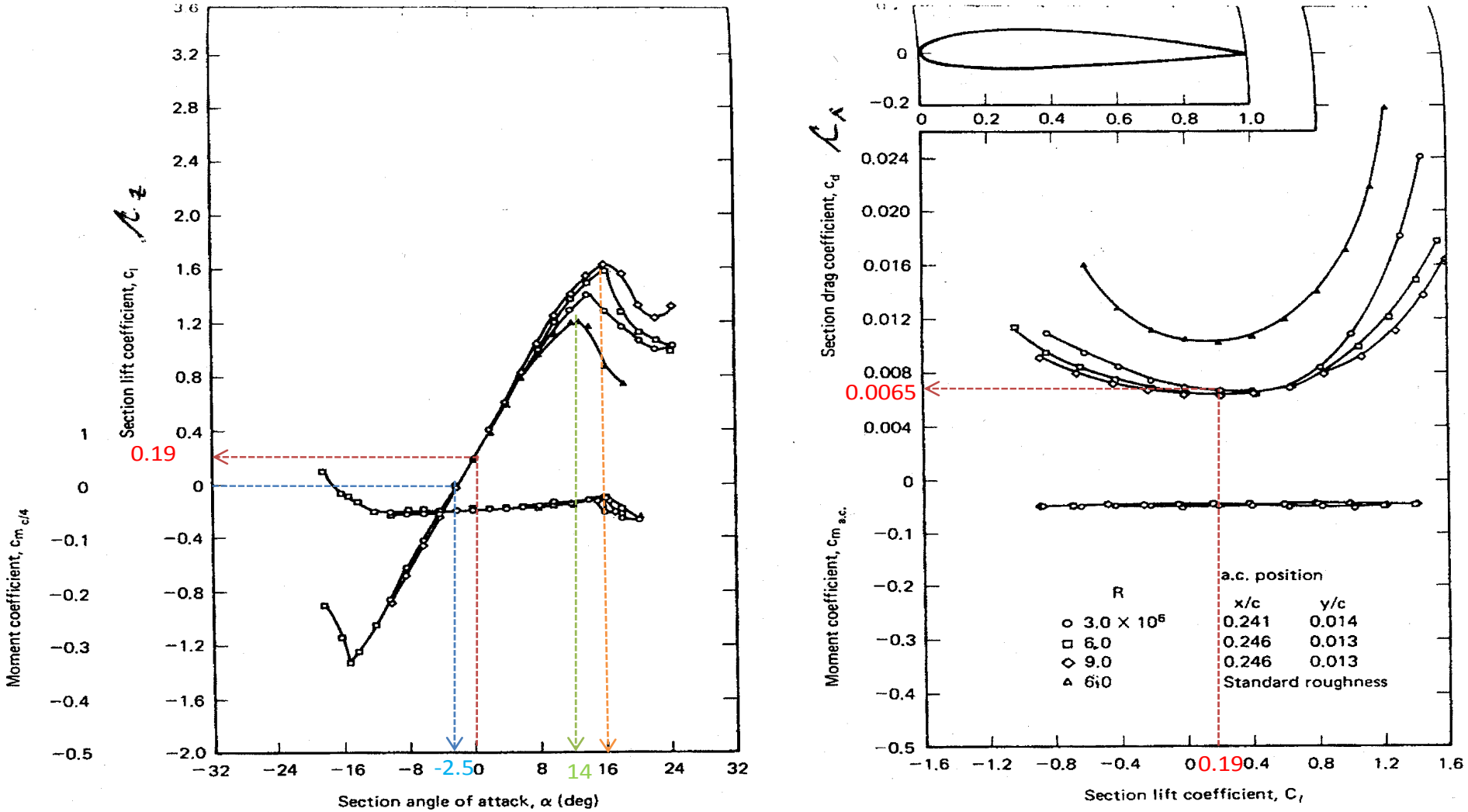


Figure 13.12 Characteristics of the NACA 2415 airfoil section. From I. Abbott and A. von Doenhoff, *Theory of Wing Sections*, 1959. Reprinted by permission of Dover Publications, Inc., New York.

3. Na aeroprofil aeroprofil NACA 2418 nastrujava zrak gustoće $\rho = 0.818$ kg/m^3 i dinamičke viskoznosti $\mu = 15.680 \cdot 10^{-6}$ Pas, brzinom $V = 65$ m/s. Duljina tetive aeroprofila je 1.4 m. Odredi:

a) maksimalnu finesu i

b) silu uzgona i silu otpora pri napadnom kutu $\alpha = 10°$.

Rješenje:

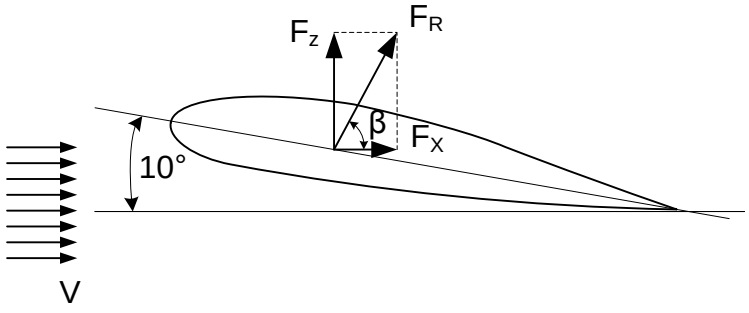
a)

α [°]	**c_z**	**c_x**	**c_z/c_x**
0	0,23	0,0069	33,33
2	0,41	0,0071	57,75
4	0,62	0,0078	79,49
6	0,8	0,0087	91,95
8	1	0,0098	102,04
10	1,2	0,0112	107,14
12	1,36	0,0145	93,79
14	1,48	0,0172	86,05

$$\mathrm{Re} = \frac{\rho V c}{\mu} = \frac{0.818 \cdot 65 \cdot 1.4}{15.680 \cdot 10^{-6}} = 4.75 \cdot 10^6$$

$$f_{\max} = \left(\frac{c_z}{c_x}\right)_{\max} = 107.14 \qquad pri \quad \alpha = 10°$$

b) $\alpha = 10° \Rightarrow c_z = 1.2 \Rightarrow c_x = 0.0112$

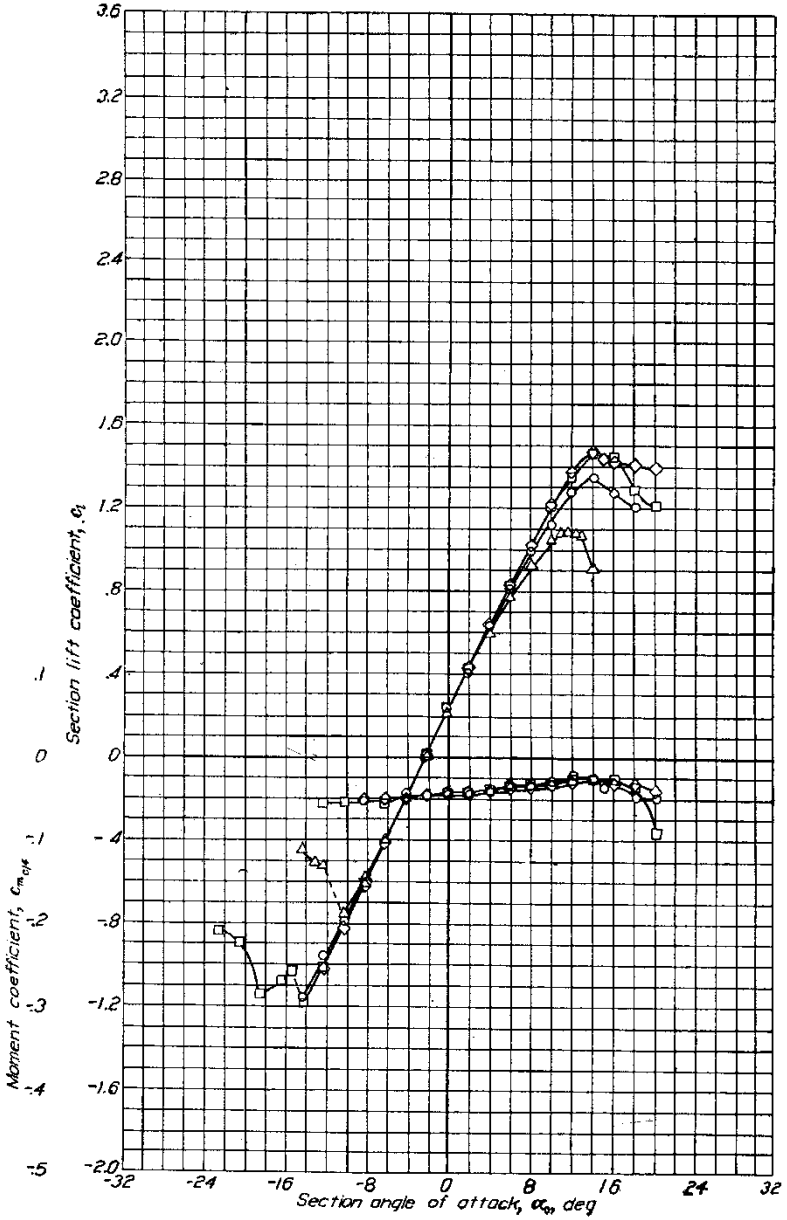


$$F_Z = c_z \frac{1}{2} \rho V^2 S = 1.2 \cdot \frac{1}{2} \cdot 0.818 \cdot 65^2 \cdot 1.4 \cdot b = 2903.1 \quad N/m$$

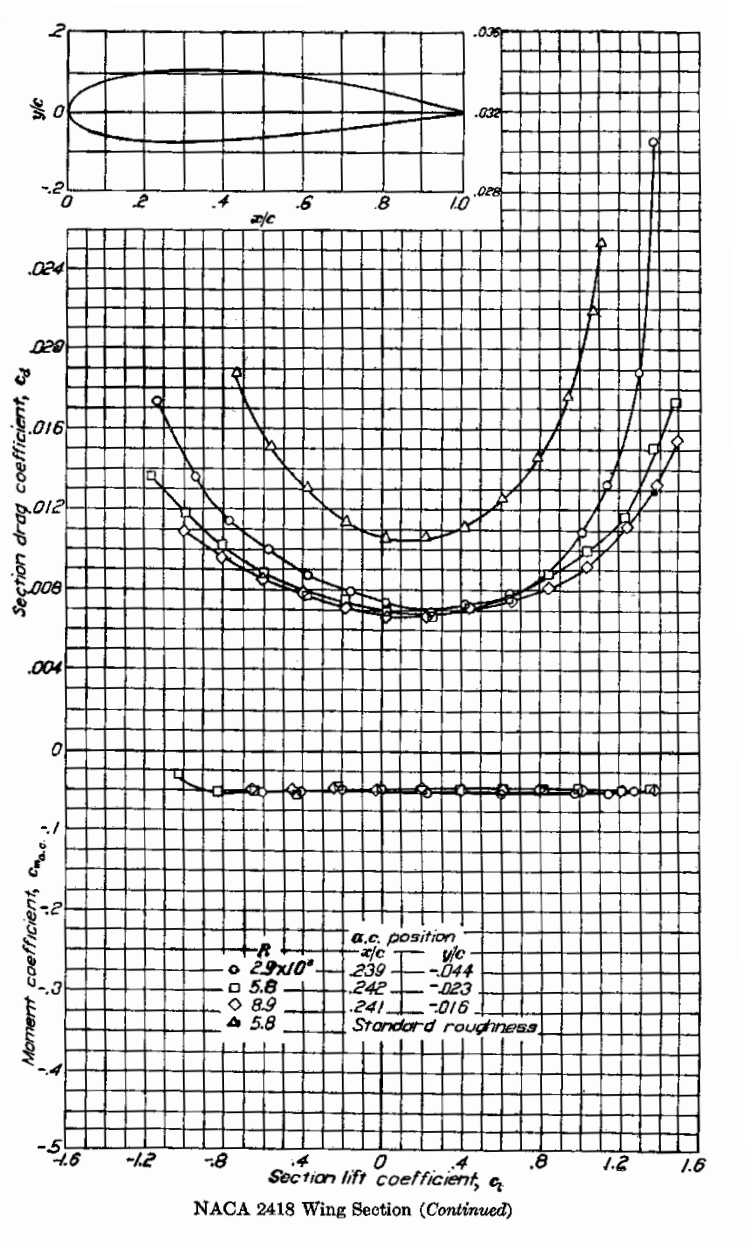
$$F_X = c_x \frac{1}{2} \rho V^2 S = 0.0112 \cdot \frac{1}{2} \cdot 0.818 \cdot 65^2 \cdot 1.4 \cdot b = 27.1 \quad N/m$$

$$F_R = \sqrt{F_Z{}^2 + F_X{}^2} = \sqrt{2903.1^2 + 27.1^2} = 2903.2 \quad N/m$$

$$\beta = arctg \frac{F_Z}{F_X} = arctg \frac{c_Z}{c_X} = arctg \frac{1.2}{0.0112} = 89.5°$$



NACA 2418 Wing Section



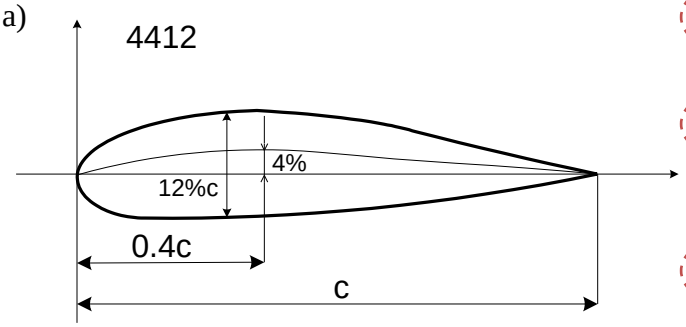
NACA 2418 Wing Section (*Continued*)

4. Za aeroprofil NACA 4412 odredi:

a) značenje oznake
b) silu uzgona i otpora pri napadnom kutu α = 6°, brzini V= 40 m/s i standardnim uvjetima na razini mora, ako je duljina tetive 2 m,
c) maksimalnu finesu aeroprofila,
d) položaj centra potiska $\bar{x}_{CP}$ pri α = 8° ako je $\bar{x}_{AC} = 0.246$,
e) koeficijent momenta u točki $\bar{x}_P = 0.250$ pri α = 8°,

Rješenje:

a)



4 najveća zakrivljenost srednje linije aeroprofila u %

4 mjesto najveće zakrivljenosti srednje linije aeroprofila u desetim dijelovima tetive c

12 maksimalna debljina profila u % tetive

b) $\alpha = 6° \Rightarrow c_z = 1 \Rightarrow c_x = 0.014$

$$F_Z = c_z \frac{1}{2}\rho V^2 S = 1 \cdot \frac{1}{2} \cdot 1.225 \cdot 40^2 \cdot 2 \cdot b = 1960 \cdot b \quad N/m$$

$$F_X = c_x \frac{1}{2}\rho V^2 S = 0.014 \cdot \frac{1}{2} \cdot 1.225 \cdot 40^2 \cdot 2 \cdot b = 27.44 \cdot b \quad N/m$$

c)

α [°]	**c_z**	**c_x**	**c_z/c_x**
0	0,38	0,01	38
2	0,6	0,01	60
4	0,8	0,012	66,7
6	1	0,014	71,4
8	1,15	0,017	67,6
10	1,27	0,022	57,7

$$f_{\max} = \left(\frac{c_z}{c_x}\right)_{\max} = 71.4 \qquad pri \quad \alpha = 6°$$

$$\frac{F_Z}{F_X} = 71.4$$

d)

$$(\bar{x}_{CP} - \bar{x}_{AC})c_z = -c_{M_{AC}}$$

$$\bar{x}_{CP} = \frac{-c_{M_{AC}}}{c_z} + \bar{x}_{AC}$$

$$\alpha = 8° \Rightarrow c_{M_{AC}} = -0.1$$
$$c_z = 1.15$$

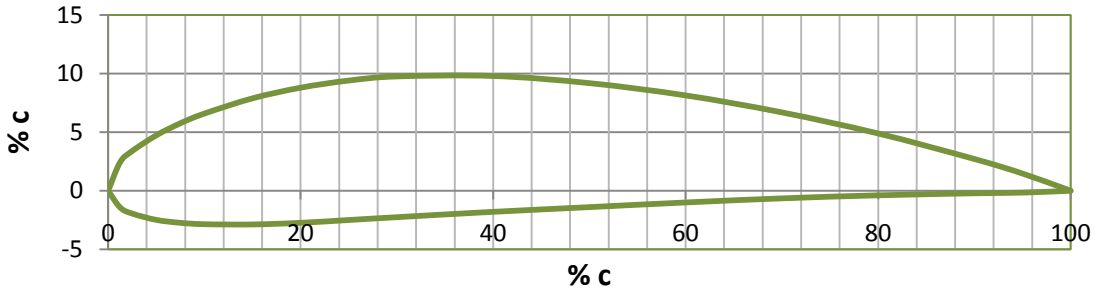
$$\bar{x}_{CP} = \frac{0.1}{1.15} + 0.246 = 0.333$$

e) $c_{M_P} = c_{M_{AC}} + c_z \cdot (\bar{x}_P - \bar{x}_{AC}) = -0.1 + 1.15 \cdot (0.25 - 0.246) = -0.0954$

AEROPROFIL NACA 4412

Udaljenost od napadnog ruba % c	Gornjaka % c	Donjaka % c
0	0	0
1,25	2,44	-1,43
2,5	3,39	-1,95
5	4,73	-2,49
7,5	5,76	-2,74
10	6,59	-2,86
15	7,89	-2,88
20	8,8	-2,74
25	9,41	-2,5
30	9,76	-2,26
40	9,8	-1,8
50	9,19	-1,4
60	8,14	-1
70	6,69	-0,65
80	4,89	-0,39
90	2,71	-0,22
95	1,47	-0,16
100	0	0

AEROPROFIL NACA 4412



AEROPROFIL NACA 4412

Napadni kut α°	Koeficijent uzgona C_z	Koeficijent otpora C_x	Koeficijent momenta C_{Mac}
-8	-0,45	0,022	-0,097
-6	-0,23	0,014	-0,092
-4	-0,03	0,012	-0,092
-2	0,2	0,01	-0,092
0	0,38	0,01	-0,093
2	0,6	0,01	-0,095
4	0,8	0,012	-0,098
6	1	0,014	-0,1
8	1,15	0,017	-0,1
10	1,27	0,022	-0,095
12	1,36	0,03	-0,092
14	1,35	0,042	-0,092
16	1,25	0,059	-0,095