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DETERMINATION OF THE CHARACTERISTICS OF WINGS USING THE SIMILARITY THEORY

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***Abstract**: This scientific work presents the way in which the small, and very small span wings can be obtained starting from the great span wings and using the two scales of the similarity theory. Basing on two scales model it can transcribe from model at nature the coefficients c_x, c_y and lengthening λ of GOTTINGEN- 612 profile.*

1.INTRODUCTION

In the following we will set out the coordinates (polars) of wings of small and very small elongation, which can be obtained starting from the coordinates of the wings of big elongation, if the theory of similitude is used at two scales. In order to obtain this it is necessary to transcribe from model to nature the coefficients c_x, c_y and elongation λ, according to the model at two scales of the wing.

2. TRANSCRIPTION OF THE COEFFICIENTS c_x, c_y AND c_M ACCORDING TO THE MODEL AT TWO SCALES

In the case of the rectangular wing in a plane, having string c constant all along the span (in this case the wing is called aerodynamically twisted with the angle of attack variable along the span) the surface of the wing is determined with the relation:

$$S = c \cdot l \qquad 1)$$

The relative elongation of the wing is:

$$\lambda = \frac{l^2}{S} = \frac{l^2}{l \cdot c} = \frac{l}{c} \qquad 2)$$

Since $K_l = K_z$ and $K_c = K_x$ the elongation scale is:

$$K_\lambda = \frac{K_l}{K_c} = \frac{K_z}{K_x} = \frac{\lambda_n}{\lambda_m} = K_1 \qquad (3)$$

$\lambda_n = K_1 \cdot \lambda_m$; K_1- distorsion ratio 4)

from which results the relation of elongation transcription:

$\lambda_n = K_1 \cdot \lambda_m$; K_1- distorsion ratio

If we write the wing's bearing force like:

$$R_y = c_y \cdot S \cdot \frac{\rho \cdot v^2}{2} \qquad (5)$$

We have:

$$K_R = K_{R_y} = K_{c_y} \cdot K_S \cdot K_\rho \cdot K_v^2 = K_{c_y} \cdot K_z \cdot K_x \cdot K_\rho \cdot K_v^2 \qquad (6)$$

The scale of the forces can also be written like:

$$K_R = K_{R_y} = K_1^2 \cdot K_\rho \cdot K_v^2 \cdot K_x^2 = K_\rho \cdot K_z^2 \cdot K_v^2 \qquad (7)$$

And by the equalization of the relations (6) and (07) we get:

$$K_{c_y} \cdot K_z \cdot K_x \cdot K_\rho \cdot K_v^2 = K_\rho \cdot K_z^2 \cdot K_v^2 \qquad (8)$$

hence resulting the scale of the unitary coefficient of the bearing force:

$$K_{c_y} = \frac{c_{y_n}}{c_{y_m}} = \frac{K_z}{K_x} = K_1 \qquad (9)$$

having thus:

$$c_{y_n} = K_1 \cdot c_{y_m} \qquad 10)$$

The advance resistence being:

$$R_x = c_x \cdot S \cdot \frac{\rho v^2}{2} \qquad (11)$$

and taking into account the relation (8), because the scale of forces is dependent on their nature we can write:

$$K_R = K_{R_x} = K_{c_x} \cdot K_z \cdot K_x \cdot K_\rho \cdot K_v^2 = K_\rho \cdot K_z^2 \cdot K_v^2 \qquad 12)$$

from which results the relation:

$$K_{c_x} = \frac{c_{x_n}}{c_{x_m}} = \frac{K_z}{K_x} = K_1 \qquad (13)$$

having:

$$c_{x_n} = K_1 \cdot c_{x_m} \qquad (14)$$

As it is known for a given profile the coefficients c_x, c_y and c_M are functions of the incidence angle α, and the criteria of similitude Re, Fr, Sh şi Eu; also, the boundary conditions of the wing in the unlimited fluid or in the vicinity of a solid or fluid surface have a great influence.

Let's examine now the scale of c_M in conditions of similitude at two scales, with small angles of attack. In this case we can write the relation:

$$M = R_y \cdot e \qquad 15)$$

In which e represents the distance from the pressure center of the profile to its board of attack.
So, we can write:

$$K_M = K_R \cdot K_c = K_\rho \cdot K_v^2 \cdot K_z^2 \cdot K_x \qquad (16)$$

and

$$K_M = K_{c_M} \cdot K_\rho \cdot K_z \cdot K_x \cdot K_v^2 \cdot K_x \qquad 17)$$

Equalizing (16) cu (17) we get:

$$K_\rho \cdot K_v^2 \cdot K_z^2 \cdot K_x = K_{c_M} \cdot K_\rho \cdot K_z \cdot K_x^2 \cdot K_v^2 \qquad (18)$$

From which results:

$$K_{c_M} = \frac{(c_M)_n}{(c_M)_m} = \frac{K_z}{K_x} = K_1 \qquad (19)$$

or:

$$(c_M)_n = K_1 (c_M)_m \qquad (20)$$

By the help of the relations (03), (10), (14), and (20) it is possible to transcribe the non-dimensional λ, c_y, c_x and c_M from the model to nature, which as seen, have in nature the values from the model multiplied by the distortion ratio K_1.Being non-dimensional, these coefficients vary to the same extent when they shift from model to nature.
We should also say that in order to obtain the nature wing's hydrodynamic coefficients we can also use the following formula: If we write the speed on the model like:

$$v_m = \frac{\mathrm{Re}_m \cdot \nu_m}{c_m} \qquad 21)$$

And having known that between the speed of the nature wing and model wing is the following relation of similitude:

$$v_n = v_m \cdot \frac{K_x}{\sqrt{K_z}} \quad (22)$$

we get:

$$v_n = \frac{\mathrm{Re_m} \cdot v_m}{c_m} \cdot \frac{\frac{c_n}{c_m}}{\sqrt{\frac{l_n}{\lambda_m \cdot c_m}}} \quad (23)$$

from which:

$$v_n = \frac{\mathrm{Re_m} \cdot \nu_m \cdot c_n \cdot \sqrt{\lambda_m \cdot c_m}}{c_m^2 \sqrt{l_n}} \quad (24)$$

or:

$$\frac{\sqrt{c_m}}{c_m} = \frac{v_n \cdot \sqrt{l_n}}{\mathrm{Re_m} \cdot \nu_m \cdot c_n} \quad (25)$$

$$(2\ c_m \sqrt{c_m} = \frac{\mathrm{Re_m} \cdot \nu_m \cdot c_n \cdot \sqrt{\lambda_m}}{v_n \cdot \sqrt{l_n}} \quad (26)$$

obtaining in this way the relation of determination of the model's string's length c_m:

$$c_m = \sqrt[3]{\left(\frac{\mathrm{Re_m} \cdot \nu_m \cdot c_n \cdot \sqrt{\lambda_m}}{v_n \cdot \sqrt{l_n}}\right)^2} \quad 27)$$

Using the definition relation of the relative elongation we can determine the span of the model wing:

$$l_m = \lambda_m \cdot c_m \quad 28)$$

We calculate the scale of the string K_C and the scale of the span K_l:

$$K_c = K_x = \frac{c_n}{c_m} \quad 29)$$

$$K_l = K_z = \frac{l_n}{l_m} \quad (30)$$

We determine the distortion ratio K_1

$$K_1 = \frac{K_l}{K_c} = \frac{K_z}{K_x} \quad (31)$$

We state the scales of density , speed, and force.

$$K_\rho = \frac{\rho_n}{\rho_m} \quad (32)$$

$$K_v = \frac{K_x}{\sqrt{K_z}} = \frac{v_n}{v_m} \quad (33)$$

$$K_R = K_\rho \cdot K_x^2 \cdot K_z = \frac{R_{y_n}}{R_{y_m}} = \frac{R_{x_n}}{R_{x_m}} \quad (34)$$

Both the model and the real wing are rectangular in plan,and we can determine, with the known data the areas of the surfaces:

$$S_m = l_m \cdot c_m \quad (35)$$

$$S_n = l_n \cdot c_n \quad (36)$$

According to the law of the model we calculate the speed of the nature (real) wing:

$$v_n = v_m \cdot K_v = v_m \cdot \frac{K_x}{\sqrt{K_z}} \quad (37)$$

With the known data we can further determine the bearing force of the model wing:

$$R_{y_m} = c_{y_m} \cdot S_m \cdot \frac{\rho_m \cdot v_m^2}{2} \quad 38)$$

Using the law of model or the relation (07), we will calculate the bearing force of the real wing:

$$R_{y_n} = K_R \cdot R_{y_m} = K_x^2 \cdot K_z \cdot K_\rho \cdot R_{y_m} \quad 39)$$

From which the coefficient of the real wing bearing force:

$$c_{y_n} = \frac{R_{y_n}}{S_n \cdot \frac{\rho_n \cdot v_n^2}{2}} \quad (40)$$

We calculate the advance resistance of the model wing:

$$R_{x_m} = c_{x_m} \cdot S_m \cdot \frac{\rho_m \cdot v_m^2}{2} \quad (41)$$

and on the basis of the law of model we get the advance resistance of the real wing:

$$R_{x_n} = K_R \cdot R_{x_m} = K_\rho \cdot K_x^2 \cdot K_z \cdot R_{x_m} \quad (42)$$

From which the coefficient of advance resistance of the real wing is deduced:

$$c_{x_n} = \frac{R_{x_n}}{S_n \cdot \frac{\rho_n \cdot v_n^2}{2}} \quad (43)$$

In conclusion, taking into account what we have mentioned before, we can say that the values of the coefficients c_{y_n} and c_{x_n} of the real nature wing do not depend on the dimensions of the model wing;

they depend only on the relative elongation of the wing, and for every single elongation of the wing only one polar is established.

It is true that if we extend the relations (10) and (14) we get:

$$c_{y_n} = c_{y_m} \cdot \frac{K_z}{K_x} = c_{y_m} \cdot \frac{\frac{l_n}{l_m}}{\frac{c_n}{c_m}} = c_{y_m} \cdot \frac{\lambda_n}{\lambda_m} \quad (44)$$

$$c_{x_n} = c_{x_m} \cdot \frac{K_z}{K_x} = c_{x_m} \cdot \frac{\frac{l_n}{l_m}}{\frac{c_n}{c_m}} = c_{x_m} \cdot \frac{\lambda_n}{\lambda_m} \quad (45)$$

This is to confirm once more that within the relations between coefficients the dimensions of model wing do not interfere.

3. TRACING THE GOTTINGEN – 612 PROFILE'S POLAR WITH RELATIVE ELONGATION λ = 3, KNOWING THE CORRESPONDING PROFILE'S POLAR CORRESPONDING TO THE RELATIVE ELONGATION λ = 5

The string's length c_n = 0,3 m and the ship's speed v_n = 25m/s is considered for the nature wing. We also stress that the initial polar was drawn in the aerodynamic tunnel, an the small span wing under observation will function in water.
Cinematic viscosity values of the two fluids are:

$$\nu_{aer} = 0{,}0000143\frac{m^2}{s} \qquad \nu_{apa} = 1{,}191\cdot 10^{-6}\frac{m^2}{s}$$

Thus, for the $c_n = 0{,}3m$, $v_n = 25\frac{m}{s}$

and $\nu_{apa} = 1{,}191\cdot 10^{-6}\frac{m^2}{s}$ there results:

$$\mathrm{Re}_n = \frac{v_n \cdot c_n}{\nu_{apa}} = \frac{25\cdot 0{,}3}{1{,}191\cdot 10^{-6}} = 6{,}27\cdot 10^6 \qquad (46)$$

Re_n = 6.300.000.

The GOTTINGEN-612 profile is characterized by: λ_m = 5 and Re_n = 420.000. The following data are to be found in the specialty literature (see table no. 1)

Table no. 1

α	c_{ym}	c_{xm}
-10,4	-0,340	0,0796
-8,9	-0,250	0,0216
-6,0	-0,056	0,0096
-3,0	0,141	0,0109
-0,1	0,322	0,0159
2,8	0,526	0,0261
5,8	0,723	0,0437
8,7	0,900	0,067
11,6	1,044	0,0941
14,6	1,073	0,135
17,7	0,952	0,260

The distortion ratios for the three elongations $\lambda_{n_1} = 3$; $\lambda_{n_2} = 2$ şi $\lambda_{n_3} = 1$ will be:

$$K_1' = \frac{\lambda_{n_1}}{\lambda_m} = \frac{3}{5} = 0{,}6 \qquad (47)$$

$$K'' = \frac{\lambda_{n_2}}{\lambda_m} = \frac{2}{5} = 0{,}4 \qquad (48)$$

$$K''' = \frac{\lambda_{n_3}}{\lambda_m} = \frac{1}{5} = 0{,}2 \qquad (49)$$

Using the equations obtained through the theory of similitude (10) and (14) we can draw up the table no. 2 for the nature wing with elongation $\lambda_{n_1} = 3$:

$\lambda_{n_1} = 3$; K_1' = 0,6 ; Re_n = 6.300.000. (table no. 2).

Table no. 2

α[º]	c_{ym}	c_{xm}
-10,4	-0,204	0,0477
-8,9	-0,15	0,0129
-6,0	-0,033	0,00576
-3,0	0,091	0,0065
-0,1	0,1932	0,0095
2,8	0,3156	0,0156
5,8	0,434	0,0262
8,7	0,54	0,0402
11,6	0,626	0,0564
14,6	0,644	0,081
17,7	0,5712	0,156

4.CONCLUSIONS

Going on in the same manner, that is starting from the polars of big span wings and using the theory of similitude at two scales, the polars of other profiles (of small and very small span), which were analysed, can be built; for example:
GOTTINGEN-439, GOTTINGEN- 480, NACA-4409, CLARK Y, RAF-32 , GOTTINGEN-565, GOTTINGEN-670, GOTTINGEN-682, GOTTINGEN-507, and NACA-6412, (for λ=3, λ=2 and λ=1) .

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