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AXIAL PLANE AIRFOIL CASCADE. GRAPHICS FOR ENERGETICAL AND CAVITATIONAL ANALYSIS IN INCOMPRESSIBLE IDEAL/PERFECT FLUID

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Abstract: *The work continues the discussions of a previous presentation (Fluid Mechanics and Its Applications – Caius Iacob Colloquium, Brasov 2006, cited as reference) regarding the operation of the program CASCADExpert in order to describe energetic and cavitational behavior of a plane airfoils cascade (NACA 8410, NACA 0010).The first part of this work partially restores the theoretical and calculation background, which was detailed in the cited paper. Starting from 3D surfaces created for* C_{pmin} (β_{IN}, β_S), C_L (β_{IN}, β_S), C_D (β_{IN}, β_S), *at t/L =const., lines of equal value can be built. For* C_{pmin} *as example, these representations allow fast and reliable determination of dangerous cavitational regimes of the cascade. The curves* $C_{Ftang} > 0$, $C_{Ftang} < 0$, *were built in the same manner, in different frames and that may give an insight into the operating field in which significant forces occur from active torque composition. The analysis took into consideration the classical curves for a plane cascade profiles having a constant stagger angle* β_S = *const. and as parameter ratio t / L = 0.5, 0.75, 1.00, 1.25 or at constant ratio t / L = constant having as parameter the stagger angle* β_S = *30°, 60°, 90°, 120°. Finally, the calculations and representation were oriented towards design so there were built curves of equal value for* C_{Ftang} , C_{Faxial}, C_{pmin} *in the field* δ_U-β_{IN}, *as well as synthetic images valuable for the designers of axial hydraulic machines, as they explicitly indicate the areas recommended for the machine's operating system, or the avoidable ones*. .
Keywords: *airfoils cascade, NACA airfoils, ideal/perfect fluid, energetic and cavitational curves, design parameters for axial hydraulic machines*

1. INTRODUCTION

The paper herein stands for the follow-up of a technical dissertation submitted during the previous edition of the conference: Fluid Mechanics and Their Technical Applications – Caius Iacob, Braşov, 2006 [9], which resulted in having determined curves and surfaces characteristic for a family of airfoils cascades, numerically tested in ideal fluid, through the CASCADExpert software, elaborated by a group of professorial staff and researchers from the National Centre of System Engineering of Complex Fluids (Romeo Susan-Resiga, Sebastian Muntean, Teodora Frunză).

There have been designed and provided, under the same conditions of the numerical experiment, useful graphical tools, in the attempt at bringing the research results closer to the necessities of the builders of axial hydraulic machines. As there has already been ascertained and downed in several technical works, [7], [8], [1], the tests in ideal fluid have yielded similar results (through the distribution of C_p on the extrados and intrados) in certain airfoils cascades and under certain operating conditions, as compared to the experimental

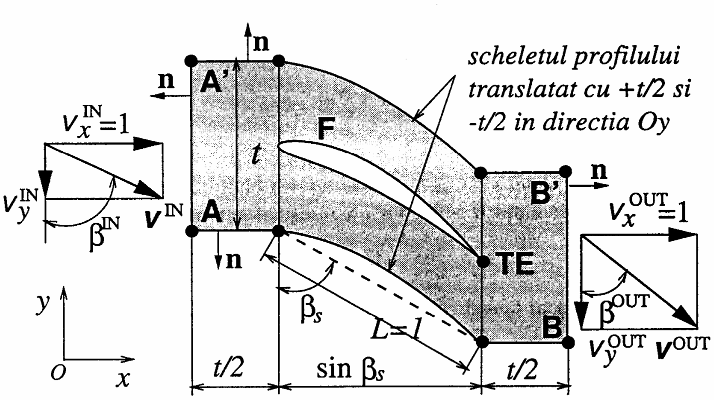

Figure 1: A double connected domain and the geometrical and kinematical parameters

results by Speidel and Scholz [5]. Therefore, the synthetic curves submitted herein may prove their usefulness.

2. FUNDAMENTAL THEORETICAL RELATIONS OF THE MODEL

The theoretical bases that enabled the development of the CASCADExpert software have been minutely enunciated and presented in [1], [7], [8], [9], and [10].
We have restricted the discussion herein to describing the doubly connected domain used by the authors of the model (fig.1) and to enunciating the relations that have permitted the deduction of the energetic and cavitational control values. The relations and notations in [1], [7] were connected to the classical theory pertaining to R. Comolet who, for the dependence between the input and outlet angles of the current within the airfoils cascade, submits:

$$tg\alpha_2 = A + B\ tg\alpha_1 \tag{1}$$

or $$tg\alpha_2 = A\left(t/L\right) + B\left(t/L\right)tg\alpha_1 \tag{2}$$

that is for a fixed stagger angle, the factors A, B exclusively depend on the relative pitch t/L of the airfoils cascade

$$2tg\alpha_m = tg\alpha_1 + tg\alpha_2 \tag{3}$$

or from the combination of (2) with (3)

$$tg\alpha_2 - tg\alpha_1 = \frac{2A}{B+1} + 2\frac{B-1}{B+1}tg\alpha_m \tag{4}$$

and one of the important parameters of the airfoils cascade

$$\delta_U = tg\alpha_2 - tg\alpha_1 = \Delta tg\alpha_1 \tag{5}$$

as.. $tg\alpha_2 = f\left(tg\alpha_1\right)$

Adapting these results to the notations in Fig. 1

$$\alpha_1 = \beta_{IN} - 90^\circ \quad \text{and} \quad \alpha_2 = \beta_{OUT} - 90^\circ \tag{6}$$

Therefore $$\delta_U = tg\alpha_2 - tg\alpha_1 = \frac{1}{tg\beta_{IN}} - \frac{1}{tg\beta_{OUT}} \tag{7}$$

respectively $$\alpha_\infty = arctg\left[-\frac{ctg\beta_{IN} + ctg\beta_{OUT}}{2}\right] \tag{8}$$

$$v_\infty = \left[1 + \left(\frac{tg\alpha_1 + tg\alpha_2}{2}\right)^2\right]^{\frac{1}{2}} \tag{9}$$

The lift force coefficient being deduced through Joukowski relation

$$C_L = -2\frac{t}{L}\delta_U \cos\alpha_\infty \tag{10}$$

For the pressure coefficient C_p we have the possibility of referring to v_∞ (speed deduced by theoretical incidence) and v_{OUT} (speed at outlet).

$$C_p\left(\text{at outlet speed}\right) = \frac{p - p_{OUT}}{\frac{1}{2}\rho\left(v_{OUT}\right)^2} = 1 - \left(\frac{v}{v_x}\right)^2 \sin^2\beta_{OUT} \tag{11}$$

And, through analogies,

$$C_p\left(\text{at } v_\infty\right) = 1 - \left(\frac{v}{v_x}\right)^2 \sin^2\beta_\infty \qquad \text{where} \qquad \beta_\infty = \alpha_\infty + 90^\circ \tag{12}$$

3. ANALYSIS CURVES 2D AND EQUAL VALUE CURVES

The surfaces that reflect spatial dependences (3D) are spectacular and intuitive, however less too practical for extracting concrete data. Therefore, we prefer their projection on the plane β_S - β_{IN}.
In the case of an airfoils cascade consisting in airfoils NACA 8410 at t/L=0.75 C_{pmin}=f (β_S-β_{IN}) it constitutes in a (riding) saddle-shaped surface fig 2, which, in projection upon the horizontal plane, forms the lines of equivalent value for C_{pmin} (fig 3).

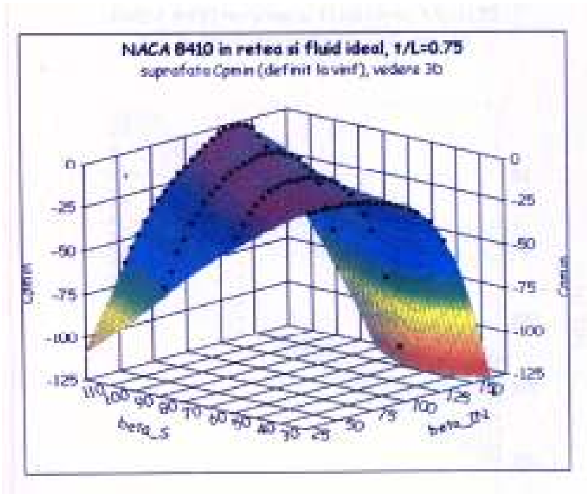

Figure 2: Surface build with this values of C_{pmin}, NACA 8410 in a cascade density t/L=0.75

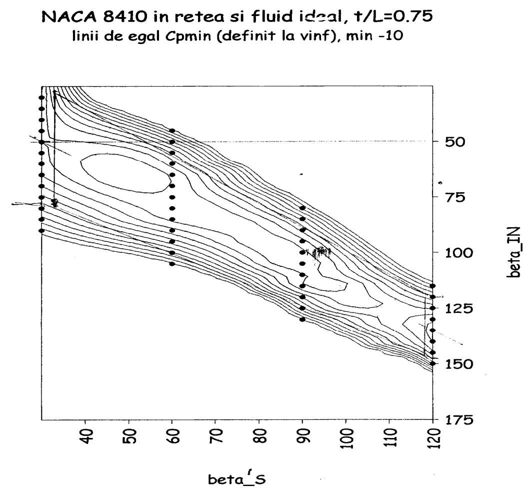

Figure 3: Curves of equal value of C_{pmin}

Out of this last representation, we may determine that a cavitationally reasonable area, for this airfoils cascade, appears around the point of coordinates β_S =50° and β_{IN}=70°, however reasonable values may be found on the line that goes from that point down to β_{IN}=135°.

For a detailed analysis of the airfoils cascade, we may approach a series of representations (dependences) at β_S=const and we will obtain

C_L=f (β_{IN}) which describes the influence of the input angle on the lift force of the airfoil within the airfoils cascade.

All these curves are designed and drawn resorting to t/L as parameter, that is for t/L=0.50; 0.75; 1.00; 1.25.

All graphs 2D and 3D drawn up for the profile NACA 8410 have been likewise remade for the symmetrical profile NACA 0010, but precisely due to the symmetry of the airfoil section, their evolution is more predictable.

We have traced the same curves for t/L=const, respectively t/L=0.75 resorting to the relief (stagger) angle β_S as representation parameter

β_S = 30°, 60°, 90°, 120°.

This last analysis displays more practical importance as such a situation corresponds to the axial machines whose blades spin round the shaft thrust in the hub, therefore with variable relief angle of the airfoils cascade.

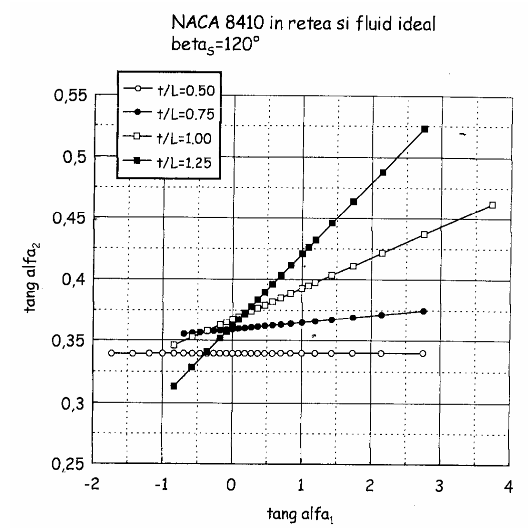

Figure 4: Dependence between the input angle and the output angle of the flow, for different t/L

There have been also drawn up, C_L=f (β_{IN}) fig. 5

C_{pmin}=f (β_{IN}) fig. 6

C_{Ftang}=f (β_{IN}) defined at v_∞.

C_{Faxial}=f (β_{IN}) defined at v_∞.

If we should comment one of the representations (fig 6) we might state that these curves suggest we can avoid the cavitation upon quite a wide interval β_{IN}, approximately 25°-> 150° if we take due precaution to remain on the closest curve to C_{pmin}=0, that is to modify the relief angle β_S.

This is a useful conclusion in rough terms, however of no practical usefulness because of the energetic constraints.

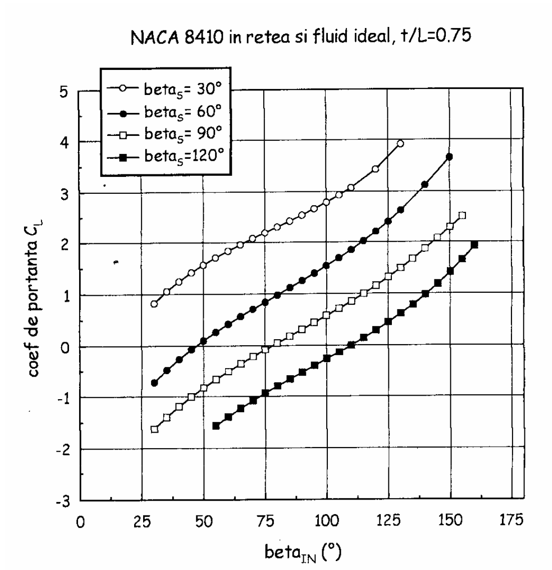

Figure 5: Lift coefficient dependence vs. the input angle at different stagger angles of cascade

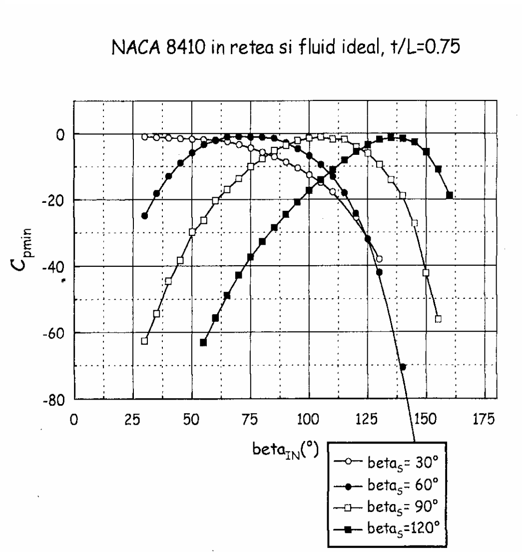

Figure 6: Variation of C_{pmin} at different angles β_S and t/L constant

4. SYNTHETIC DESCRIPTION OF A GIVEN AIRFOIL FUNCTIONING IN THE AIRFOILS CASCADE AND IN IDEAL FLUID

The graphical investigations took two senses to the same effect.
In-depth, that is towards the simple dependences upon the pressure coefficient C_p

- Influence of the relative pitch of the cascade (t/L) fig. 7
- Influence of the input angle β_{IN}
- Influence of the relief (stagger) angle β_S

The distribution of the pressure coefficient integrates all elements characterizing the energetic and cavitational behaviour of the airfoil (singular or within the airfoils cascade), hence it remains the starting point for any analysis or comparison.
Deciphering the graphical representation in the article herein allows us to bring forth the following remarks:

a) The influence of the relative pitch of cascade t/L is more strongly perceived on the intrados than on the extrados (wherein the curves are very close) ;
b) Once with the augmentation of the relative pitch of cascade t/L, there also rises the closed representation area of C_p.
c) Once with the augmentation of the relative pitch, there draws closer to the horizontal (to a plateau region) the distribution of the pressure on the intrados.

In extension (to draw the general conclusion)
Casting our eye over the studies and practice of the researchers from Timişoara, especially over Prof. Viorica Anton's works who obtained on a purely experimental path, consequently in ideal fluid, the universal diagrams of the airfoils cascades, the idea occurred to us that we should draw up such diagrams ever since this very stage, that is for airfoils cascades in ideal fluid.
This opportunity speaks for itself, taking into consideration the analogy of the physical experiment with the numerical experiment, but especially through raising the estimate output and the availability of the post-processing solutions.
There was only necessary to multiply the numerically tested points in order to improve the quality of the curves, this time semi-automatically plotted.
We have traced a set of 3 diagrams 3D, and their adjoin projections through lines of equal value.

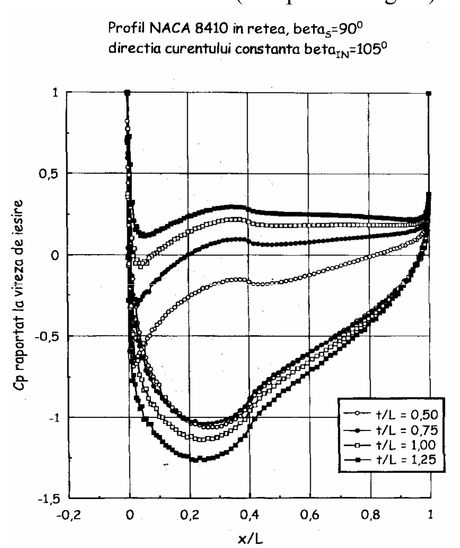

Figure 7: Pressure distribution around the airfoil in cascade at different values of t/L

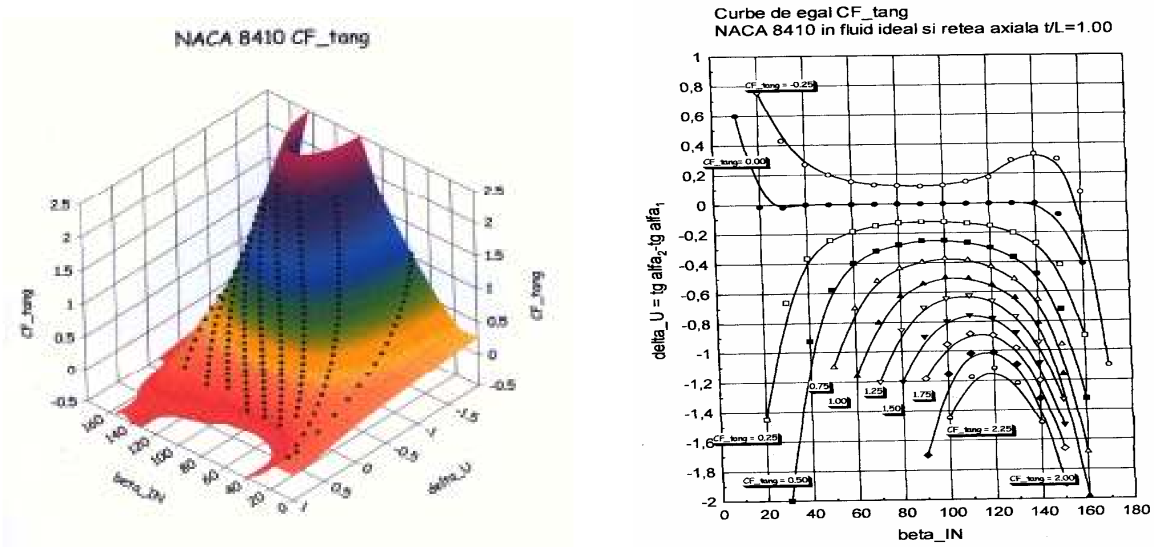

Figure 8: Tangential force coefficient for NACA 8410 in cascade and projection contours of the curves of equal value C_{Ftang}

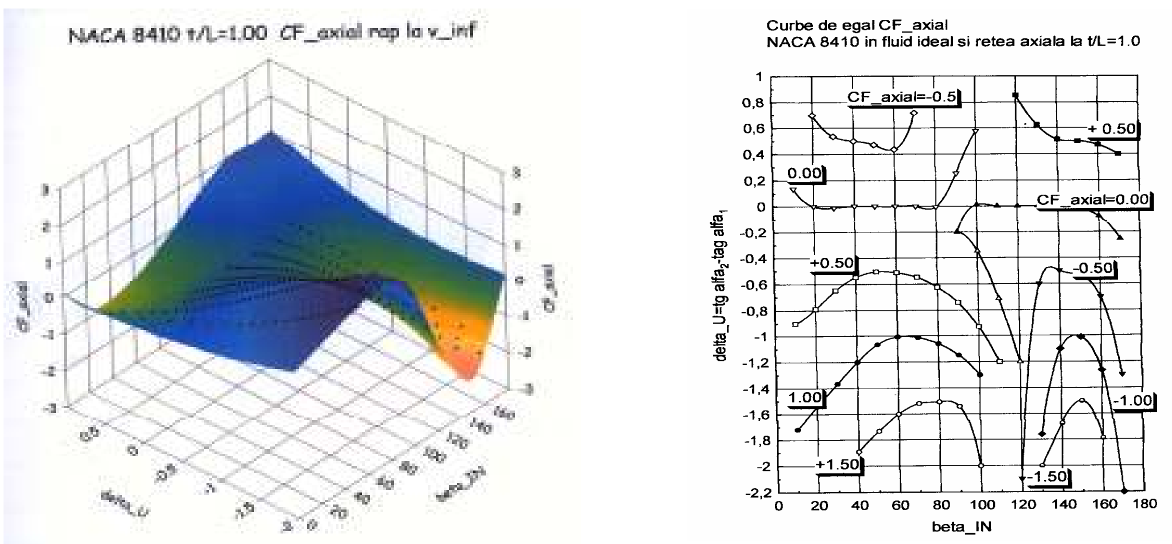

Figure 9: Axial force coefficient for NACA 8410 in cascade and projection contours of the curves of equal value C_{Faxial}

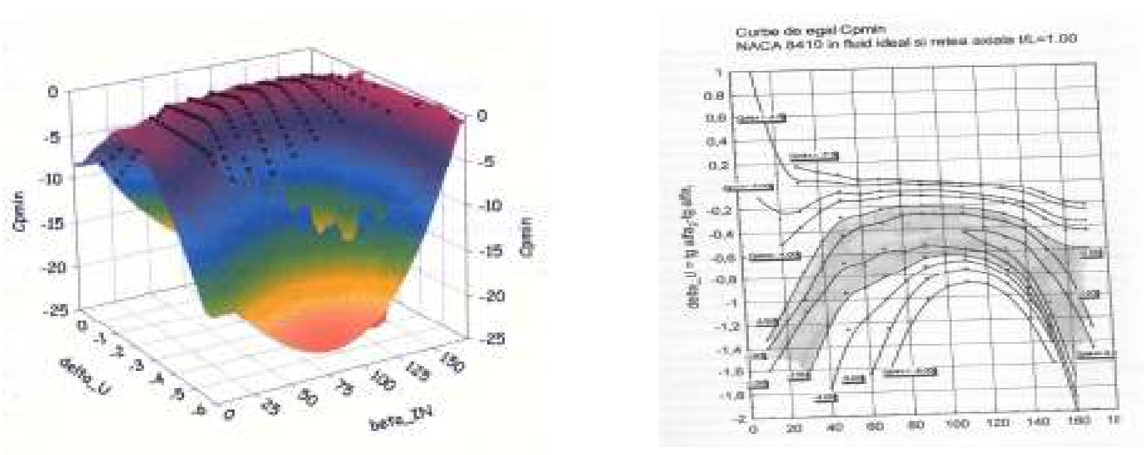

Figure 10: Minimal value of pressure coefficient for a cascade at t/L=1.0 and the area recommended for a design without cavitational risks

All these three coefficients being referred to v_∞.
These three graphs have been ad jointly represented everyone in spatial variant and projected through lines of equal value.
The surfaces and the curves in fig. 8 and 9 provide concentrated energetic information, proving their usefulness in the calculations of functional optimizing and in the calculation of the mechanical strain.
The curves in fig.10 have been traced down to the depth of C_{pmin}=-7.5 (-8) with the pitch cascade of 0.5 and it displays the strong point of emphasizing the range of minimum cavitational risk. At the same time, there is likewise emphasized the fact that in the range delimited through β_{IN} >110° and δ_U <-0.8, the cavitational risks become major at the slightest operational sideslip. The delimitation of this range suggests to begin the design from the cavitational criterion, there ensuing that the acceptable pairs of values δ_U - β_{IN} should be subsequently confirmed through energetic coefficients.

5. CONCLUSIONS AND PERSPECTIVES FOR FURTHER DEVELOPING THE RESEARCH

According to the formulizing provided in the works by V. Anton [2], the universal diagram will be obtained through superimposing the three diagrams of iso-value (of equal value) [fig.8, 9, 10] with further addition of the curves of hydraulic losses.
There are differences of aspect between these representations, in the first place because we work in ideal fluid and hence there cannot be plotted the curves of hydraulic losses.
Other formal differences are given by the fact that the representation values have been differently defined in these two papers; we having adopted for δ_U, for instance, R. Comolet's formulation.
There is however of consequence the fact that such graphical representations have emerged ever since the stage of the numerical experiment in ideal fluid, there being thereby provided concentrated and significant, information for determining the most correct option, in choosing an airfoils cascade either accelerating or decelerating.
The direction for further development of the research could be the remaking itself of the numerical experiment, through a simulation code, which likewise functions under the conditions of the real fluid. Only after extracting and processing the data referring to hydraulic losses, we might plot a universal diagram of the airfoils cascade, of usefulness for the judicious design of the axial hydraulic rotors.

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