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# Effects of the Blades Orientation on a Cross-Flow Water Turbine Performance

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**Abstract**: Efficiency and power improvement of cross-flow turbines harnessing rivers and ocean water energy is a key issue. Therefore, in this paper, we present the results of an experimental investigation on the effects of the blades orientation on a cross-flow water turbine performance. Four similar test models (same dimensions and blades) bur for different blades orientation angle i = 1.75 °, 4.5 °, - 1.75 ° and - 4.5 ° have been tested to evaluate the performance of this vertical axis water turbine (VAWT), for several water flow velocities V varying from 0.3 to 0.59 m/s, which correspond to a water free flow Reynolds number of $2.08\ 10^4$ to $4.36\ 10^4$. An analysis of these experimental results has shown that the best performance (biggest power and power coefficient) was obtained for the test model with its blades orientation angle set to 1.75 ° and the worst performance was given for the test model blades orientation of -4.5 °. A comparison of the present results with those obtained in a previous experimentation for a similar test model but with i = 0 °, has shown that the test model with its blades orientation angle fixed to 1.75 °, furnished relative increases of optimum mechanical power and of corresponding power coefficient respectively as much as 82 % and 67 % with respect to the results for i = 0 °, at a flow velocity equal to 0.37 m/s. While, the test model, with negative angle of -4.5 °, gave smaller generated power and power coefficient with corresponding relative decreases of about 49 % and 36 % with respect to those obtained for the test model with its blades fixed at 0 °.

**Keywords:** Renewable energy, Cross-flow turbine, Orientation angle, Rivers, Power

## Introduction

Ongoing fossil energies decreasing availability concern and global warming issues, led to growing attention giving to renewable energy as an alternative and in particular to water Darrieus turbine, to harness water energy of hydraulic reservoirs with small head, rivers and sea currents. Produced electricity can be either transmitted to an onshore grid (Moranchel, Bueno, Rodriguez and Sauz, 2014) or stored (Vaezi and Izadian, 2015) and (Takaoka and Itoh, 2016).

An experimental study, was carried out by Kaprawi, Santoso and Sipahutar (2015), for a combined Darrieus and Savonius water turbine placed in a river, during which, they found that the maximum power coefficient of 0.19 and torque coefficient of 0.107 were obtained when the attaching angle on the returning side of Savonius bucket β is set to 30°. A wall grid analysis and comparison with experiments was presented by Maître, Amet and



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Peltone (2013). Their study showed that a too coarse wall grid leads to early and overestimated stalls and have negligible contributions on the power. Ploesteanu, Tarziu and Maître (2003) conducted a study on the flow modeling for a Darrieus turbine at moderate Reynolds number and found that the determined effort coefficients results show significant deviations from the experimental ones. The experimental study presented by Rus T., Rus L.F., Abrudan, Domnita and Mare (2016) show that, for the same velocity, vertical axis wind turbines rotate at lower RPM than water turbines.

Thyagaraj, Rahamathullah and Suresh Prabu (2016) conducted an experimental study on a modified hydro-kinetic four bladed Savonius turbine which improved the power coefficient from 0.16 to 0.19. Sanusi, Soeparman, Wahyudi and Yuliati (2016) carried out and experimental study of a wind Savonius turbine with combined blades; their results show an increase of the maximum power coefficient by up to 11 % with respect to the conventional blades at the tip speed ratio (TSR) of 0.79. Shahinur, Sabuj Shah,Nazmul and Ashraful (2013) presented an analysis of the possibility of using small-scale hydro power plant in Surma and Gumoti (Bangladesh) and deducted that these two rivers can produce respectively 14.804 MWhr and 18.834 MWhr per year.

An experimental investigation for a vertical water Darrieus turbine, was carried out and presented in (Benzerdjeb, Abed, Hamidou, Bordjane and Gorlov, 2017); the tests were done for Darrieus turbine model with a geometric angle of incidence of its 3 blades set to 0°. Their results have shown a 604% relative increase of the mechanical power generated by this turbine for a relative increase of the water flow velocity of only 100%.

## Work Purpose

The aim of this work is to conduct several experiments to evaluate the performance (the variation of the torque, mechanical power, and power coefficient) of a vertical axis water Darrieus turbine (VAWT), for its 3 NACA0020 blades positive and negative geometric angle of incidence (i = 1.75 °, 4.5 °, -1.75 ° and - 4.5 °), for different water flow velocities (V = 0.37 to 0.46 m/s). The analysis of this experimental results and the comparison with the previous experimental results presented for i = 0 ° in (Benzerdjeb et al., 2017) will allowed us to determine the optimum blade angle which gives the maximum torque and power.

## Experiment

### The Experimental Setup

Figure 1 shows the experimental setup which is composed of a big tank with a height of 60 cm, a width of 92 cm and a length of 244 cm. The water supplied by a submerged pump pours into the first part of this tank, which can be qualified as a storage and discharge tank has a length of 100 cm. Water flows from this reservoir through a covered channel 120 cm long and with 23 cm by 23 cm rectangular section.

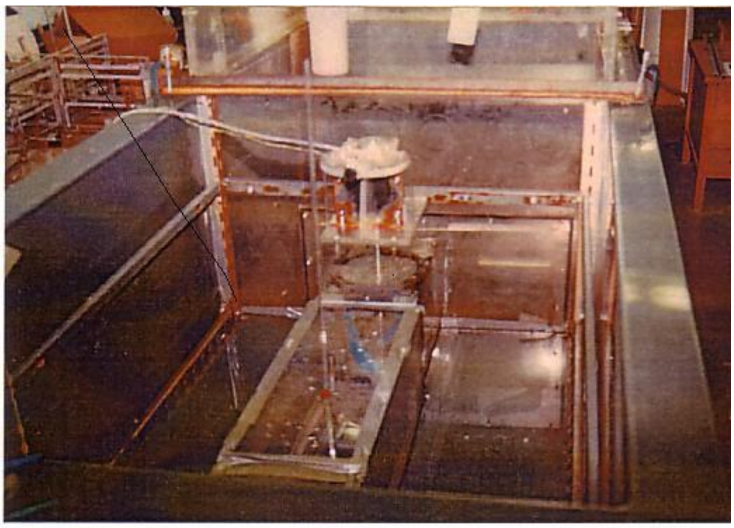

Figure 1. Experimental setup

Faure (1984) showed during the experiments that the extracted energy increases when the channel width (duct) is reduced, by forcing the flow of the fluid through the turbine.

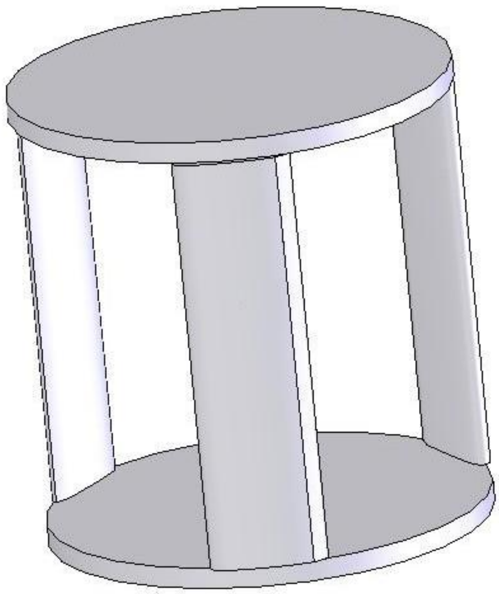

Figure 2. Experimental model

Each experimental model of the water Darrieus turbine (figure 2) is fixed in this channel with its axis of rotation in a vertical position and is coupled to a device for measuring the speed of rotation and the torque and their measurements are done via an electronic indicator.

**Experimental Series**

A total of fourteen experiments were conducted for four models of the Darrieus turbines with the same height of 23 cm and the same diameter of 21.5 cm. These models have three NACA0020 blades with a cord of 7 cm and are fixed with a separation angle of 120 °. The first model, with its blades are set at a geometric angle of incidence i = 1.75 °, was tested at different water velocity values (V = 0.3, 0.37, 0.41, 0.46 and 0.49 m/s). Then, a second model with i = 4.5 ° was tested for V = 0.35, 0.39, 0.45, 0.46 and 0.59 m/s. Two other series of experiments were carried out for the two other similar models but with the angle of geometric incidence of their blades respectively equal to i = - 1.75 ° (for V = 0.37, 0.41 and 0.46 m/s) and i = - 4.5 ° (for V = 0.37 and 0.43 m/s). The free flow Reynolds number Re vary respectively from 2.08 $10^4$ to 4.36 $10^4$.

The measured experimental results will be used to calculate the corresponding mechanical power, and power coefficient will be compared with those presented in (Benzerdjeb et al., 2017) for i = 0 °.

## Formulation

Figure 3 represents an axial section of the Darrieus turbine with the geometric angle of incidence of its blades.

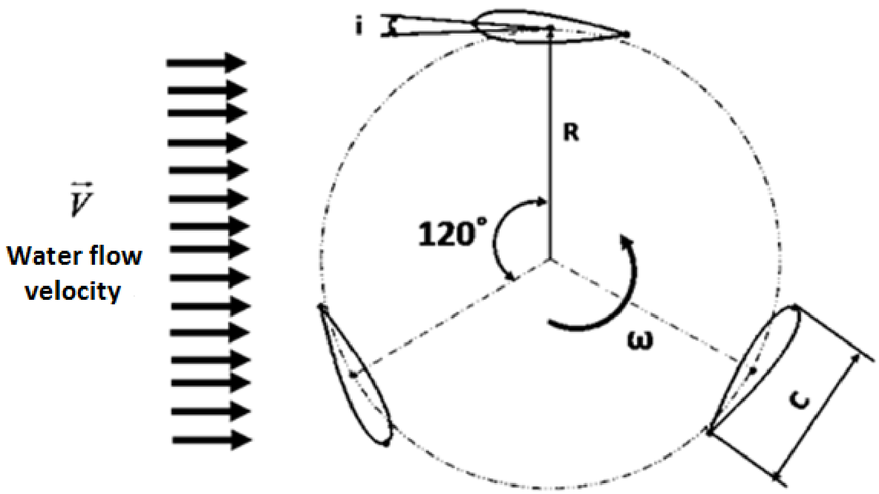


Figure 3. Darrieus turbine axial section

The free flow, the relative flow and the rotational Reynolds numbers, respectively $Re_V$, $Re_W$ and $Re_U$, based on the blade chord (C), are given (Maître et al., 2013) and (Paillard, Hauville and Astolfi, 2013) by,

$$Re_V = \frac{CV}{\nu} \tag{1}$$

$$Re_W = \frac{CW}{\nu} \tag{2}$$

$$Re_U = \frac{CU}{\nu} \tag{3}$$

where ν is the water kinematic viscosity.

The mechanical power ($P_t$) generated by the Darrieus tidal turbine (Cocina, Leo, Pastorelliand and Spertino, 2016) and (Vieira and Sanz-Bobi, 2016), the available power ($P_w$) of the water flow passing through the Darrieus tidal turbine and its power coefficient ($C_P$) (Bertin and Smith, 1998) are respectively given by,

$$P_t = T_t.\omega = T_t\frac{2\pi N}{60} \tag{4}$$

$$P_w = 2\rho.g.b.R.V.H_{ef} \tag{5}$$

$$C_P = \frac{P_t}{P_w} = \frac{\pi N T_t}{60\rho g b R V H_{ef}} \tag{6}$$

where,

$T_t$ = turbine torque
ω = turbine angular velocity (= 2π.N/60)
N = number of revolutions per minute
ρ = water density
g = gravitational acceleration
b = blade length
$H_{ef}$ = water effective height
2bR=A= turbine projected area through which the water passes

## Results and Discussion

On figures 4 and 5, we can observe, that the relative flow Reynolds number varies between 4.61 $10^4$ (for maximum power output) and 2.15 $10^5$ (for free turbine rotation) for i = 1.75° and between 3.45 $10^4$ and 2.0 $10^5$ for i = -1.75°, with a symmetry about θ = 180° (4.28 $10^4$ to 2.33 $10^5$ for i = 4.5° and 3.99 $10^4$ to 1.54 $10^5$ for i = -4.5°). The rotational Reynolds number varies from 5.94 $10^4$ (at the lowest RPM) to 1.93 $10^5$ (at the highest RPM) while the free flow Reynolds number varies from 2.08 $10^4$ to 4.36 $10^4$.

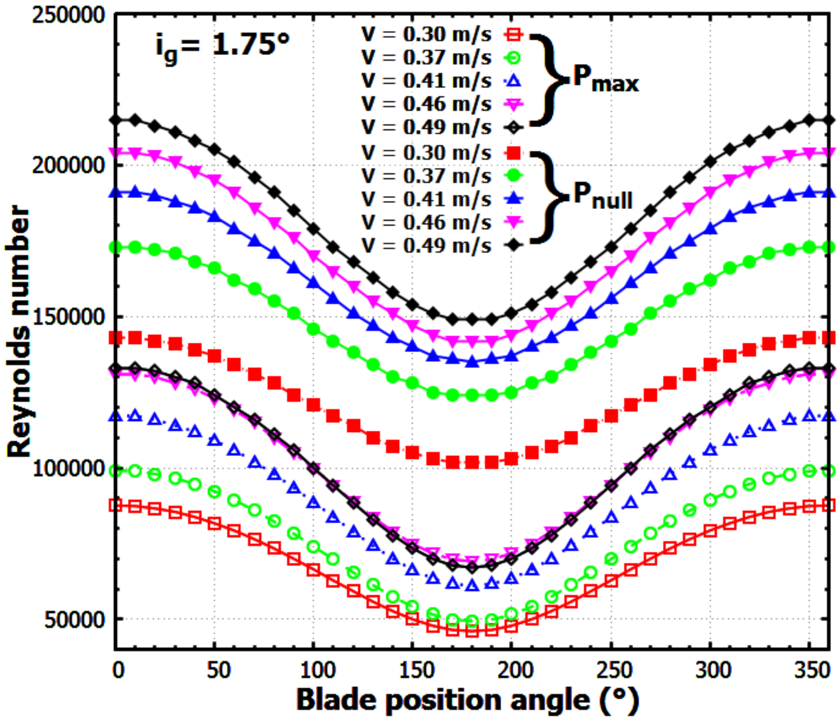


Figure 4. Relative Reynolds number (i =1.75°)

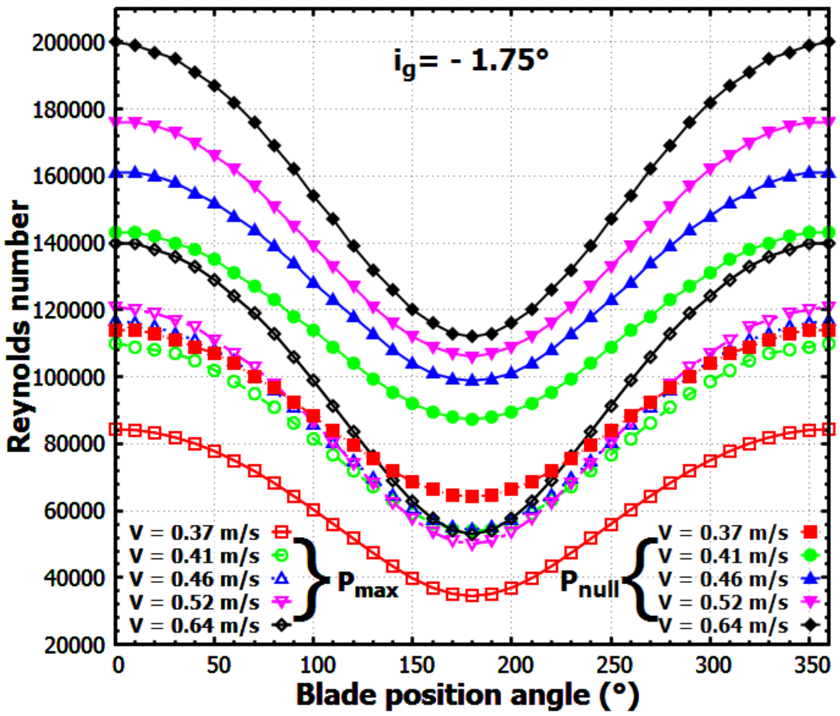


Figure 5. Relative Reynolds number (i = -1.75°)

From fig. 6 and 7 we can notice that for similar water flow velocity the best performance is obtained when the water Darrieus turbine blades geometrical incidence angle ‘i’ is set to 1.75 °. In fact, for V = 0.37 m/s and when ‘i’ is changed from 0 ° to 1.75 °, the maximum power and power coefficient increase respectively from 1.66 W to 3.015 W and from 16.92 % to 28.2 % which correspond to a relative increase of 81.82% and 66.67%. This power relative increase could be as much as 95% for V = 0.43 m/s. For i = 1.75 °, the power relative increase is 44% for a water relative increase of 11%.

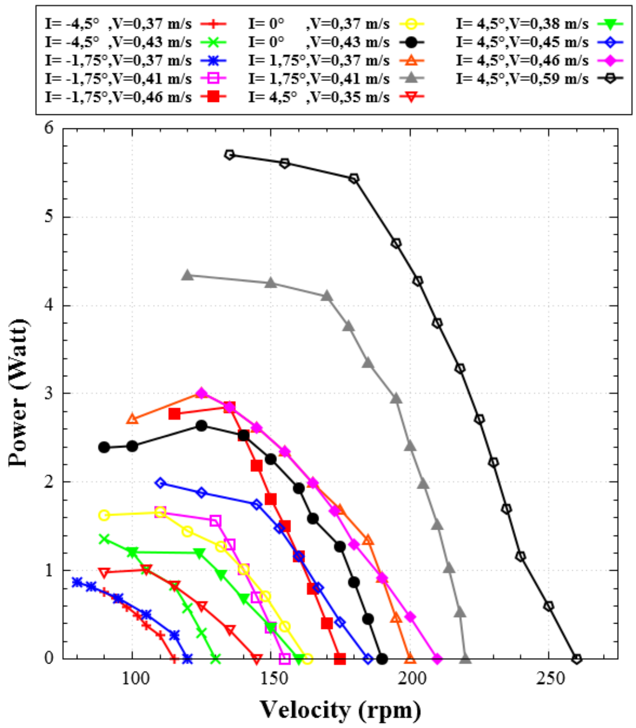


Figure 6. Darrieus turbine power

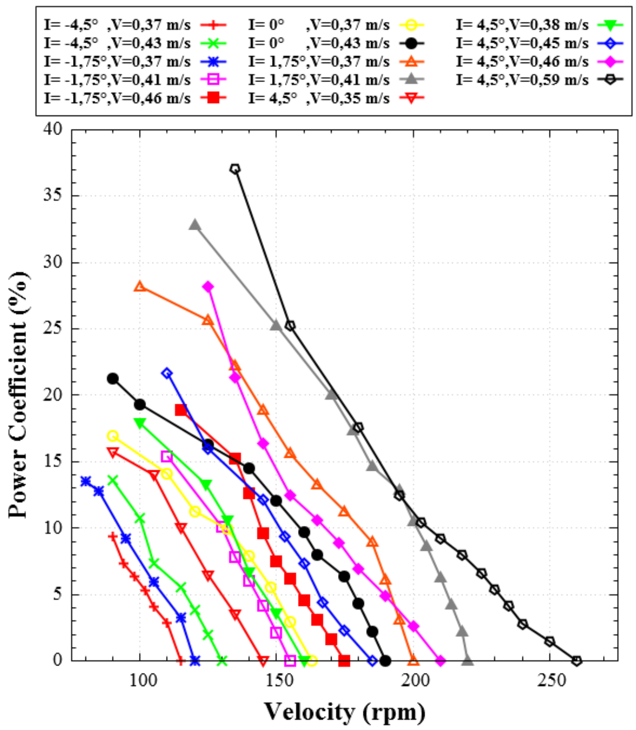


Figure 7. Darrieus turbine power coefficcient

Figures 8 and 9 represent the working curves for the maximum torque and maximum power of this tested water Darrieus turbine at water velocity of 0.37 and 0.41 m/s versus the blades geometrical incidence angle. We can see that the best performance is obtained for the test model blades set at the optimum angle of 1.75°.

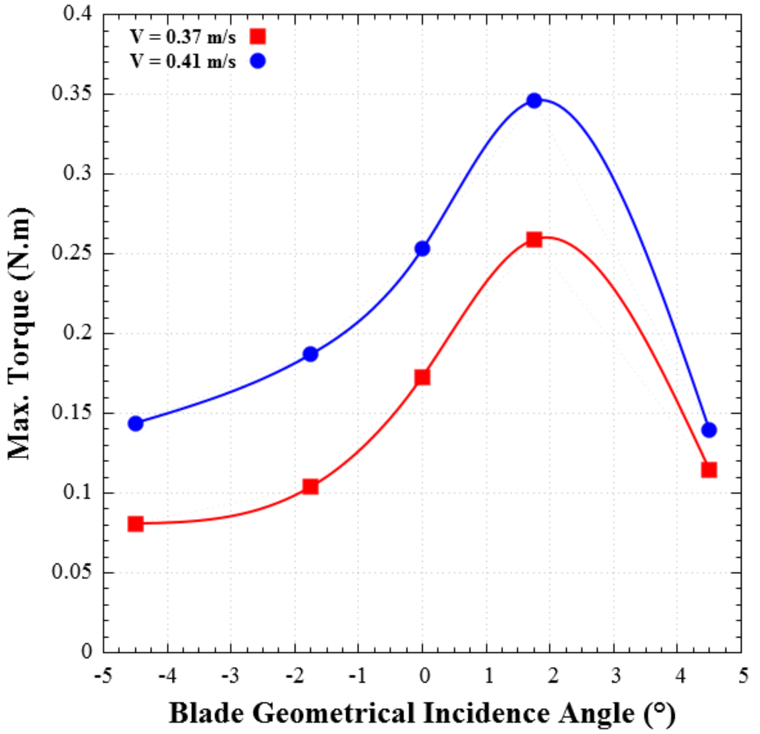


Figure 8. Darrieus turbine maximum torque

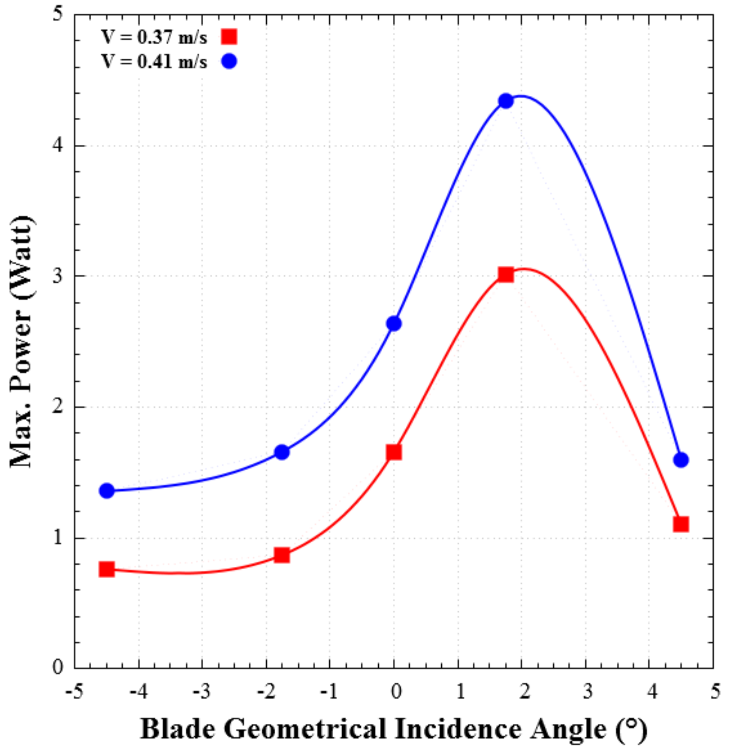


Figure 9. Darrieus turbine maximum power

## Conclusion

The objective of this experimental study was to evaluate the influence of the NACA0020 blades geometric incidence angle (i = 1.75 °, 4.5 °, - 1.75 ° and - 4.5 °) on the performance of a vertical axis water Darrieus turbine (VAWT) at different flow velocities (0.37 to 0.59 m/s). The results of this study were compared to the results of a previous experimental study done for a similar test model with its blades set at 0 °.

The analysis of the experimental results of these four tested models showed that the model with its blades fixed at i = 1.75 ° gave the best performance. Indeed:

- the maximum power and power coefficient relative increase are respectively 1.82 and 1.67 times those of i = 0 ° at V = 0.37 m/s;
- this maximum power relative increase could be as much as 1.95 that for i = 0 ° at V = 0.43 m/s;
- the power relative increase is 44% for a water velocity relative increase of only 11%.

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