Effect Of Leading-edge Geometry And Thickness On The Performance Of Miniature Cryogenic Expansion Turbine

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Introduction

— Effect of trailing-edge geometry and thickness on the performance of turbine has already haven a experimental verification[1].

— While leading edge are often established in an arbitrary and intuitive way although test results seem to indicate that they have a sensible effect on the form of pump or turbine characteristics[2].

— For avoiding the excessive loss caused by the separation flow from the suction surface near the lading-edge, the flow at stagnation point is approximately radial[2][3] .

Goal:
In order to study the specified effect of leading-edge geometry and thickness on turbine, we compared the **thermal performance** of the **four leading edge geometries** with **four different thicknesses** based on numerical simulation.
For **ellipse leading-edge**, whether **the direction of the streamline** is radial at stagnation point should be further explored.

Methodology

Figure 1 shows the four different leading-edge geometries.
Figure 2 shows a impeller with a ellipse a leading-edge, and its thickness is 0.7mm. Blade number is 10, the inlet diameter of the turbine is 16mm, the working fluid is Helium-4.
Figure 3 shows the 3D mesh of the impeller(leading-edge amplification), the total element number is 471293, and total number of faces is 57546.
Impeller inlet mass flow rata, static temperature and outlet static pressure were known, we changed the coordinate component of absolute velocity to alter the inlet velocity triangle.

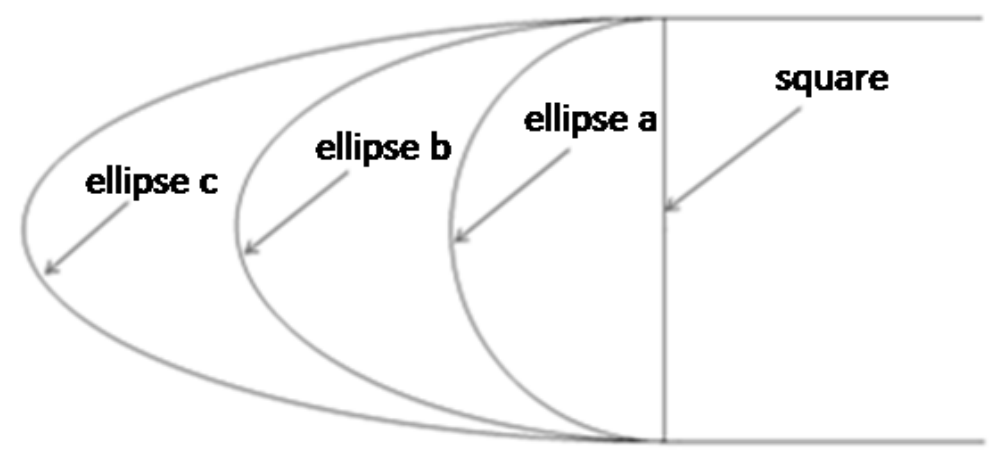

Figure 1. Different leading-edge geometries

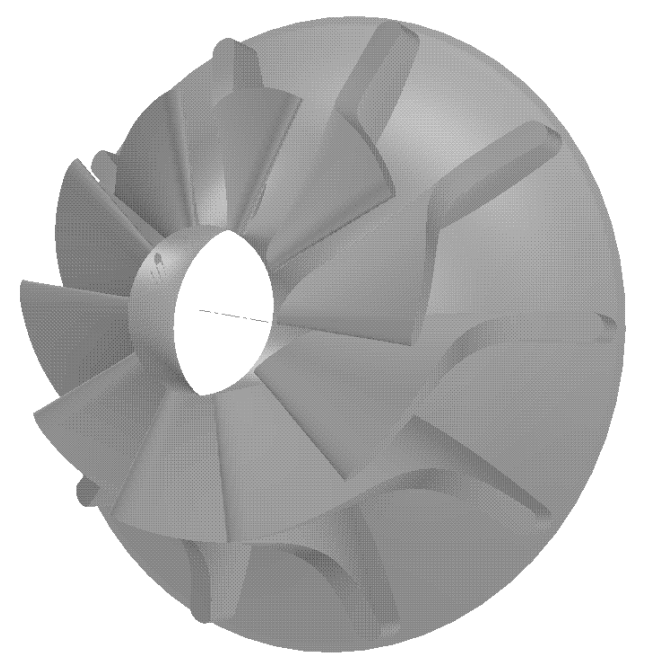

Figure 2. Geometry of the impeller

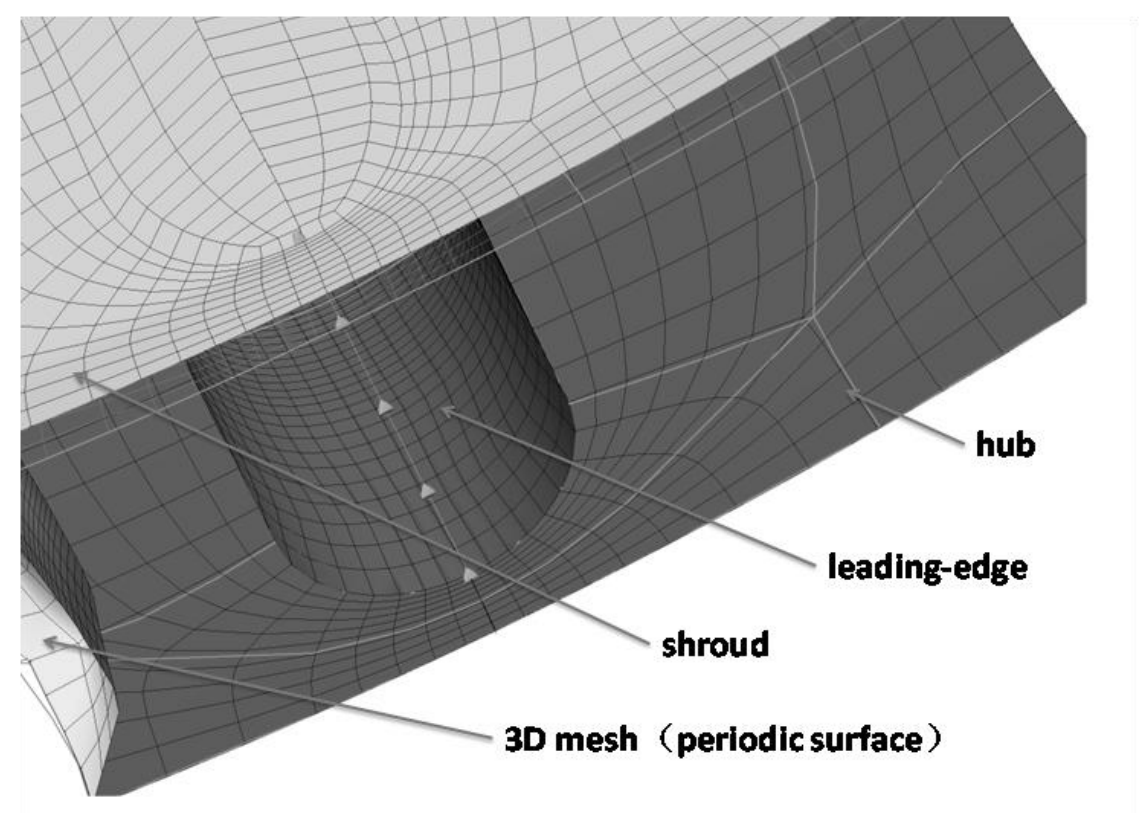

Figure 3. Impeller mesh for numerical calculation(leading-edge)

Continuity Equation
In the flow passage part of the turbine expander, it is generally considered to be a stable so-called shaped flow[4], so the continuity equation is:

$$\int_A \rho C \cdot dA = 0$$

Momentum Equation
In the flow channel of the turbine expander, the volume force is not considered generally, so the momentum equation of the inviscid fluid is[5]:

$$\frac{dC}{dt} = -\frac{1}{\rho}\nabla P$$

Energy Equation
The stable flow energy equation without friction loss in a turbine expander can be simplified to:

$$\dot{W}_e = -\int_A \left(i + \frac{C^2}{2}\right)\rho C \cdot dA$$

A is cross-sectional area of control body, **ρ** is density of working fluid, **C** is absolute velocity of working fluid, **P** is pressure, **i** is specified enthalpy of working fluid.

Results

a. Comparison between different geometries and thicknesses

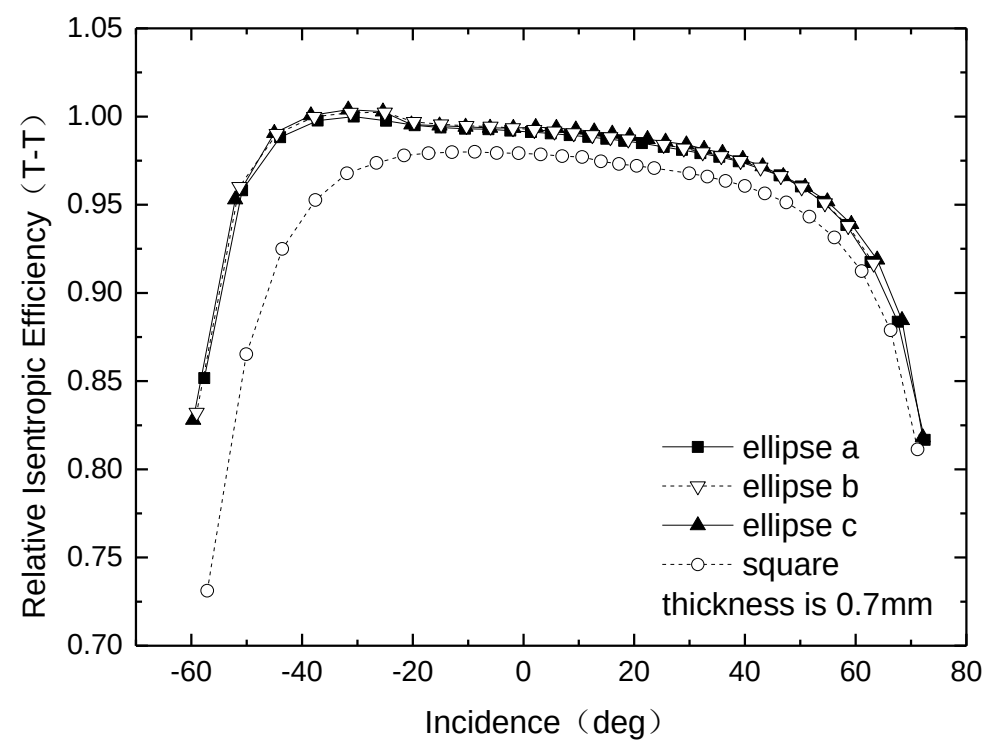

Figure 4. Comparison of relative isentropic efficiency with different leading-edge geometries

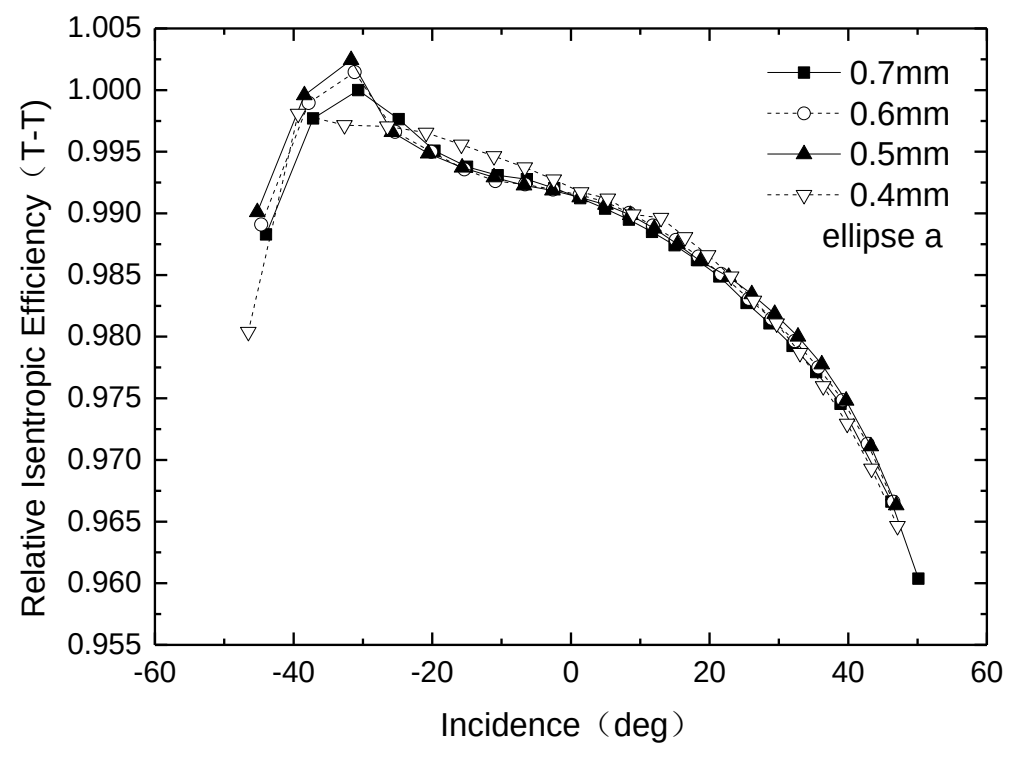

Figure 5. Comparison of relative isentropic efficiency with different leading-edge thicknesses

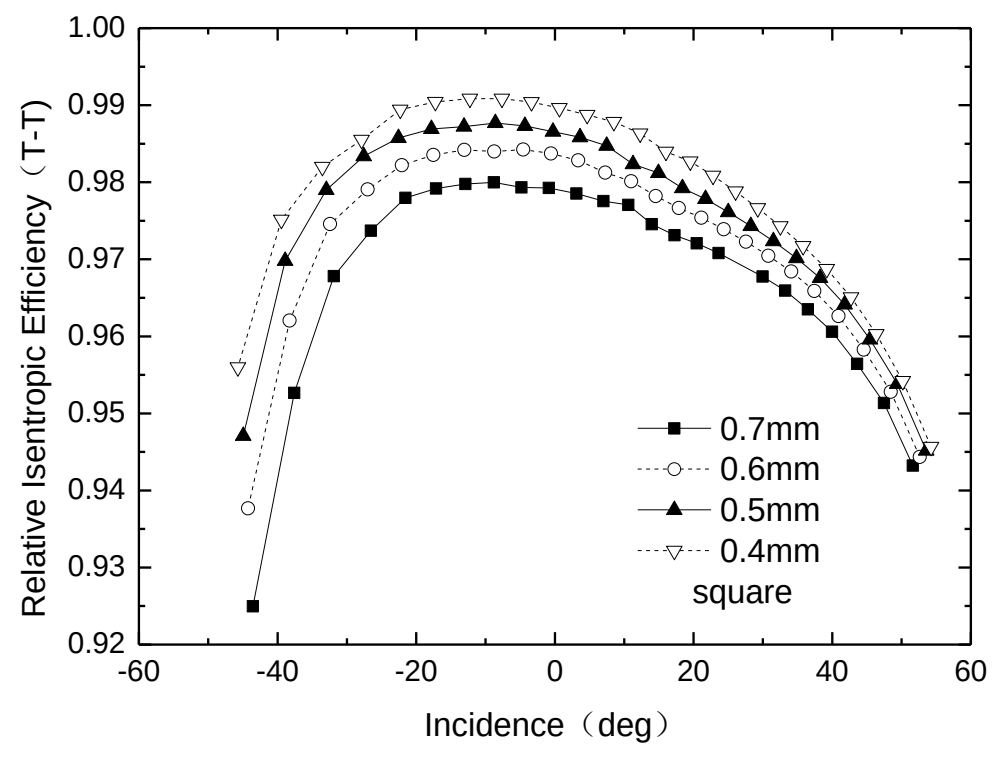

Figure 6. Comparison of relative isentropic efficiency with different leading-edge thicknesses

◆ For the same leading-edge thickness(0.7mm), square leading-edge caused more loss than ellipse leading-edge.

◆ For ellipse geometries, there was no significant difference when the leading-edge thickness changed at the positive incidence range. While at the range of negative incidence, it shows the leading-edge loss to increase with increased leading-edge thickness, excepting the thickness 0.4mm, that means we could not improve the efficiency just decrease the leading-edge thickness blindly.

◆For square leading-edge, at the whole range of incidence, the leading-edge loss to increase with increased leading-edge thickness.

b. The direction of the streamline at the rotor leading-edge

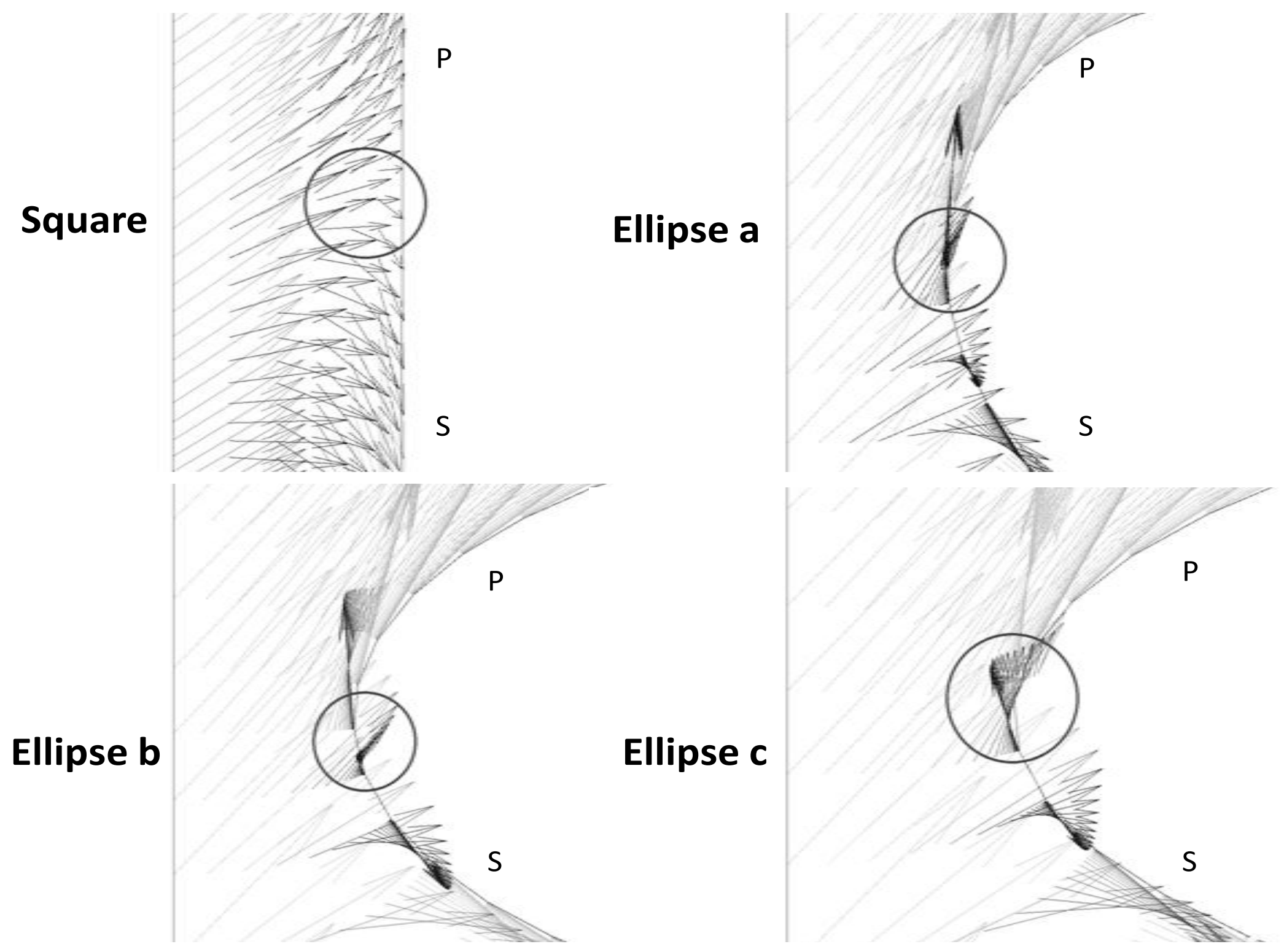

Figure 7. Relative velocity vector at leading-edge（P is pressure surface ，S is suction surface）

For the square front, the relative velocity vector direction in the marking place is perpendicular to the stagnation plane, that is, the streamline direction is the same as the leading-edge blade direction. While for ellipse leading-edge, the direction of streamline at stagnation position still needs to maintain a certain negative degree, in order to make the fluid get cross the blade from suction surface to pressure surface.

Conclusions

This paper study the effect of leading-edge geometry and thickness on the performance of miniature expansion turbine based on numerical simulation method, the following conclusions can be drawn:

◆ Square leading-edge caused more loss than ellipse leading-edge at the same leading-edge thickness.

◆ With the decrease of leading-edge thickness, the square's optimal incidence angle was toward to zero degree, the ellipse's optimal incidence angle was toward to larger negative angle.

◆ The optimum criterion at the stagnation position of blade leading-edge could only apply to the square leading edge, the ellipse leading-edge does not follow it.

◆ For ellipse leading-edge, it still needs to maintain a certain negative degree at stagnation position to offset the relative velocity vortex component caused by the rotation of the running wheel.

References

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