

Aerodynamics & Flight Mechanics Research Group

An Analysis of Sweep Angle Contours

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SCHOOL OF ENGINEERING SCIENCES
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Introductory Remarks

The combination of rotation and forward speed makes the local inflow distribution across a helicopter rotor disc complex. One aspect is the angle of inflow at a given point of a rotor blade at a given azimuth angle; i.e. the sweep angle. This technical note derives, in closed form, the equation governing the sweep angle contours.

Derivation of Contours

The rotor dimension is normalised to a unit radius. Also, the velocity components are normalised on the rotor tip speed. A general point of a rotor blade is at a normalised radius of (x_{RAD}) and azimuth angle (ψ).

The velocity components defining the local sweep angle is shown in Figure 1:

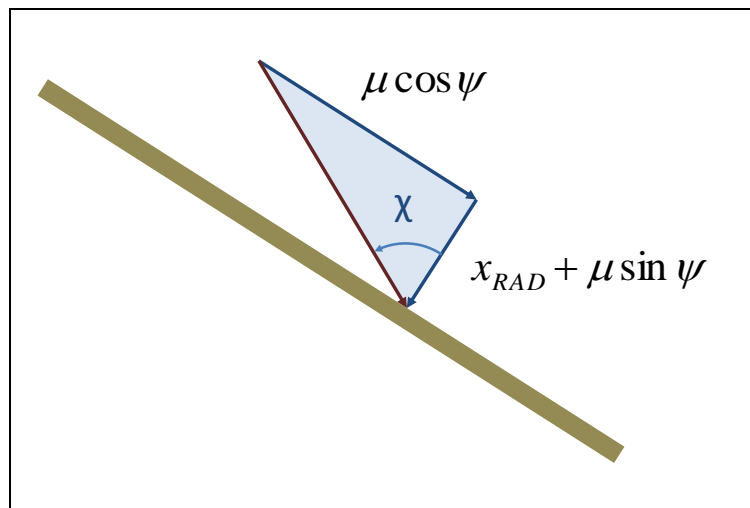


Figure 1 - Local Velocity Components

From this, the sweep angle is defined by:

$$\tan \chi = \frac{\mu \cos \psi}{x_{RAD} + \mu \sin \psi} \quad (1.)$$

In order to determine the contour equations we use the following axes system:



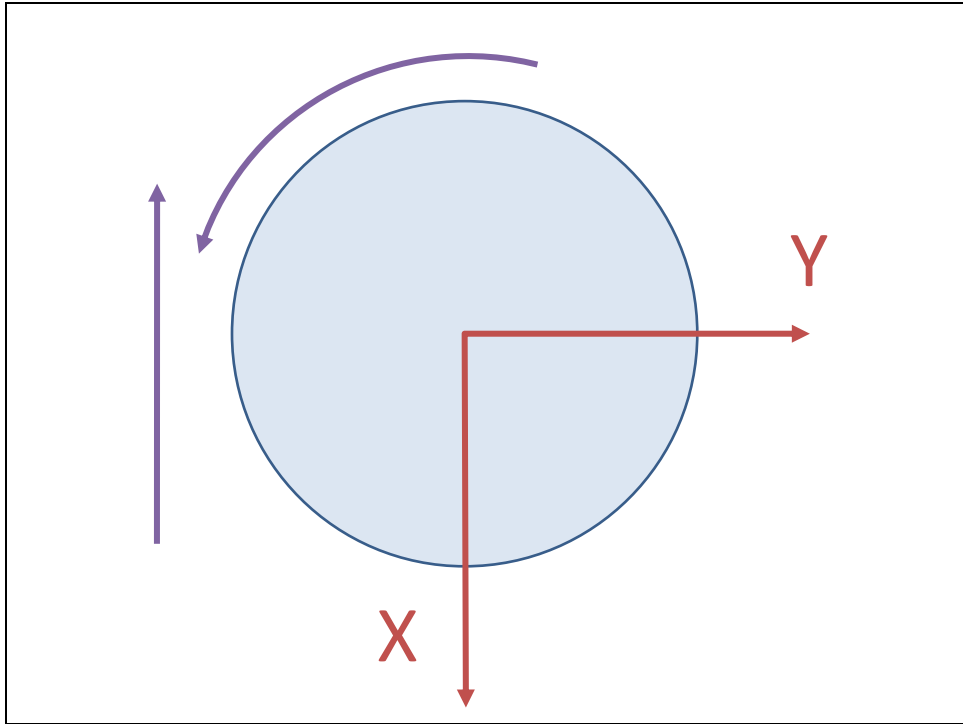


Figure 2 – Axes System Definition

The X axis (abscissa) lies in the incident airflow due to forward speed, i.e. over the tail and the y axis (ordinate) lies to starboard.

With this axes, the relationship between the normalised rotor radius (x_{RAD}), the azimuth angle (ψ) is shown in Figure 3:

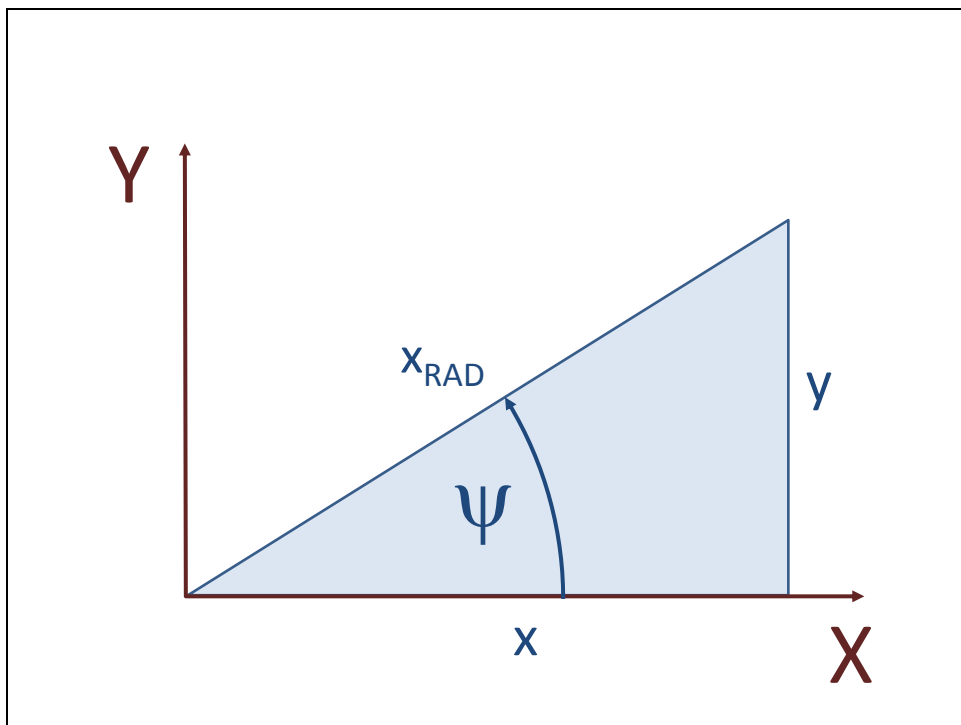


Figure 3 – Transformation between Rotor Polar and Cartesian Coordinates



The transformation equations are:

$$x_{RAD} = \sqrt{x^2 + y^2}$$

$$\cos \psi = \frac{x}{x_{RAD}} \quad (2.)$$

$$\sin \psi = \frac{y}{x_{RAD}}$$

Substituting (2) into (1) and clearing fractions gives:

$$x_{RAD} + \mu \cdot \frac{y}{x_{RAD}} = \mu \cdot \cot \chi \cdot \frac{x}{x_{RAD}} \quad (3.)$$

And hence:

$$x^2 + y^2 - \mu \cdot \cot \chi \cdot x + \mu y = 0 \quad (4.)$$

The equation of a general circle is given by:

$$x^2 + y^2 - 2gx - 2fy + c = 0 \quad (5.)$$

Where the centre of the circle is:

$$(-g, -f) \quad (6.)$$

and the radius:

$$\sqrt{g^2 + f^2 - c} \quad (7.)$$

From (5-7), the circle of equation (4) has centre:

$$\left(\frac{\mu}{2} \cdot \cot \chi, -\frac{\mu}{2}\right) \quad (8.)$$

and radius:

$$\sqrt{\left(\frac{\mu}{2} \cot \chi\right)^2 + \left(-\frac{\mu}{2}\right)^2} \quad (9.)$$

which reduces to:

$$\frac{\mu}{2} \csc \chi \quad (10.)$$



Geometrical Construction

This can be shown geometrically in the following Figure:

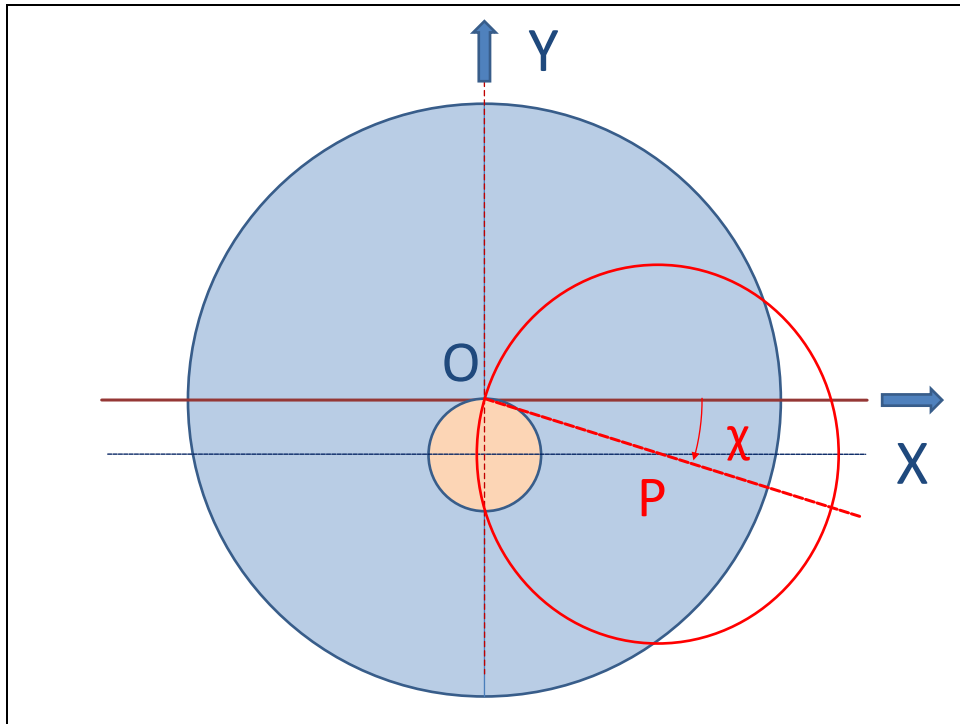


Figure 4

The construction begins with drawing a line parallel to the flight direction (x) positioned at the distance of half the advance ratio; this is in fact passing through the centre of the reverse flow region. A second line is constructed from the origin (O) at an angle to the abscissa equal to the sweep angle contour required. This intersects the first construction line at point P . Using P as the centre and OP the radius, a circle is drawn. The part of this circle within the rotor disc (the unit circle) is the required contour.



Examples

The surfaces and contours for a range of advance ratios from 0.1 – 0.5 are shown in Figures 5 – 14.

(The colour bar represents the sweep angle in degrees.)

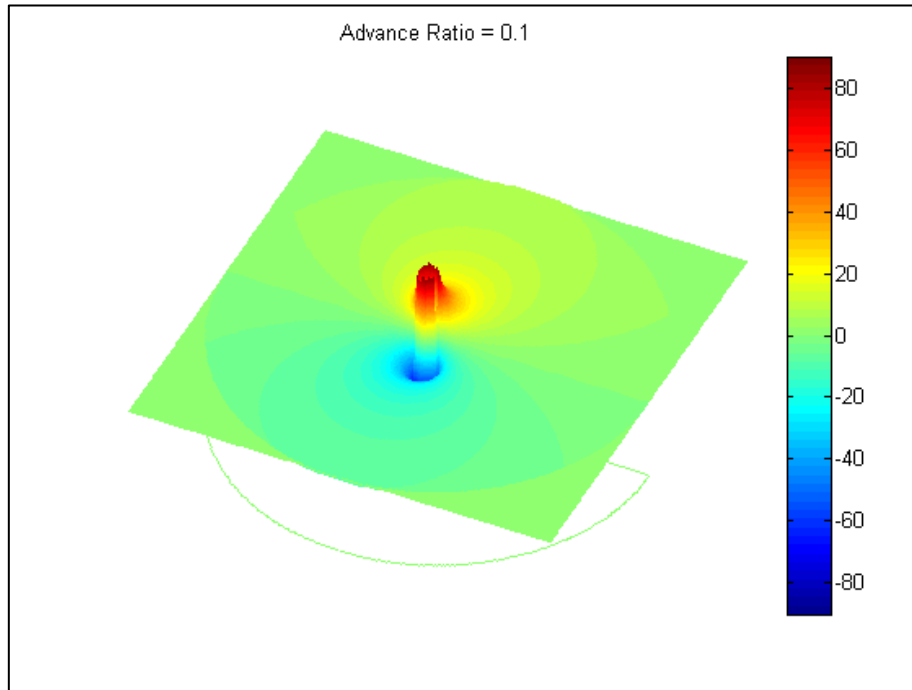


Figure 5

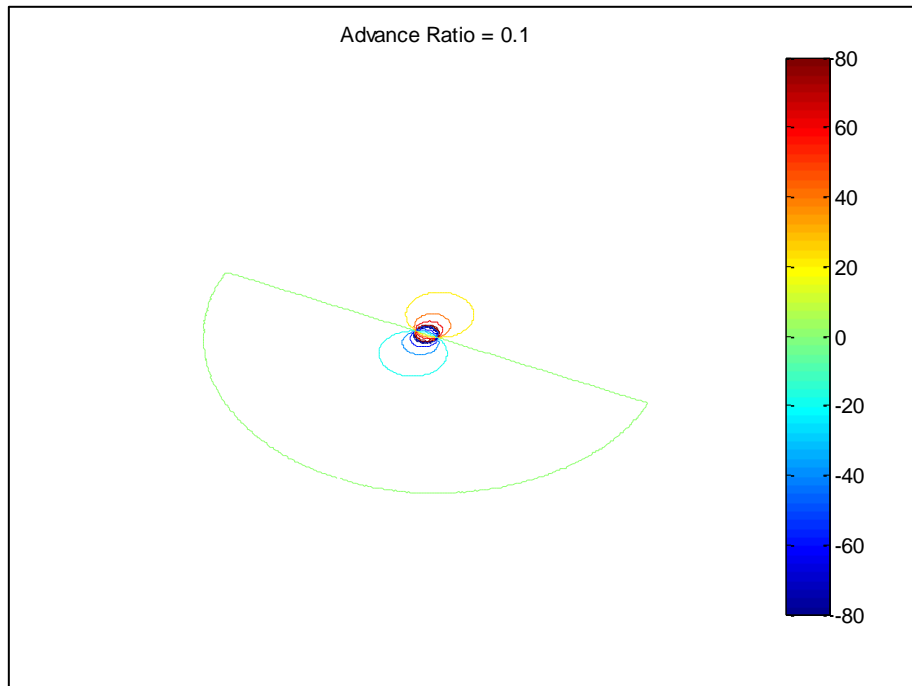


Figure 6



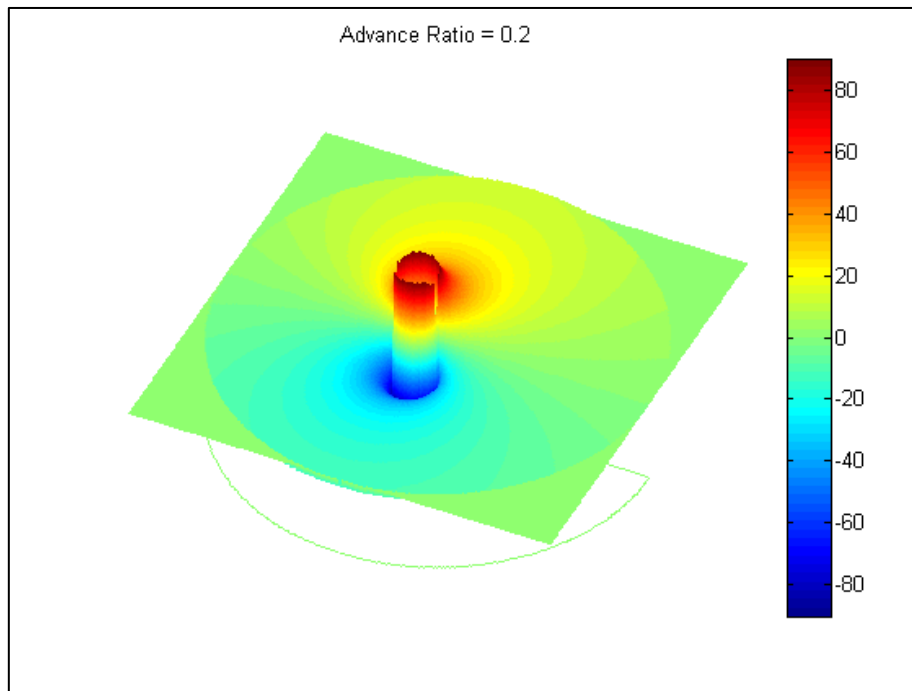


Figure 7

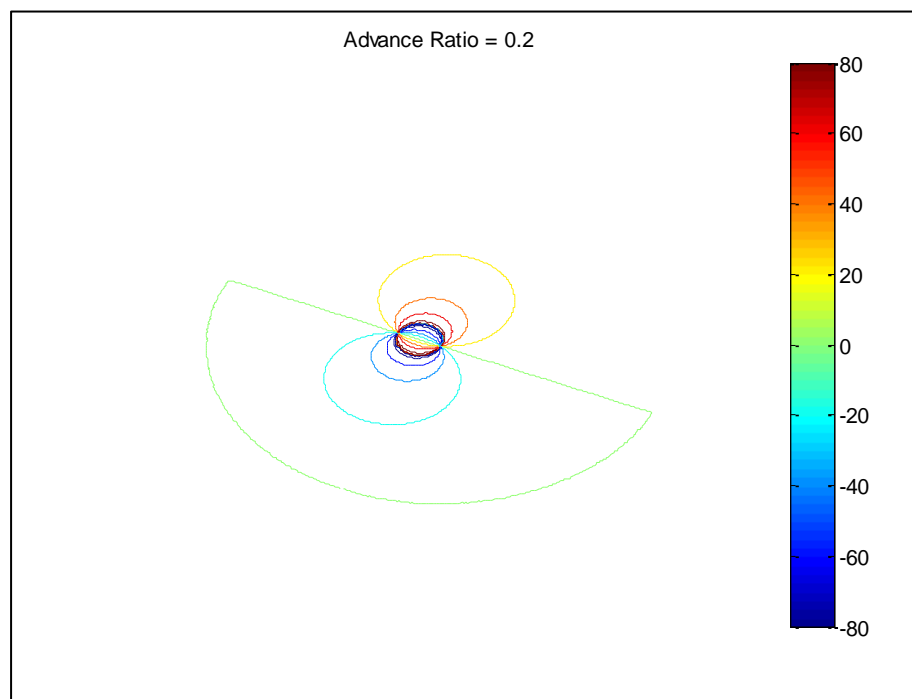


Figure 8



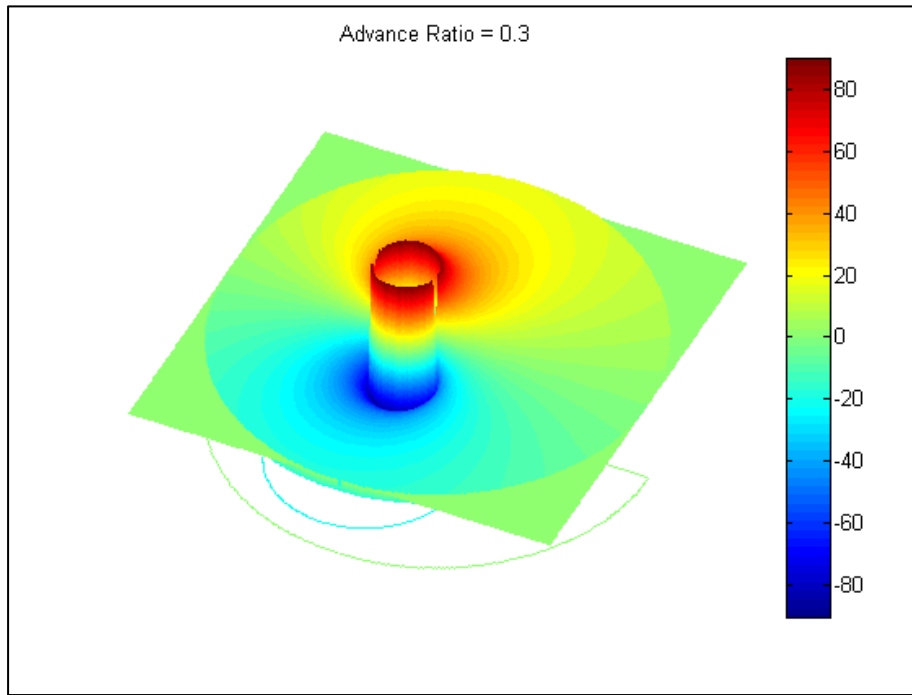


Figure 10

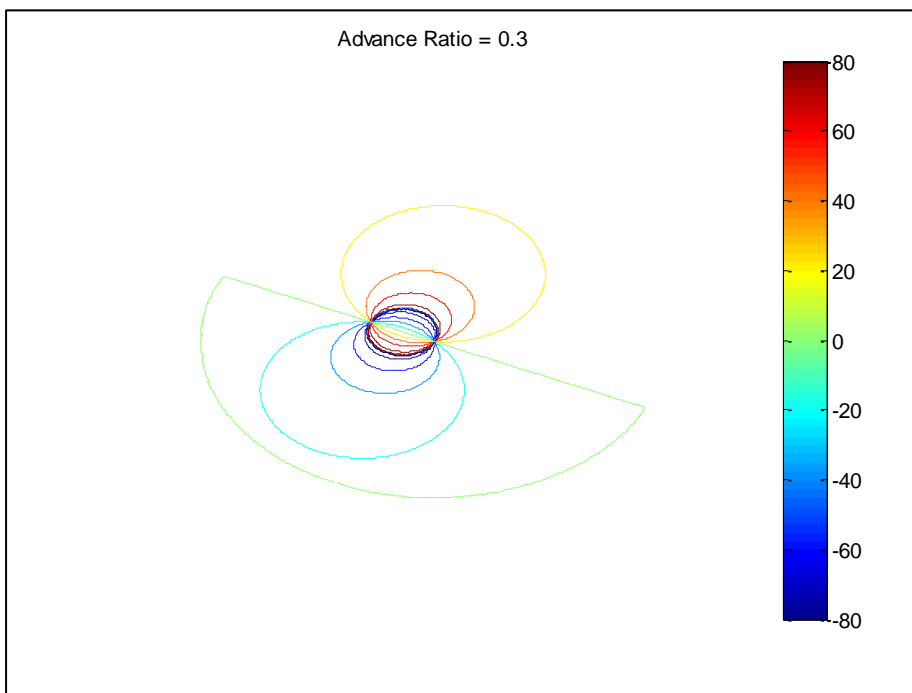


Figure 9



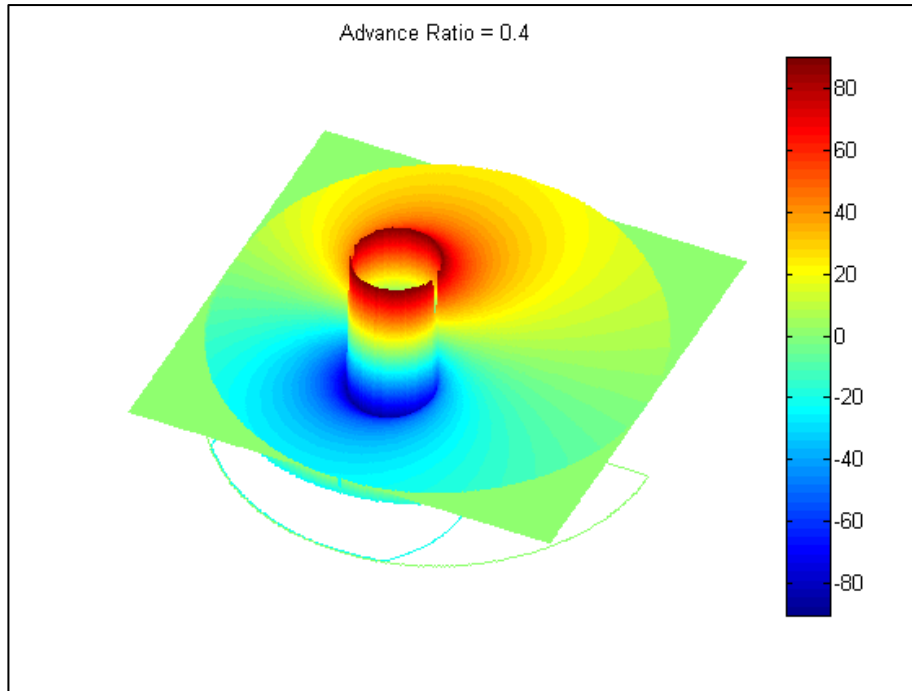


Figure 11

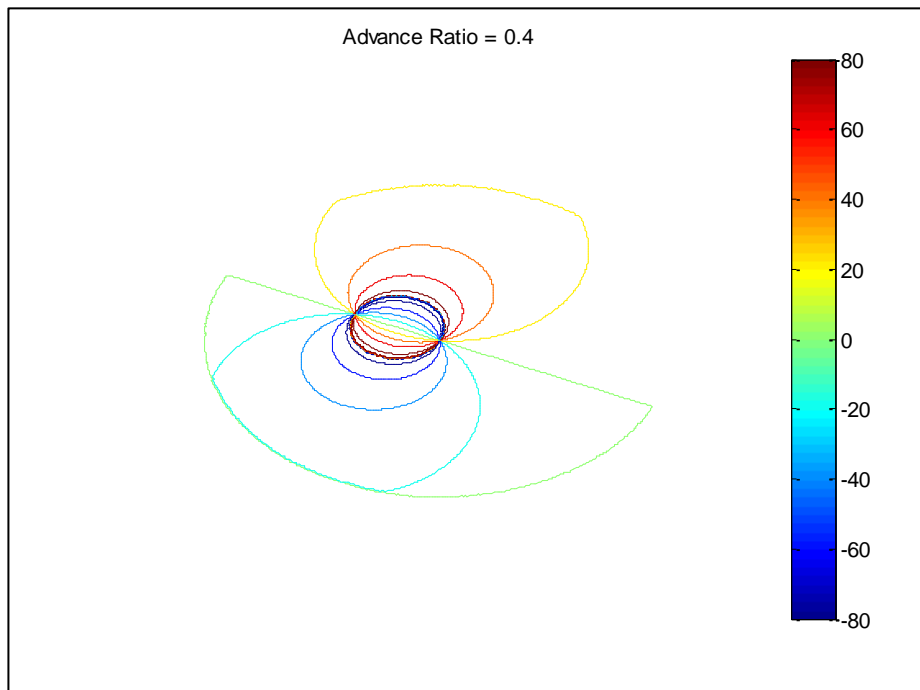


Figure 12



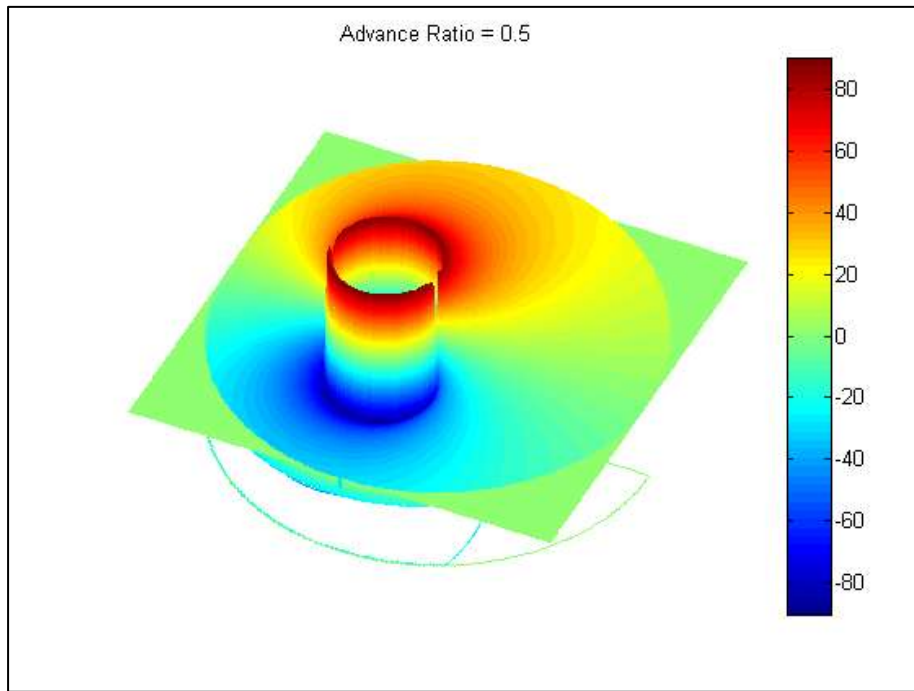


Figure 14

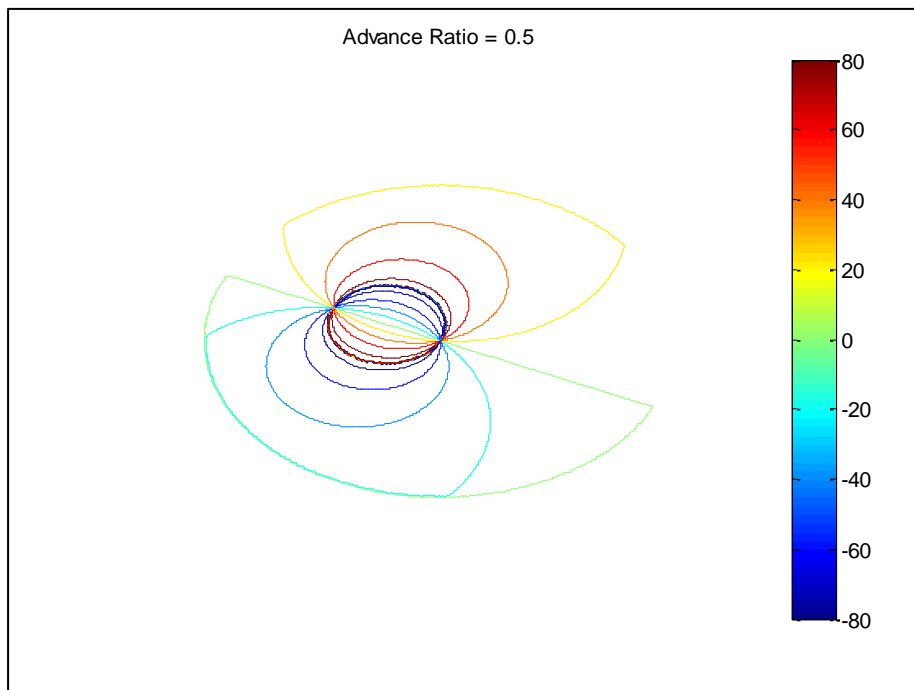


Figure 13



Conclusions

Examination of the equation governing the sweep angle contours enables the following conclusions to be made:

- The sweep angle contour is a circle.
- The zero angle contour is the advancing blade ($\psi = 0^\circ$) and the retreating blade ($\psi = 270^\circ$).
- The 90° contour is the periphery of the reverse flow region.
- All the contours pass within the reverse flow region. The sweep angle remains the same, but the flow direction is completely reversed.

