# Experimental investigation of boundary layer transition on rotating cones in axial flow in 0 and 35 degrees angle of attack

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**Abstract** This paper includes some experimental data about transitional Reynolds number on rotating cones in axial flow. The experimental data's are obtained through in a wind tunnel with hot wire anemometer and smoke visualization. We did build this wind tunnel especially for studying flow around rotating bodies. Two cones we use for this work, first cone has apex angle 30 degrees and it's diameter of the base of the cone is 5 cm and the second cone has 45 degrees apex angle and 4 cm diameter of the base. The results are compared with some other experimental works for 30 degrees cone and it was validated with especially some other experiments .we compare our results by linear stability theory which was done by[4]. We just emphasis. Also we compare visualization and hot wire anemometer results graphically, our goal in this paper is to check reliability of using hot wire anemometer and smoke visualization in stability problem and check reliability of linear stability theory for this two cases and compare our results with some trusty experimental works
.**Keywords:** Transitional Reynolds number, Wind tunnel, rotating cone

## 1 Introduction

A study of transition in the boundary layer along a cone rotating in axial flow donate to the understanding of the basic mechanism in transition regions of complex three-dimensional boundary layers on rotating axisymmetric bodies and also in internal flows of turbomachines, because in the case of rotating cones one can examine changes in the boundary-layer characteristics caused by the rotational motion by using a small number of geometrical and mechanical parameters. In the case of rotating cones, centrifugal instability must play an important role in the transition phenomenon. Experimental studying in instability & transition problems was by such different methods, for example with heat and mass transfer (Illingworth 1953 ; Salzberg & Kezios 1965; Tien & Tsuji 1965; Koh & Price 1967) and visualization and hot wire (R.Kobayashi & Y.Kohama 1982) and some different methods, in this study we use two aluminum cone with 30 and 45 degrees apex angle. We made the cones by C.N.C machining with a very high sensitivity and smooth's the surface of the cone by surface finishing technology. The turbulence intensity of wind tunnel in this study was less than 0.02 % at maximum speed.

## 2 Experimental setup

We consider an orthogonal curvilinear coordinate on a rigid cone (Fig.1). By definition sectional Reynolds number and rotational speed ratio are by these relations:

$$Re_x = \frac{U_e x_l}{\upsilon} \qquad [1]$$

$$S = \frac{\omega R_b}{U_e} \qquad [2]$$

$$T_s = \frac{1}{S} \qquad [3]$$

By definition of Kobayashi[Ref.1] the transition point was here as the point where velocity fluctuations gave a frequency spectrum for the turbulent boundary layer as shown with curve (d) in Fig.2.we use this definition in this study also we use flow visualization to show the transition region on the cone in present work.
Salzberg & Kezios **(1965)** measured the transition Reynolds number
By experiments on local mass transfer from a rotating **30"** naphthalene cone of *2R*, **= 68** mm, and formulated it in relation to their rotational parameter as:

$$Re_{x,t} = 110960\left\{0.73\left(\frac{\omega R_b}{U_\infty}\right)^{-2} + 0.08\left(\frac{\omega R_b}{U_\infty}\right)^{-1}\right\}^{\frac{6}{7}} \qquad [4]$$

In this paper we trying to study the validity of this relation by visualization and hot wire measurement.
To measuring turbulence characteristics of flow arond the cone we use a hot wire sensor by 5 μm diameter of wire.
In solution of linear stability teory by garret&peak [Ref.4] they are shown that linear stability teory is almost valid fore cone with apex angle more than 50 defrees,so the difference between analytic and experimental results in cone with 30 degrees apex angle are justificate by this.

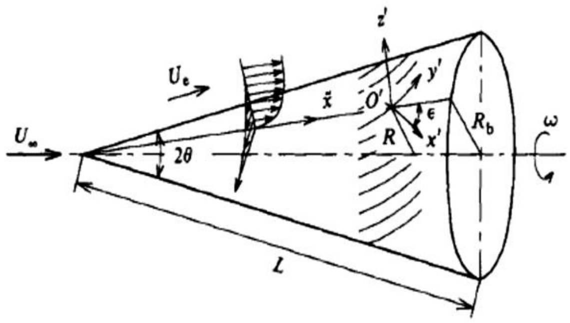



**Fig.1**: schematic of the orthogonal curvilinear coordinate on a rigid cone

### 3 Results and discussion

In Fig.4 we have shown our results in varying local Reynolds number versus S factor in transition points. We compare them by theoretical and experimental results of Kobayashi [Ref.1].
We show in Fig.2 frequency spectra of velocity fluctuations is two transition regions. It seems that by increasing rotational speed ratio, the portion of smaller eddies in energy spectra increases.

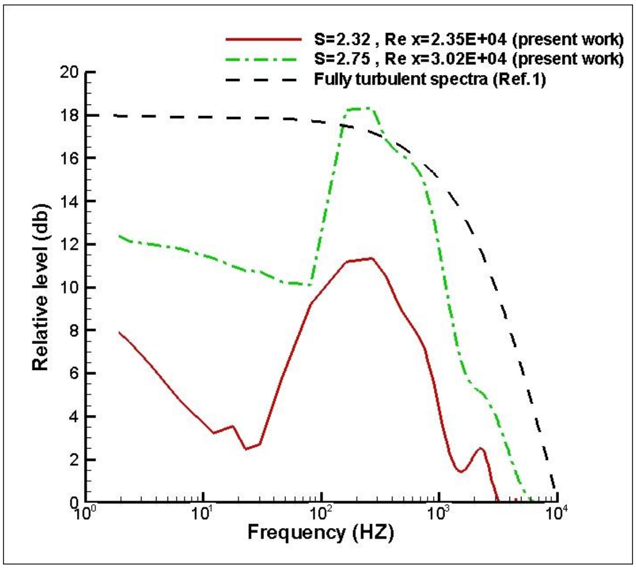



**Fig.2**: Frequency spectra of velocity fluctuations in transition region

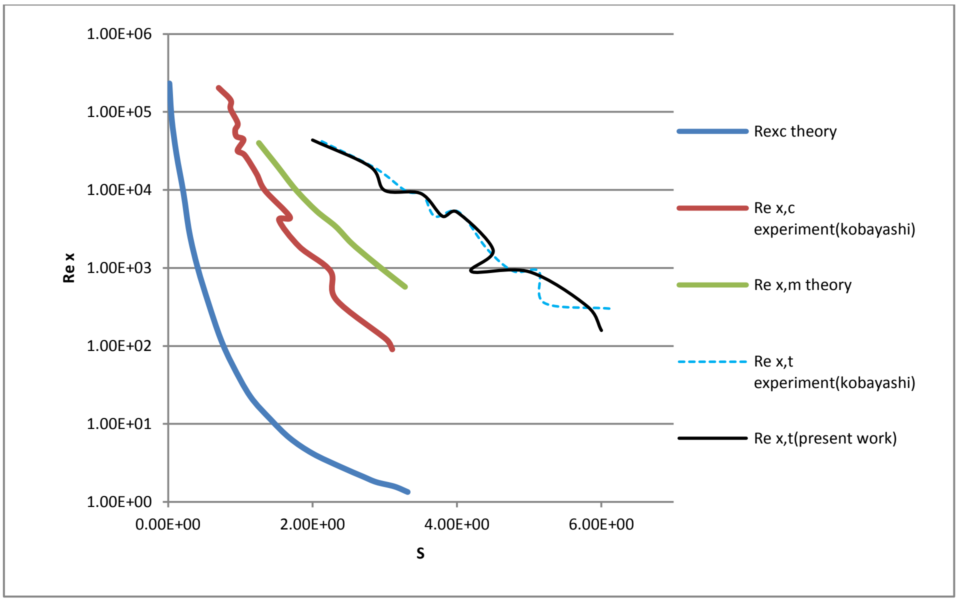



**Fig.3**: Critical Reynolds number and transitional Reynolds number for 30 degrees apex angle cone measured by hot wire anemometer [5] and compare with Kobayashi results.

In Fig.4 we plot the our hot wire transitional rotational Reynolds number results for 45 and 30 degrees cones and linear stability theory results which has done by [2] for 40 and 60 degrees cones. It is shown that there is a good correspondence by linear stability till Ts= 0.2.

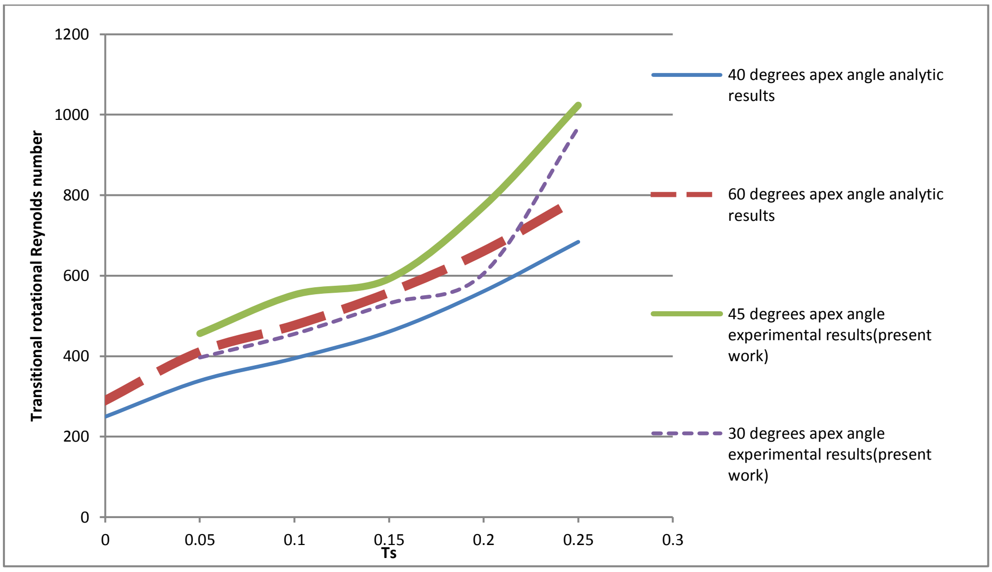
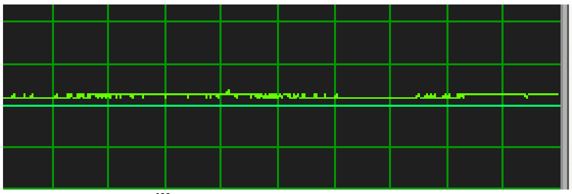
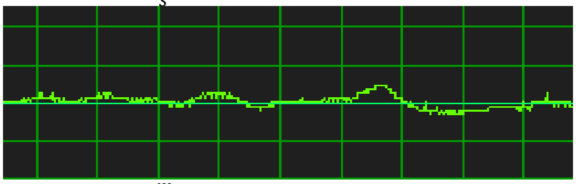



**Fig.4**: Rotational Transition Reynolds number versus rotational speed ratio.

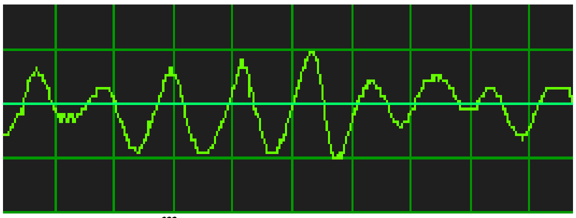
In Fig.5 we put the image of velocity fluctuations that they are scope graph outputs of hot wire anemometers. The oscillogram for $Re_{rotational}$= 60 is for a state of the laminar boundary layer. The scope graph for $Re_{rotational}$ = 385 and 6c for 399 were made in a region of sinusoidal oscillations due to the appearance of spiral vortices, and Fig. 5d for $Re_{rotational} = 401$ shows nonlinear oscillations. The ocillogram of Fig.5e for $Re_{rotational} = 450$ is in the turbulent boundary layer that brought irregular fluctuations in the low-frequency range is seems. We determined the critical point of instability as the state where the periodic signals resulting from the spiral vortices were just detected on frequency spectra and the transition point as the state where the velocity fluctuations just lost the periodicity entirely on the scope graph.



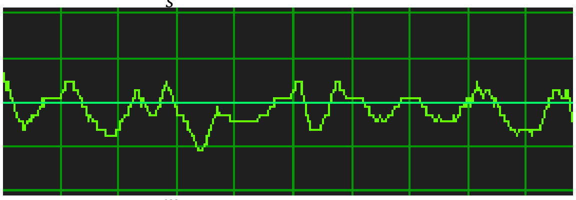
a) $U_\infty = 1.98\frac{m}{s}, Re_{rotational} = 60$



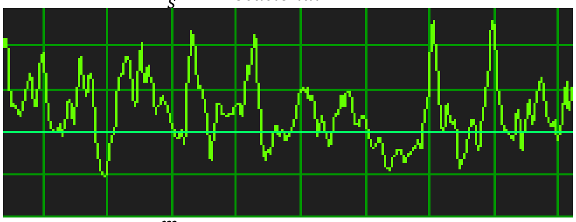
b) $U_\infty = 1.98\frac{m}{s}, Re_{rotational} = 385$



c) $U_\infty = 1.98\frac{m}{s}, Re_{rotational} = 399$



d) $U_\infty = 1.98\frac{m}{s}, Re_{rotational} = 401$



e) $U_\infty = 1.98\frac{m}{s}, Re_{rotational} = 450$

**Fig.5**: scope graphs on the 30 degrees apex cone were rotate in different conditions. Distance of hot wire sensor from the surface is 0.5 mm.

## 4 Visualization

Another method that we use to studying transition of boundary layer on rotating cone was smoke visualization. for doing this we build and calibrate a smoke generator, our smoke generator was work with tobacco smoke.

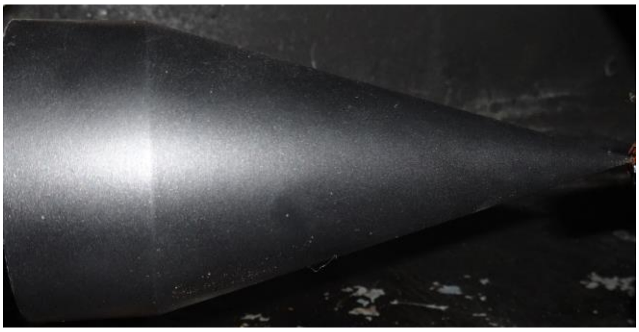


**Fig.6**: the cone that we use to this experiment (30 degrees apex angle and 5 cm diameter of the base).

In the case 30 degrees apex angle cone with 50 RPM rotational speed of the cone and 2.1 m/s free stream velocity we had fully laminar boundary layer around cone [Fig.8]. By increasing rotational Reynolds number till 400 the transition was observe in visualization on the surface of the cone [Fig.9] and by increasing Rotational Reynolds number to 800 the boundary layer was fully turbulence from apex [Fig.10].

**Fig.7**: Flow visualization around cone rotating in rotational Reynolds number 27.8 and 2.1 m/s free stream velocity.

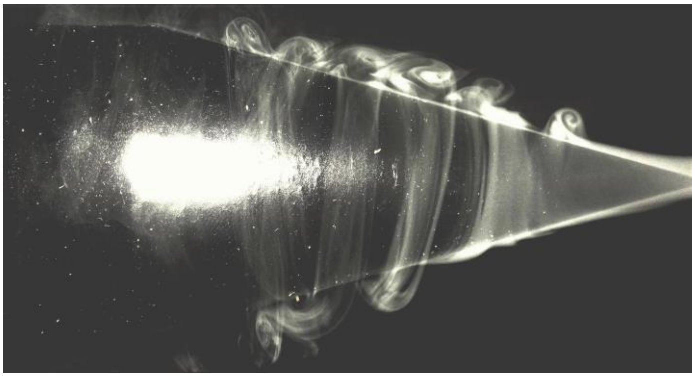


**Fig.8**: Flow visualization around cone rotating in rotational Reynolds number 148.1 and 1.98 m/s free stream velocity.

**Fig.9**: Flow visualization around cone rotating in rotational Reynolds number (at base) 401.2 and 1.98 m/s free stream velocity.

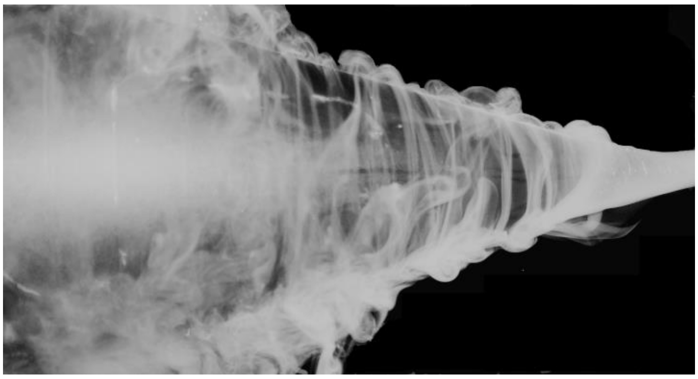


**Fig.10**: Flow visualization around 30 degrees apex angle cone rotating in rotational Reynolds number (at base) 935 and 1.31 m/s free stream velocity.

**Fig.11**: Flow visualization around 30 degrees apex angle cone rotating in rotational Reynolds number (at base) 941 and 1.36 m/s free stream velocity.

**Fig.12**: Flow visualization around 30 degrees apex angle cone rotating in rotational Reynolds number (at base) 825 and 1.23 m/s free stream velocity.

**Fig.13**: Simple smoke visualization of flow over 30 degrees total apex angle cone( 35 degrees angle of attack , $Re_{rot} = 80$) ,the boundary layer is fully laminar but spiral vortices are apeare in middle of cone.

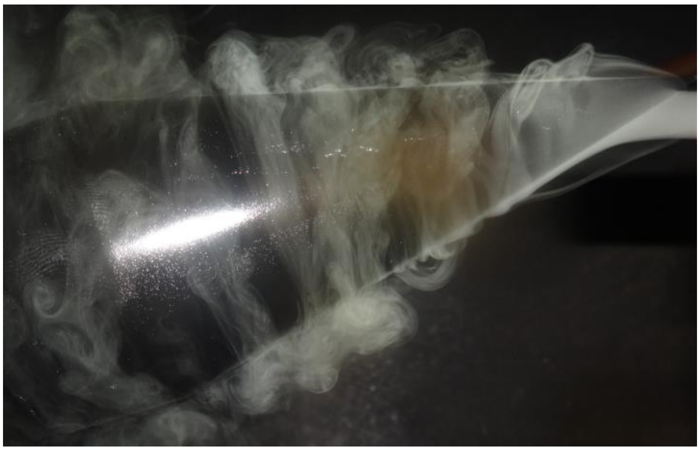


**Fig.14**: Simple smoke visualization of flow over 30 degrees total apex angle cone( 35 degrees angle of attack , $Re_{rot} = 220$) ,Transition occures at middle of cone surface.

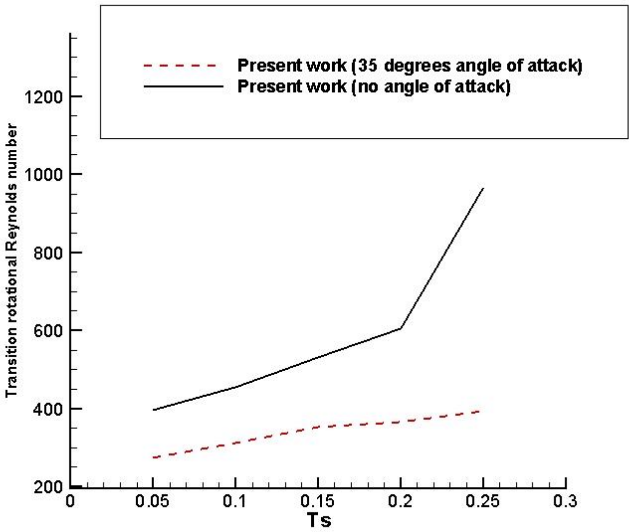



**Fig.15** : Comparison of transitional rotational Reynolds number in 0 and 35 degrees angle of attack in different rotational speed ratios.

## 5 Conclusion

**A** study of transition in the boundary layer along a cone rotating in axial flow was conducted. The critical Reynolds number and transitional Reynolds numbers in two angles of attack were measured by hot wire anemometer and compare reasonably well with Kobayashi results. Another method that we use to study the transition of boundary layer on rotating cone was smoke visualization, this method also confirm our hot wire results.

We find that the salzberg&kezios (1965) relations are trusty relation for the case of 30 degrees apex angel cone rotating in axial flow and also our wind tunnel was suitable for the stability and transition study. Moreover the smoke visualization can help us to understand better the transition mechanism and have better picture of flow phenomena.

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