ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Computational Investigation of Low-Pressure Turbine Cascade in Lowreynolds Number Flows

R Christu Paul [1], A X Amal Rebin [2], R Senthil Kumar[3*], C Ramesh[4], A M Shanawaz [5],

D Raja Joseph[6]

[1] Professor, Department of Automobile Engineering,

[2] Associate Professor, Department of Mechanical Engineering

Hindustan Institute of Technology and Science, Chennai-603 103

3 Associate Professor, Department of Aeronautical Engineering,

Kalasalingam Academy of Research and Education, Krishnancoil

[4] Associate Professor, School of Aeronautical Sciences

Hindustan Institute of Technology and Science, Chennai-603 103

[5] Professor, Department of Mechanical and Automation Engineering,

PSN College of Engineering and Technology, Tirunelveli-627 152

[6] Associate Professor, School of Aeronautical Sciences

Hindustan Institute of Technology and Science, Chennai-603 103

Abstract: This paper results in a computational investigation of low-pressure turbine cascade at low Reynolds number laminar flows. The investigation is carried out on a T-106 blade profile of chord length 60mm. An experiment was carried out for three different Reynolds numbers at three different incident angles. The blades are designed through Solid Works software. Simulation analysis will be done by using Ansys Fluent software on the designed T106 blade profile which will be developed through Solid works software. The final result of the paper shows us the effect of pressure distribution on the blades at different incident angles along with their velocity contours. The experimental investigation for secondary flow formation can conduct through pitot tube technique.

Key Words: - Low pressure Turbine Cascade, Pressure distribution, T106 blade, secondary flow.

List of abbreviations:

Re = Reynolds NumberCh = Chord length

H = PitchS = Span

a1b = Inlet blade angle g = Blade stagger angle

Ptotal = Total pressure value Pstatic = Static Pressure Value

= Density of air i.e. 1,2256 kg/m^3

= Velocity of air

= Infinity/ atmospheric pressure

Cp= Coefficient of pressure

Introduction:

The performance of gas turbine engine is greatly influenced bythe turbine section of engine. Low Pressure Turbine is the most critical feature in all the aero engines. The Low-Pressure Turbine (LPT) is engineered primarily to provide high aerodynamic performance in low pressure ratio service. The actual part that makes up the turbine portion of a gas turbine isa turbine blade. The blades extract energy from the high-temperature, high-pressure gas created by the combustor. All three of these variables will contribute to blade failures that could possibly damage the engine, so turbine blades are specially engineered to withstand this situation. Every LP Turbine (low-pressure turbine) is typically a double-flow reaction turbine with approximately 5-8 stages (with veiled blades and last 3 stages freestanding blades). LP turbines generate between 60-70 per cent of the power plant unit's total power production. The Low-Pressure Turbine (LPT) isdesigned primarily to provide high aerodynamic performance in low pressure ratio service. There is less air above at higher altitudes so it is less compressed, and therefore less density. Inthis circumstance we use low pressure generator for proper generator function and it also provides high lift.

Any turbomachine's function relies directly on shifts in the angular momentum of the operating fluid, as it crosses individual blade line. The different forms of cascade tunnels that involve low speed, high speed, sporadic blowdown and suction tunnels. Two main forms of cascade tunnels are:

- low-speed, operating in the range 20-60 m/s
- high-speed, for the compressible flow range of testing

The regular cascade of blades comprises of a set of similar tips, which are similarly spaced and parallel. With the blades arranged in cascade, the space chord ratio and the stagger angle, which is the angle between the chord line and a reference direction perpendicular to the cascade front, are two significant additional geometric variables which determines the cascade.

Motivation:

Low pressure turbine is the most important component of all the aero engine. Now a days, low pressure turbines are becoming one of the most important engine components that increases the performance of the aircraft. The most important advantage of the low-pressure turbine is that it develops high lift with low density air at far heights from the ground. So, we have simulated low-pressure turbine cascade with different Low-Reynolds number flows and blade angles.

Objective:

To simulate the flow through the low-pressure turbine cascadeat different incident angles and at different low Reynolds numbers in a cascade wind tunnel. And to study the velocity contours and pressure vs cp graph.

Design:

x/c	y/c	x/c	y/c	x/c	y/c	x/c	y/c	x/c	y/c
0.852022	-0.499894	0.590809	0.041609	0.134837	0.151909	0.114539	0.051907	0.566712	-0.054864
0.854287	-0.499152	0.581625	0.052984	0.122597	0.144092	0.126483	0.056272	0.576342	-0.063994
0.856024	-0.497879	0.572194	0.064157	0.110472	0.135697	0.137856	0.059993	0.585810	-0.073291
0.857388	-0.496202	0.562565	0.075027	0.098656	0.126874	0.149354	0.063309	0.595251	-0.082951
0.858425	-0.494252	0.552660	0.085647	0.086915	0.117442	0.160399	0.066097	0.604502	-0.092792
0.858921	-0.492134	0.542536	0.095906	0.075496	0.107622	0.171531	0.068513	0.613686	-0.102927
0.858849	-0.489945	0.532108	0.105857	0.064090	0.097111	0.182359	0.070508	0.622688	-0.113225
0.858336	-0.487832	0.521465	0.115384	0.053025	0.086239	0.193243	0.072168	0.640270	-0.134439
0.856981	-0.484433	0.510501	0.124541	0.041933	0.074534	0.203964	0.073488	0.657151	-0.156283
0.854884	-0.479210	0.499342	0.133204	0.031245	0.062457	0.214716	0.074522	0.673265	-0.178579
0.852085	-0.472232	0.487867	0.141440	0.020435	0.049183	0.225362	0.075276	0.688595	-0.201154
0.848607	-0.463560	0.476249	0.149133	0.010278	0.035401	0.236021	0.075789	0.703073	-0.223816
0.844469	-0.453274	0.464341	0.156368	0.007569	0.031203	0.257060	0.076098	0.716738	-0.246414
0.839713	-0.441446	0.452322	0.163044	0.005124	0.026842	0.277659	0.075493	0.729583	-0.268769
0.834337	-0.428134	0.440047	0.169240	0.003235	0.022872	0.287634	0.074850	0.741636	-0.290734
0.828372	-0.413425	0.427639	0.174893	0.001625	0.018778	0.297594	0.074004	0.752938	-0.312161
0.821836	-0.397388	0.415012	0.180039	0.000631	0.015282	0.307184	0.072977	0.763519	-0.332903
0.814726	-0.380103	0.402272	0.184630	0.000000	0.011694	0.316734	0.071626	0.773423	-0.352847
0.807069	-0.361644	0.389355	0.188696	0.000088	0.008846	0.335108	0.068196	0.782696	-0.371894
0.798872	-0.342097	0.376273	0.192225	0.000351	0.006020	0.353287	0.063847	0.791327	-0.389909
0.790120	-0.321545	0.363052	0.195189	0.001225	0.003898	0.373463	0.058063	0.799366	-0.406004
0.780839	-0.300063	0.349624	0.197578	0.002663	0.002099	0.393279	0.051654	0.806821	-0.422490
0.771018	-0.277748	0.336102	0.199358	0.004054	0.001040	0.412745	0.044491	0.813669	-0.436886
0.760651	-0.254690	0.322457	0.200535	0.005660	0.000389	0.431923	0.036586	0.819910	-0.449898
0.749746	-0.230987	0.308772	0.201087	0.007649	0.000031	0.441443	0.032270	0.825496	-0.461463
0.738285	-0.206733	0.294991	0.201010	0.009663	0.000000	0.450826	0.027661	0.830405	-0.471509
0.726255	-0.182047	0.281229	0.200303	0.012095	0.000289	0.460367	0.022685	0.834580	-0.479967
0.713682	-0.156981	0.267419	0.198967	0.014480	0.000826	0.469785	0.017480	0.837962	-0.486768
0.700516	-0.131702	0.253684	0.197008	0.017259	0.001730	0.479443	0.011805	0.840543	-0.491860
0.686776	-0.106292	0.239943	0.194412	0.019942	0.002874	0.488953	0.005886	0.842197	-0.495145
0.672425	-0.080891	0.226333	0.191202	0.025860	0.006081	0.498720	-0.000528	0.843535	-0.497014
0.657461	-0.055603	0.212761	0.187358	0.039158	0.014055	0.508326	-0.007180	0.845263	-0.498560
0.641855	-0.030573	0.199372	0.182919	0.052488	0.021970	0.518154	-0.014344	0.846593	-0.499318
0.625580	-0.005925	0.186068	0.177858	0.065205	0.029003	0.527832	-0.021709	0.848086	-0.499770
0.617178	0.006200	0.172994	0.172231	0.078096	0.035710	0.537943	-0.029707	0.849626	-0.499988
0.608581	0.018188	0.160048	0.166003	0.090332	0.041618	0.547860	-0.037944	0.852022	-0.499894
0.599805	0.029981	0.147370	0.159246	0.102755	0.047127	0.557378	-0.046301		

FIG.NO:1 Blade Coordinates

Chord Length	80mm
Pitch	52.5mm
Span	250mm
Span/Chord Ratio	0.625
Inlet blade angle	37.73°
Exit Blade Angle	63.2°

Table. No 1: -Design data of T106 blade profile

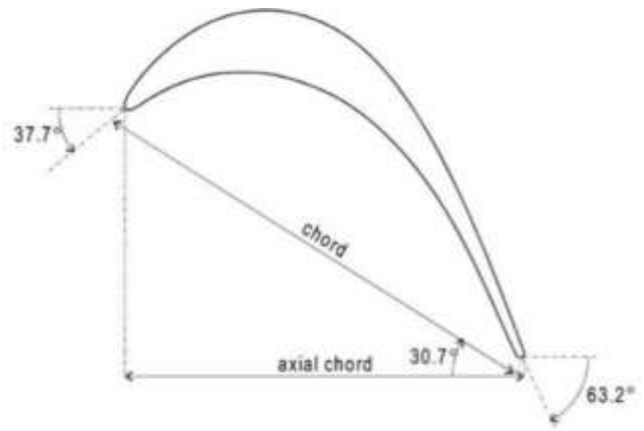

Fig. No. 2: - Designed T106 turbine blade

Fig. No.3: - 2D control volume of T106 blade

Import Airfoil Coordinates to create 2D control volume to perform simulation. Go to 'insert', then go to 'curves' and then click on 'Curves to XYZ points…', then you will find a 'curve file' in which you have to browse your airfoil coordinates file, then click on 'ok'.

Then draw the mean chamber line and mirror it on its up and lower side with required spacing and then drew a line tangent to leading edge and trailing edge for both the mean chamber lines and join them. Then go to surfaces and select the planar and sketch to form a control volume shown in figure 3.

Meshing:

Import the control volume into geometry and name as inlet, outlet, upper surface, lower surface and airfoil surface. Then open meshing solver and give element size as 0.5mm, give number of divisions 300 at inlet and outlet, then give number of divisions 1000 at upper and lower surface and select behavior as hard. Then go to inflation and select airfoil surface and give number of layers as 10 with growth rate 1.2. This type of meshing is useful for applying periodic boundary conditions at lower and upper surface of control volume. Number of elements created are between 65654- 100000 and number of nodes are between 49419-70000.

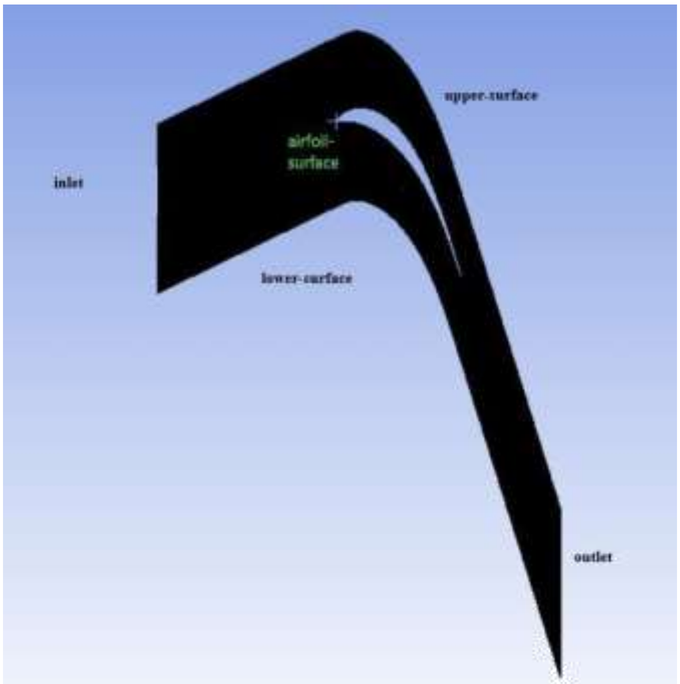

Fig. No. 4: - Entire domain meshingAnalysis:

Now double click on 'setup', as it opens up click on 'check' and 'report quality' to find about domain extents, volume statistics, face area statistics, check mesh and mesh quality. Then select 'Pressure-Based' as our simulation incompressible.

Then double click on 'models' and double click on 'viscous' and select 'k-omega, SST', it is selected because k-omega SSTmodal of turbulence is capable of solving turbulence parameters very close to boundary or wall region and used for low Reynolds number flow applications.

Now go to boundary conditions and double click on inlet, give 'velocity-inlet' in types and click on 'edit', then give required inlet velocity and gauge pressure and gauge pressure is zero, pressok. In our case velocities are 15m/s, 20m/s, 25m/s with 66298.3, 88396, and 110495 Reynolds numbers respectively.

Then select 'pressure-outlet' at outlet and take gauge pressure as zero and give required gauge pressure.

Give gauge pressure at inlet as 101187.12Pa and gauge pressure at outlet as 101325Pa for velocity 15m/s.

Then give gauge pressure at inlet as 101079.88Pa and gauge pressure at outlet as 101325Pa for velocity 20m/s.

Then give gauge pressure at inlet as 100942Pa and gaugepressure at outlet as 101325Pa for velocity 25m/s.

Then give periodic for upper and lower surface. In order to make upper-surface and lower-surface at 'periodic' follow below given steps. Periodic in required because we are simulating for turbine blades and to avoid problems with boundary effects caused by finite size and to make the system more like an infinite one, at the cost of possible periodicity effect.

Then type the following in 'console'.

- Type Define and click 'enter'
- Type Boundary-conditions and click 'enter'
- Type modify-zone and click 'enter'
- Type make-periodic and click 'enter'
- Give Periodic zone [()]- (ID)
- Give shadow zone [()]-(ID)
- If your modal is transitional then press 'no'
- Type 'yes' and click 'enter'
- Type 'yes' and click 'enter'

Now double click on 'reference values' and select 'inlet' near 'compute from'. Now double click on 'Solution Methods' and give second order for all, as this will improve the accuracy of the result

Then go to 'report definition' and go to new and select lift and drag in order to get cl and cd graph w.r.t iterations.

Now go to ‘Monitors’ and click on ‘Residual’ and give 0.00001 at ‘Absolute criteria’. This is done to increase theaccuracy or result.

Then, go to ‘Initialization’ and select ‘Standard Initialization’ and select ‘inlet’ at ‘compute from’ and press initialize

Then go to ‘Run Calculation’ and give required numberof iterations required and then click on ‘calculate’.

After the solution is converged then close the setup and open ‘results. There you can find required number ofresults like pressure, velocity, graphs, tables, etc.

Results: -

As we discussed earlier, we designed T106 blade for60mm chord length and conducted simulation at threevelocities of 15m/s, 20m/s, 25m/s and three incident angles of 0, +5, -5. This simulation analysis results in pressure distribution over the blade profile i.e. pressure contour and velocity contour. The pressure distribution graphs are listed as below.

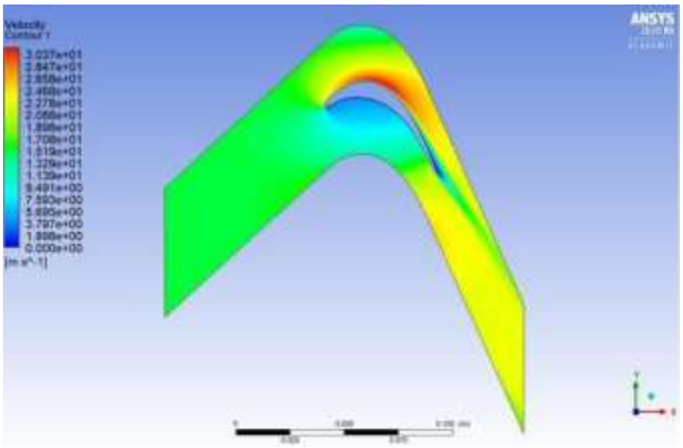

Fig. No.5: - Velocity contour for 15m/s velocity at Zeroincidence angle

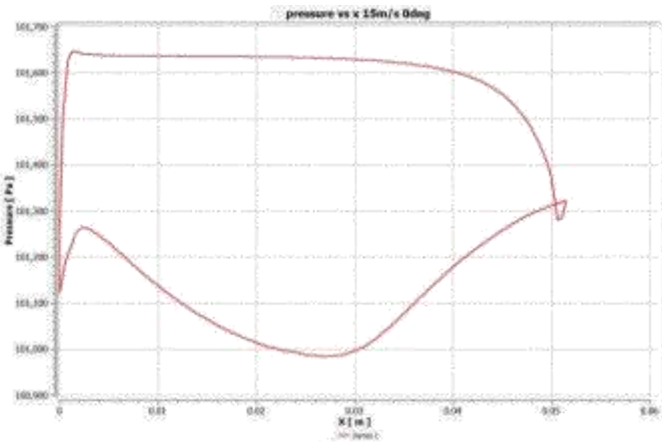

Fig. No.6: - Pressure distribution graph for 15m/s velocity at Zero incidence angle

The high pressure for Reynolds number 49724 at Zero incident angle was recorded around 3.5% of chord and the value as 101654 Pa and it gets decreased slowly till the 73.3% of chord. The last pressure value recorded at 86.67% of chord i.e. 0.052. The corresponding velocity contour is shown above.

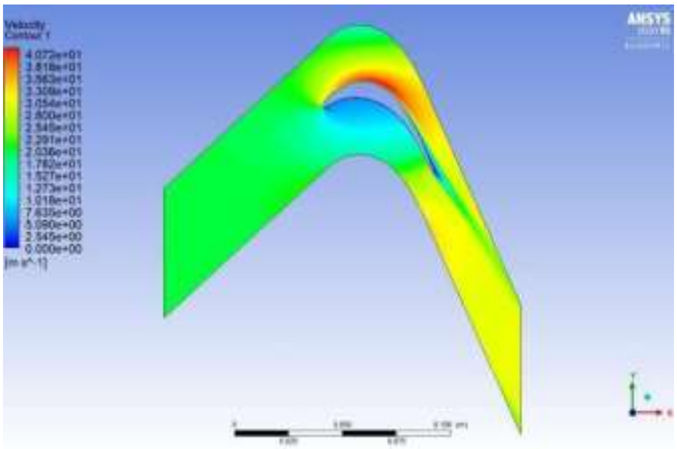

Fig. No.7: - Velocity contour for 20m/s velocity at Zero incidence angle

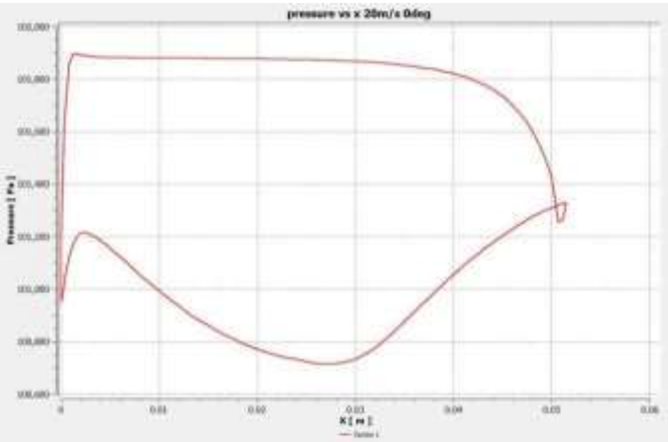

Fig. No.8: - Pressure distribution graph for 20m/s velocity at Zero incidence angle

In the case of Reynolds number 66298, highest pressure value was 101900 Pa at the chord of around 3% that is even before comparing to the Reynolds number 49724. And the last pressure value before the flow leaving the surface of the bladeis around 87% i.e. nearly the same value for Reynolds number49724. So, the pressure value has mild increase than the previous Reynolds number and the corresponding velocitycontour is sown above.

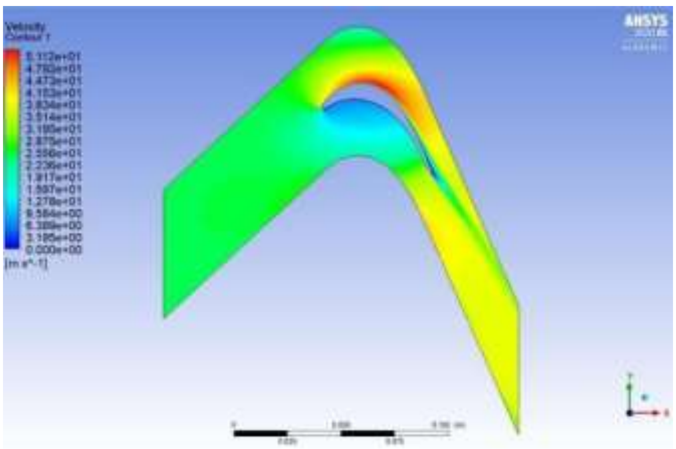

Fig. No.9: - Velocity contour for 25m/s velocity at Zero incidence angle

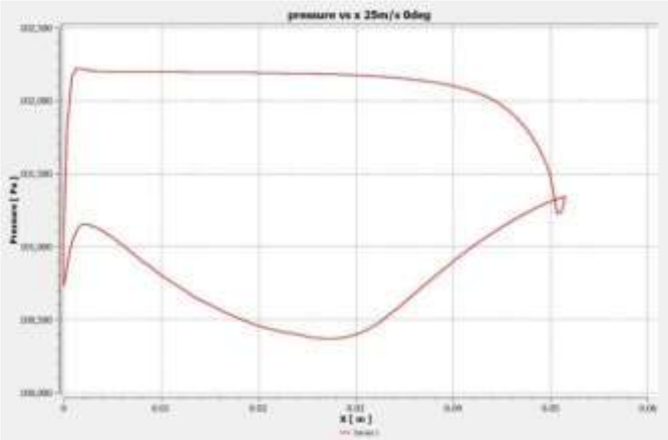

Fig. No.10: - Pressure distribution graph for 25m/s velocity at Zero incidence angle

For Reynolds number 82873, the highest-pressure value recorded as 102250 which is more than the flow of Reynolds numbers 49724 and 66298 of same incidence. But the detachment of the flow from surface happening mostly about the same chord length as like as the previous Reynolds numbers.

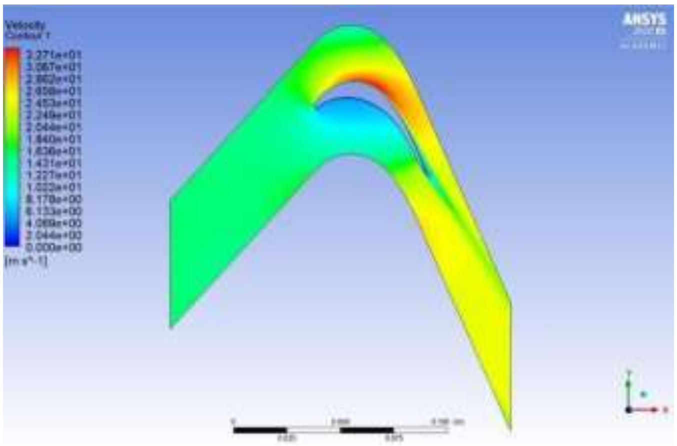

Fig. No.11: - velocity contour for 15m/s velocity at +5 incidence angle

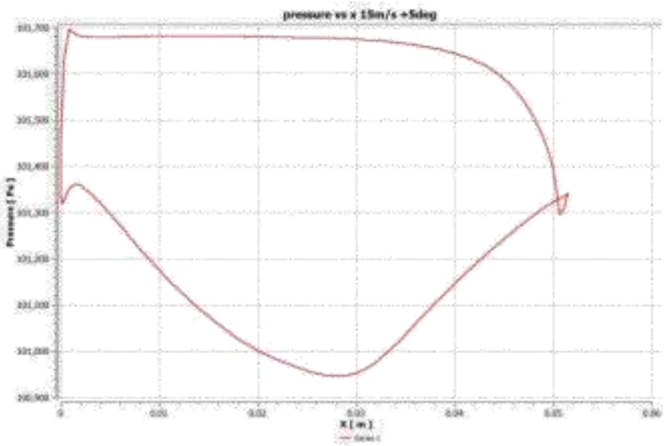

Fig. No.12: - Pressure distribution graph for 15m/s velocity at

+5 incidence angle

On increasing the incident angle to +5, the highest-pressure value is recorded as 101700 which is more than the Reynolds number of zero incidence i.e. around the chord of 2.8% andthe distribution follows over the surface is similar to the zero incident of same Reynolds number. The leaving of the flow also similar to the zero-incident computation with mild changeof chord length.

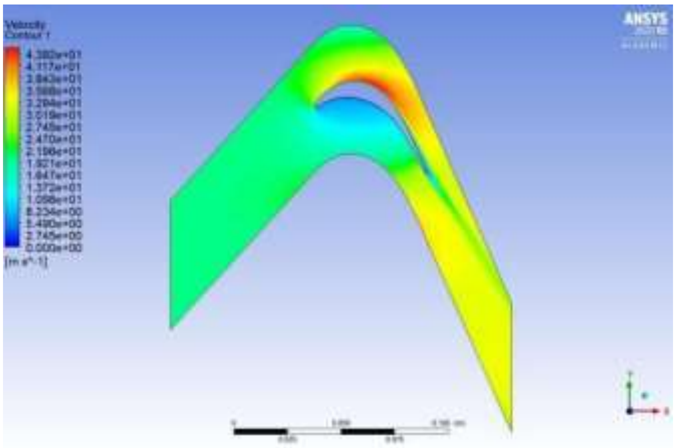

Fig. No.13: - velocity contour for 20m/s velocity at +5 incidence angle

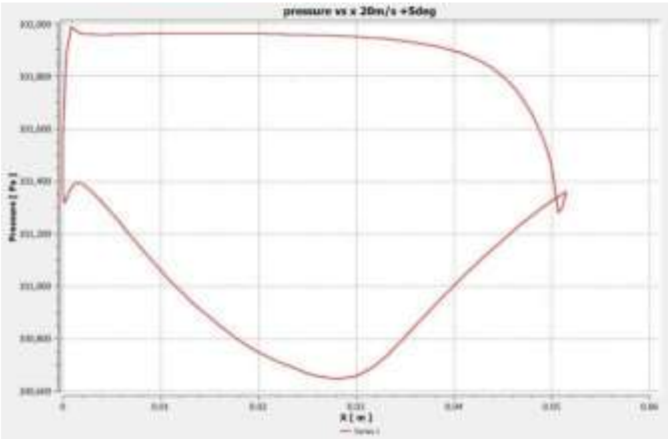

Fig. No.14: - Pressure distribution graph for 20m/s velocity at

+5 incidence angle

Pressure for Reynolds number 66298 at +5 incident anglereceives 300Pa more than the Reynolds number 49724 i.e. 10200Pa, but the value is high when compared to zero incidentof same Reynolds number flow. The detachment of the flow happens slightly before the Reynolds number 49724 as the pressure keep on reducing from the 5.4% of chord on the pressure side. Velocity recorded high on the pressure side thanthe suction side as shown in the velocity contour figure above.

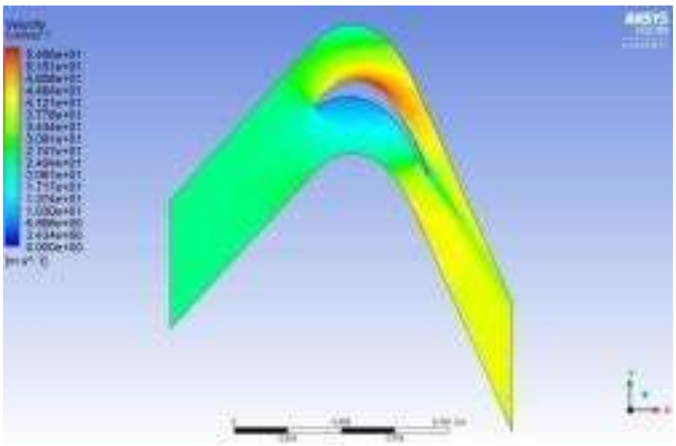

Fig. No.15: - velocity contour for 25m/s velocity at +5 incidence angle

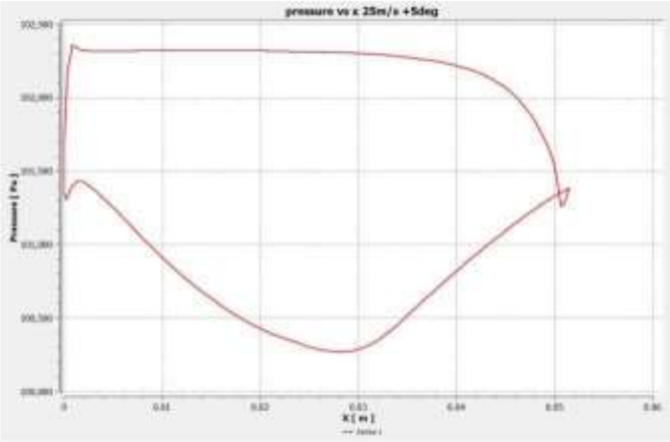

Fig. No.16: - Pressure distribution graph for 25m/s velocity at

+5 incidence angle

For the Reynolds number 82873 for +5 incident angle, the highest-pressure value is recorded as 102385Pa at the 3.6 % ofcord which is high compared to the Reynolds number 66298of same incident also for the same Reynolds number of zero incidence. The flow getting detached at the 79% of the chord which is earlier compared to previous cases also the velocity contour shows the high velocity attachment for less chordlength compared to suction side of the blade.

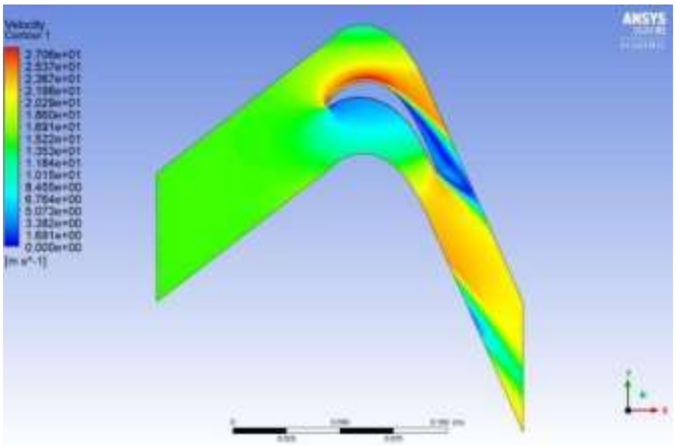

Fig. No.17: - velocity contour for 15m/s velocity at -5 incidence angle

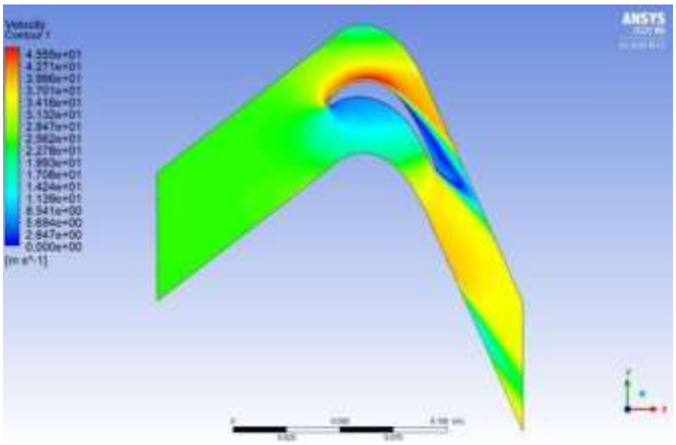

Fig. No.18: - Pressure distribution graph for 15m/s velocity at

-5 incidence angle

The highest-pressure value for the Reynolds number 49724 of

-5 incident has 100Pa less pressure than the +5 incidence, but the distribution has variation than the +5 incidence. Even the detachment of the flow happens at very earlier than the previous case of same Reynolds number. The highest pressure is as 101600Pa and the velocity contour is shown above.

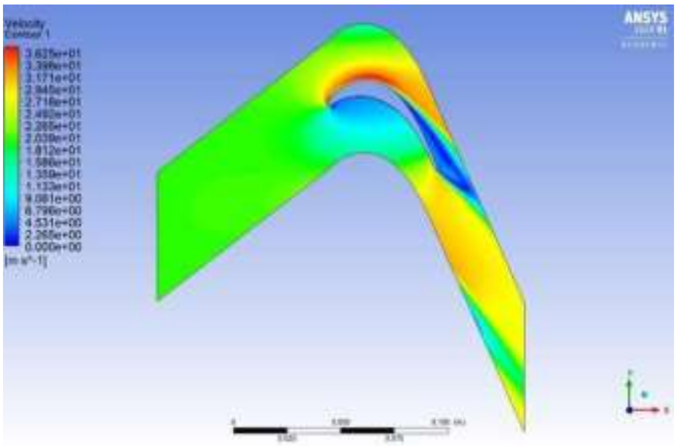

Fig. No.19: - velocity contour for 20m/s velocity at -5 incidence angle

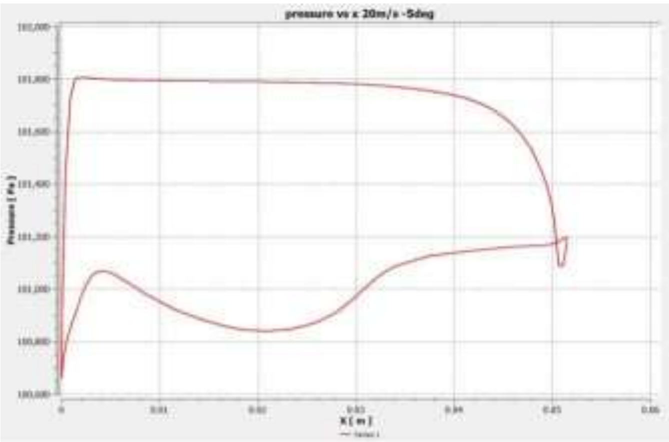

Fig. No.20: - Pressure distribution graph for 20m/s velocity at

-5 incidence angle

In the computation of Reynolds number 66298, the pressure distribution on the pressure side similar to the previous cases but there is much variation on the suction side as shown in the graph above. The pressure value is recorded as 101800Pa and the flow detachment happening at 68% which is much earlier than the previous cases, the velocity contour is shown above.

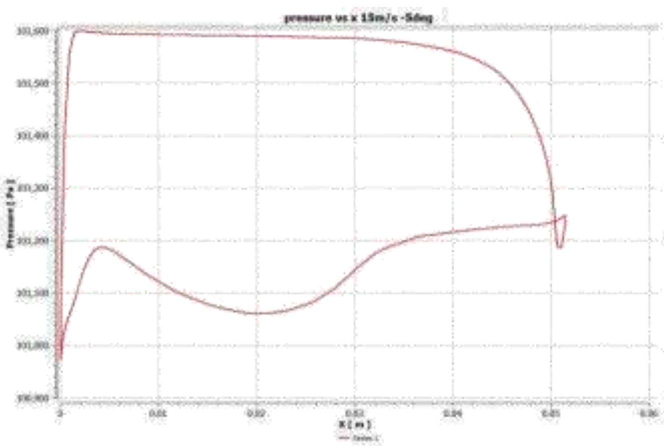

Fig. No.21: - velocity contour for 25m/s velocity at -5 incidence angle

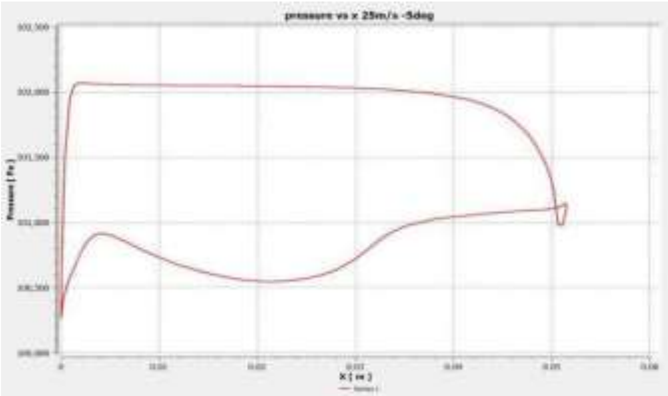

Fig. No.22: - Pressure distribution graph for 25m/s velocity at

-5 incidence angle

Reynolds number 82873 records the highest-pressure value as 102200 which is less than the +5 incidence of same Reynolds number at the 3.34% of the chord. The flow separation happened at 66.8% of the chord which is slightly earlier to theReynolds number 66298 but much earlier to the remaining cases. The velocity contour for the Reynolds number 82873 is as shown above.

Here, in this project the result analysis has been studies andgraphically represented as above. The pressure distribution has been not changed much for changing the velocities with same incident angles. But, the change of pressure distribution got more deviation when the incident angles have been changed compare to the different velocities at same incident angles.

Conclusion: -

The major following major conclusions are drawn from thisinvestigation:

- The static pressure distribution over the blade recorded highest around 3.3% to 3.6% of the chord length for all the Reynolds number flows.
- Pressure values increases gradually on increasing theReynolds number before transition of the flow.
- The pressure difference at different incident angles for same Reynolds number is less compare to other Reynolds numbers.
- Static pressure graphical representation is invertedbefore transition period of the flow as compared tothe other Journal papers mentioned in references.

References: -

1. EM Curtis, HP Hodson, MR Banieghbal, JD Denton, RJ Howell, NW Harvey, "Development of bladeprofiles for low-pressure turbine applications", Journal of Turbomachinery 119 (3), 531-538, 1997.
2. CH Sieverding, "Recent progress in theunderstanding of basic aspects of secondary flows inturbine blade passages" Journal of Engineering for Gas Turbines and Power 107 (2), 248-257, 1985.
3. Josef Panovsky, Robert E Kielb, "A design method toprevent low pressure turbine blade flutter", Journal of Engineering for Gas Turbines and Power 122 (1), 89-98, 2000.
4. Xiao Qu, Yanfeng Zhang, Xingen Lu, Zhijun Lei, Junqiang Zhu, "Effect of Periodic Wakes and a Contoured End wall on Secondary Flow in a High-Lift Low-Pressure Turbine Cascade at Low ReynoldsNumbers", Computers and Fluids 2109.
5. OP Sharma, TL Butler, "Predictions of endwall lossesand secondary flows in axial flow turbine cascades", Journal of Turbomachinery 109 (2) 229-236,1987.
6. M Nowinski, J Panovsky, "Flutter mechanisms in lowpressure turbine blades", Journal of Engineering for
7. Gas Turbines and Power 122 (1), 82-88, 2000.
8. Asghar, et al, "Influence of a Novel 3D Leading edgegeometry on the Aerodynamic performance of Low- Pressure Turbine Blade Cascade Vanes", Journal of Turbomachinery (2014).
9. Yanfeng Zhang, et.al, "Effects of incidence angle on alow-pressure turbine blade boundary layer evolutionthrough large eddy simulation", al J. Turbomachinery Propulsion (2018)
10. Gajanan Tatpati, K Viswanath, N Sitaraman, "Computational and Experimental Investigation ofSeparation Control of LP Turbine Cascade Blades Using GurneyFlaps" Journal of Turbomachinery 2017.
11. Banieghbal, M. R, Curtis, E. M., Denton, J. D., et al.,"Wake Passing in LP Turbine blades", Presented at AGARD Conference, UK, 2012.
12. Stieger, R. D., 2002. "The Effect of Wakes onSeparating Boundary Layers in Low Pressure Turbine", Ph D Thesis, Cambridge University, UK.