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COMPUTATIONAL STUDY ON AERODYNAMIC LOSSES OF LINEAR TURBINE CASCADE USING WIND TUNNEL

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ABSTRACT *: A three dimensional profile of linear cascade with five blades were prepared in solidworks and computational analysis was carried out in a ANSYS CFX V14. Air is passed through a cascade geometry as a working medium. There are different geometries taken for comparison . The ANSYS CFX V14 was used for the meshing and CFD analysis of cascade at different tip clearance and incidence angle. Proper attention focus on the pressure loss co-efficient, Axial force, Axial force co-efficient, Tangential force, Tangential force co-efficient, Lift force, Lift force co-efficient, Drag force and Drag force co-efficient of the cascade geometry.*

Keywords: turbine cascade, solidworks, ANSYS CFX V14

Nomenclature
P_R :- Static pressure
P_T :- Total pressure
P_S :-Stagnation pressure
V :- Velocity
Y :- Pressure loss co-efficient
Fy :- Tangential Force
C'Fy :- Tangential force co- efficient
Fx :- Axial force
C'Fx :- Axial force co-efficient
L :- Lift force
C_L :- Lift force co-efficient
D :- Drag force
C_D :- Drag force co-efficient
EFFICIENCY

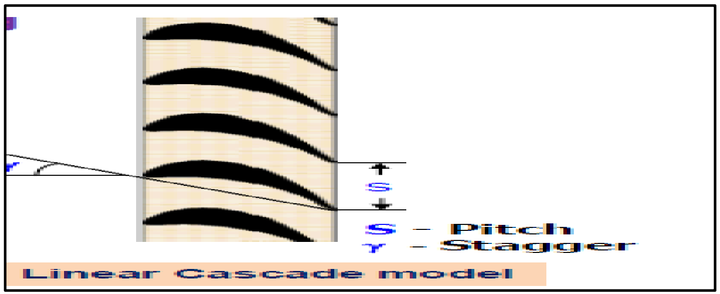
1. Introduction:

Turbines are used for propulsion and power production. Turbine efficiency is limited due to generation of various aerodynamic losses and other characteristics.

Research and development concern to improve efficiency by:
a) Increase in turbine temperature
b) Increasing efficiency of turbomachinery component
c) By reducing various aerodynamic losses.

These three factors are also used for the improve in the turbine efficiency

Turbine efficiency directly depends upon the inlet temperature it improves the performance and efficiency of turbine. operating temperature is 1800 k.Today the performance of turbine and compressor was decreased due to in-efficiency of the turbo-machinery components. Use of the highly advanced soft-wares design of the turbine components with minimal aerodynamic losses



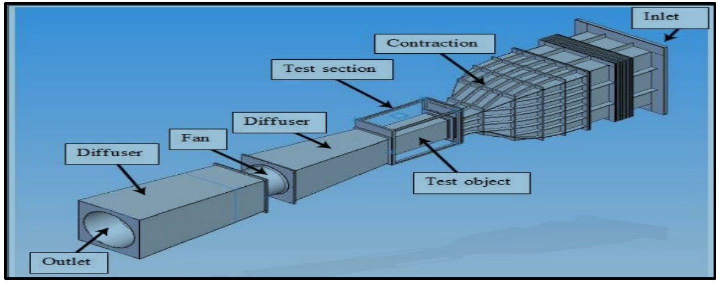


Fig: Wind Tunnel

2. DIFFERENT PART OF WIND TUNNEL

1. Inlet section :- The entry is shaped to guide the air smoothly into tunnel. Proper flow separation here would give excessive turbulence and no uniformity in velocity in the working section. So 2 to 2.5 meter air space is required to entry.
2. Contraction :-. Settling chamber and contraction cone to make the flow more parallel and more uniform and to give a little time for turbulence or decay, the mouth is followed by a setting chamber which leads to be contraction to get velocity increase. Contraction is a specially designed curved due to give good results in test section. The setting chamber usually includes a honey comb and nylon mesh screens to filter and stabilize the incoming air flow.
3. Test section :- The working section is followed by a divergent duct. The divergence results in a corresponding reduction in the flow speed
4. Diffuser :- Diffuser reduces in dynamic pressure leads to reduction in power losses at the exit.

3. LITERATURE REVIEW:

Two dimensional rectilinear cascade with 6 blades and 5 channels prepared in gambit and air as a working medium in the cascade and determine the effects of the energy loss co-efficients.They found that 1.128 , 1.146 , and 1.19 profile loss co-efficient at the 120 m/sec , 150 m/sec , 180 m/sec respectively velocity. The value of profile loss co-efficient is increased by 6.25%. Increase in velocity waves shifted towards left it means separation of fluid happening at the suction side and chances of shock wave more here[1].

Computational analysis carried out on the effect of pressure, velocity, temperature, kinetic energy, turbulence eddy dissipation, and pressure flows through linear cascade.According to pressure contours it decreases pressure between leading edge and trailing edge. According to temperature contours the temperature were taken 350 k and 315 k but at the 350 k the variation observed at inlet. There is a pressure difference in suction and pressure side of the blade hence lift force create on the blade.Velocity observed by velocity contours and stream lines[2].

.In this analysis CFD – analysis was carried out the aerodynamic forces on the NACA 64618 at high reynold number of 9 million.The results of lift and drag co-efficient taken from the experimental wind tunnel test results were 1.6 and 0.07 at an angle of attack 16°, similarly 1.48 and 0.0159 were obtained by k-ε model. 1.59 and 0.0165 were obtained by the mentors SST turbulence model.From this observation the results of the lift and drag co-efficients are equal in computational and experimental results are measured at the wind tunnel[3].

Cascade experiments carried out to obtain static pressure at the mid span of cascade it ranges from -61° to 4° at the exit mach number 0.70, 0.75, 0.80 corresponding to reynold numbers varies from $6.35x10^5$ and $6.78x10^5$ trailing edge loss.When the incidence decreases from 4° to -41° at the M=0.7 the variation of trailing edge loss and profile loss are less than 2% and 6% respectively.At the value of i=4° cascade shows good aerodynamic performance according to numerical solution.Incidence decreases from -61° the boundary layer separates and losses increaseThis losses occurs due to separation of bubbles on the pressure side[4].

According to this study design of blade was carried out by mathematical techniques rapid axial turbine design RATD.The total pressure loss co-efficient found to wake region occur at down stream distance of 1.3 chord length with a 0.75 pitch. Total pressure co-efficient vary between 1.7 and 1.9 are caused by secondary flow vortices such as passage vertex which is converted via mid span.It was shown that stagnation pressure loss manifest region of high losses at an axial distance of 0.45 of chord length[5].

As per axial gap of 3.5 mm and 5% tip clearance is the optimum set value for the maximum performanceThe torque on the first rotor is maximum as compared to second rotor because of large pressure dropThe mach number is maximum for the first rotor and it is decreases at the second rotor[6].

Experiment carried out with several models *k-ω model by Wilcox,* Menter SST model, *v2-f model by Durbin an analysis of CFD.*According to above model MSST model is the best model for CFD analysis. With the CFD codes of second order accuracy. One should use grids comprised of about more than 2 million cells(full each full blade passage) to get a definite conclusion on preference of one or another turbulence model for prediction of phenomena under consideration [7].

The measurements were taken at the high speed cascade wind tunnel at different high pressure turbine profiles T150, T151, and T152. the datum profile T150 is compared with a highly loaded design T151 and T152. moderate aerodynamic loading but smooth velocity profile distribution for an efficient cooling of blade.A maximum reduction of the total pressure losses co-efficient by 20% achieved at pitch to chord ratio higher than for T151 with respect to datum profile T150.The results related to the flow calculations indicates that 50% of the total pressure loss profile T150 and T151 reduction in the trailing edge thicknes[8].

End wall static pressure, total pressure loss, wake vorticity measurements were taken at the effect of axial reynold number $1x10^5 < Re < 5.0x10^5$ and tip height $0.015 < g/c_x < 0.05$ for flat and partial suction side squealer tip geometries.In the flat plate geometries blade loading drop linearly at the mid span of the blade and at the increase in gap height and in reynold number the blade loading is increased.For the squiler tip geometries both mid span and tip blade loading are increased.Squiler increases mid span loading at 10% for all the cases . reynold number effect on the squiler tip and flat tip geometry both are the same[9].

4. CFD ANALYSIS

Fluid design of the rectilinear turbine cascade was prepared in solidworks as a modeling software and the meshing and CFD analysis was carried out in the ANSYS CFX V14. And the results are taken at the different tip clearance and different incidence angle and at the various velocities. This fig. are related to the 0 degree incidence and 0% tip clearance.

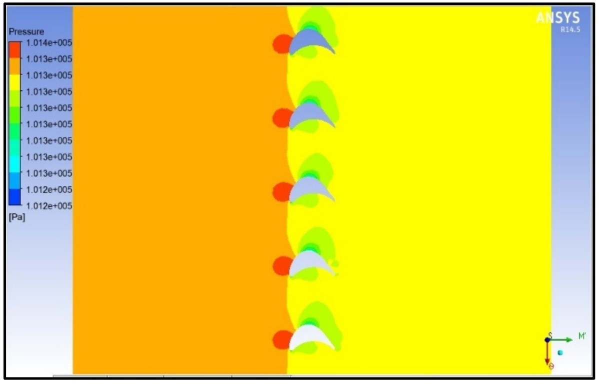


Fig: Pressure Contours

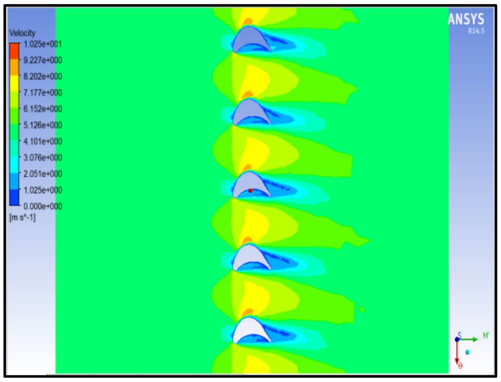


Fig: Velocity Contours

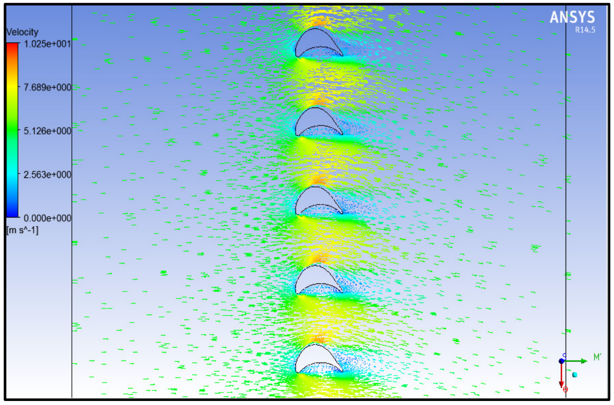


Fig: Velocity Vectors

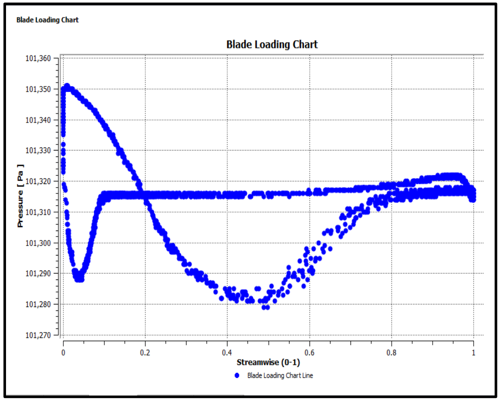


Fig: Pressure Loading Chart

For the analysis of aerodynamic losses of linear turbine cascade blades different case studies were taken
CASE A :- 0 Degree 0 % Tip clearance (velocity 5 m/sec) CASE B :- 0 Degree 2% Tip Clearance (velocity 10 m/sec)
CASE C :- 0 Degree 4 % Tip clearance (velocity 15 m/sec) CASE D :- 5 Degree 0% Tip clearance (velocity 5 m/sec)
CASE E :- 5 Degree 2 % Tip clearance(velocity 10 m/sec) CASE F :- 5 Degree 4% Tip clearance(velocity 15 m/sec)
CASE G :- 10 Degree 0 % Tip clearance (velocity 5 m/sec) CASE H :- 10 Degree 2 % Tip clearance(velocity 10 m/sec)
CASE I :- 10 Degree 4 % Tip clearance(velocity 15 m/sec)
The inlet boundary condition should be taken on the different velocities and the outlet boundary condition was taken as the normal atmospheric pressure.

5. GRID INDEPENDENCY STUDY AND Yplus BOUNDARY SEPERATION

From the 3 D model and the ANSYS CFX V14 the meshing of the geometry and the number of nodes and elements created in the geometry and Y plus boundary separation has to be shown in the below table.

GRID INDEPENDENCE TEST AND Y plus BOUNDRY SEPERATION				
CASE	NUMBER OF NODES	NUMBER OF ELEMENTS	TETRAHEDRA	Yplus
CASE A	567389	3176086	3176086	25.1174
CASE B	592945	3337110	3337110	50.2373
CASE C	609389	3437154	3437154	70.064
CASE D	551984	3087691	3087691	24.9546
CASE E	580477	3262360	3262360	50.686
CASE F	589965	3324185	3324185	73.61
CASE G	527320	2947771	2947771	26.84
CASE H	556226	3126702	3126702	53.91
CASE I	564838	3182405	3182405	78.671

6. EQUATIONS

Stagnation pressure $Ps = Pr + 0.5*\rho c^2$
Pressure loss coefficient $Y = \Delta p_o = p_{02} - p_{01}/0.5\rho c_2^2 = \Delta p_o / 0.5\rho c_2^2$
There are different-different blade forces as under:
Tangential Force :- $F_Y = 2\ (s/l) \cos^2 \alpha_2 (\tan \alpha_1 + \tan \alpha_2)$
Tangential force coefficient:- $C'_{FY} = F_Y / 0.5\ \rho l c_2^2 = 2\ (s/l) \cos^2 \alpha_2 (\tan \alpha_1 + \tan \alpha_2) / 0.5\ \rho l c_2^2$
Axial force:- $F_X = s/l \cos^2 \alpha 2\ (\tan^2 \alpha_2 - \tan^2 \alpha_1)$
Axial force coefficient: $C_{FX} = s/l \cos^2 \alpha 2\ (\tan^2 \alpha_2 - \tan^2 \alpha_1) + s/l.\ Y$
Lift force:- $L = (s/l) \cos \alpha_m (\tan \alpha 1 + \tan \alpha 2)$
Lift force co-efficient:- $C_L = L/0.5\ \rho l c_m^2 = (s/l) \cos \alpha_m (\tan \alpha 1 + \tan \alpha 2) + s/l.\ \Delta p0/0.5\ \rho\ c_m^2\ .\ \sin\alpha_m$
Drag force: $D = S\ \Delta p_o \cos \alpha_m$
Drag force co-efficient :- $CD = D/0.5\ \rho l c_m^2$
Efficiency:- $[1-((P1/P02)^\wedge(\gamma-1/\gamma))]/[1-((P1/P01)^\wedge(\gamma-1/\gamma))]$

From these equations there was different parameters of the linear turbine cascade were calculated and the results should be compare at different cases.

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7. CFD RESULTS AND ITS CALCULATIONS :-

from the different inlet and outlet conditions in the linear turbine cascade blades were taken and the different parameters were calculated from the results Pressure co-efficient, Tangential force, Tangential force co-efficient, Axial force, Axial force co-efficient, Lift force, Lift force co-efficient, Drag force, Drag force co-efficient.

CASE	INLET				OUTLET			
	Pr	P_T	VELECITY	P_S	Pr	P_T	VELECITY	P_S
CASEA	101365	101380	4.99	101380.25	101325	101342	5.25	101340.62
CASE B	101480	101539	9.99	101541.12	101325	101393	10.41	101391.2
CASE C	101646	101779	14.99	101783.62	101325	101506	14.88	101467.63
CASED	101366	101381	4.998	101381.25	101325	101341	4.967	101340.1
CASE E	101485	101545	9.99	101546.12	101325	101387	9.97	101385.9
CASE F	101676	101809	14.99	101813.62	101325	101466	15.47	101465.02
CASEG	101372	101387	4.99	101387.25	101325	101343	4.94	101340.25
CASEH	101505	101564	9.99	101566.12	101325	101396	10.46	101392
CASE I	101814	101947	14.99	101851.62	101325	101469	15.49	101464.47

CASE	Y	F_y	C'_{Fy}	F_x	C'_{Fx}	L	C_L	D	C_D	EFFICIENCY
CASE A	2.3248	1840.6	0.32	6492.77	1.129	7497.2	1.3725	3147.87	0.612	35.03%
CASE B	2.3566	6926.3	0.32	11108.09	0.5136	35427	1.63	12342.15	0.5707	30.67%
CASE C	2.321	14868	0.32	23620.92	0.508	75456	1.629	26089.58	0.562	30.02%
CASE D	2.712	1289.7	0.249	2611.06	0.635	2633.6	0.509	2925.26	0.566	26.78%
CASE E	2.626	5285.1	0.254	14713.09	0.709	18779	0.905	11380.05	0.548	27.56%
CASEF	2.414	12062	0.249	32363.06	0.669	83218	1.722	24362.28	0.504	30%
CASE G	3.165	948.15	0.1865	5208.83	1.025	9955	1.939	2707.33	0.528	27.70%
CASE H	2.604	4251	0.1865	20262.53	0.89	41597	1.825	10020.73	0.439	24%
CASEI	2.624	9322.4	0.1865	32346.2	0.647	89359	1.847	22069.54	0.456	27.65%

8. CONCLUSION :-

1) From the case study CASE A, CASE B, CASEC the pressure loss co-efficient was found 2.3248, 2.3566 and 2.2.321 respectively. Tangential force co-efficient remains same and was found 0.32. Axial force co-efficient is decrease and 1.129, 0.5136, and 0.508 respectively for CASE A, CASE B and CASE C. Lift force co-efficient was found 1.3725, 1.63, 1.629 respectively for CASE A, CASE B, and CASE C. Drag force co-efficient decrease and was found 0.612, 0.5707, and 0.562 respectively. Efficiency for the CASE A, CASE B, and CASE C 35.03%, 30.67%, 30.02% respectively.

2) From the case study CASE D, CASE E, CASE F the pressure loss co-efficient decrease respectively and is 2.712, 2.626, 2.414. Tangential force co-efficient 0.635, 0.709, 0.669 respectively for CASE D, CASE E, and CASE F. Axial force co-efficient was found 0.635, 0.709, and 0.669 respectively for CASE D, CASE E, and CASE F. Lift force co-efficient increased and was found 0.509, 0.905, 1.722 for the CASE D, CASE E,

and CASE F respectively. Drag force co-efficient was decreased and was found 0.566, 0.548, 0.504 respectively for CASE D, CASE E, CASE F. Efficiency was increased and was found 26.78 %, 27.56 %, 30 % respectively for CASE D, CASEE, and CASE F respectively.

3) From the case study CASE G, CASE H, CASE I Pressure loss co-efficient was found 3.165, 2.604, and 2.624 respectively. Tangential force co- efficient remains same and was found 0.1865 for all cases. Axial force decreased and was found 1.025, 0.89, and 0.647 respectively for CASE G, CASE H, CASE I. Lift force co-efficient was found 1.939, 1.825, and 1.847 respectively for CASE G, CASE H, CASE I. Drag force co-efficient was found 0.528, 0.439, and 0.456 respectively for CASE G, CASE H, CASE I. Efficiency was found 27.70%, 24%, and 27.65% respectively for CASE G, CASE H, and CASE I.

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