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Computational Analysis of Vortex Generator Jets in LP Turbines

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Abstract

With the trend towards higher bypass ratios in turbofans, demands are increasing for the low pressure turbines (LPT) that drive the large fan assemblies. Also, many military and civilian applications use the LPT to power an ever increasing applications of onboard communication, diagnostic, and service hardware. Aerodynamic efficiency is a major concern in today's aerospace and aircraft industries but the flow separation is one of the important factors that affect the aerodynamic efficiency. At very high altitudes the low Reynolds number flow through the low pressure turbine section of the gas turbine engine can drop below 25,000. At these low Reynolds numbers the flow is laminar and extremely susceptible to separation which can lead to increased losses and reduced lift. Small jets of air injected through the suction surface of the airfoil, called Vortex Generator Jets (VGJs), have been shown successful in suppressing separation and maintaining attached flow. We focused on designs of Low Pressure Turbine with the available L1A blade data to improve the performance of the aircraft, delay boundary layer separation and increase the lift forces and to analyze the performance of the turbine blade with vortex generator jet with the available fluent software. We conclude that flow separation can be delayed by using vortex generator.

1. Introduction

LPT design is quite complicated than other parts of the engine. On one hand, the LPT must perform optimally at high-Re conditions near sea level where maximum loading is required for take-off. On the other hand, the majority of flight time is spent in higher altitude cruise conditions, where the lower air density results in a lower Re and lower momentum flow in the LPT section. A turbine section can have multiple stages typically consisting of two rows of airfoils, a vane and a blade; some designs employ counter-rotating blades which eliminate the vane. The vane row is fixed and guides the incoming flow into the tangential direction of rotation. The row of blades turns the flow, resulting in a net torque on the shaft. The effect of the entire turbine section is to expand the gas (increase the velocity) while extracting energy to power the compressor.

2. Vortex Generator

Vortex generator is an aerodynamic surface, consisting of a small vane that creates a vortex. Vortex generators can be found on many devices, but the term is most often used in aircraft design. Vortex generators are likely to be found on the external surfaces of vehicles where flow separation is a potential problem because vortex generators delay flow separation. On aircraft they are installed on the leading edge of a wing in order to maintain steady airflow over the control surfaces at the rear of the wing. They are typically rectangular or triangular, tall enough to protrude above the boundary layer, and run in span wise lines near the thickest part of the wing. They can be seen on the wings and vertical tails of many airliners. Vortex generators are positioned in such a way that they have an angle of attack with respect to the local airflow.

The boundary layer normally thickens as it moves along the aircraft surface, reducing the effectiveness of trailing-edge control surfaces; vortex generators can be used to remedy this problem, among others, by re-energizing the boundary layer. Vortex generators delay flow separation and aerodynamic stalling; they improve the effectiveness of control surfaces and, for swept-wing transonic designs , they alleviate potential shock-stall problems.

3. Flow Control: VGJ's

Much of the research in LPT boundary layer separation has been conducted in low-speed linear cascades. Much of the focus concerning separation control has been

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with the Pack B at low Reynolds number (Re based on axial chord and inlet velocity < 30,000). Considerable success has been achieved using VGJs with this blade profile in low-speed linear cascade facilities. Steady blowing VGJs have been shown to generate two counter-rotating stream wise vortices, of which one is dominant. The core of the coherent primary vortex promotes mixing as it convects downstream, entraining high momentum fluid in the free stream which energizes the boundary layer and suppresses the separated zone. Pulsed blowing has been shown to be at least as effective as analogous steady blowing using significantly less mass flow. This is attributed to the starting vortex ring at the onset of each pulse, which enables the vortex core to penetrate further into the boundary layer. A reduction in wake total pressure loss of up to 60% is typically reported. When the cascade studies add more realistic inlet conditions (3-5%) inlet free stream turbulence and/or unsteady wakes, the low Re separation is reduced and the gains from VGJs are more modest (20-30%). Still, there is a desire to explore flow control opportunities with more aggressive blade designs to discover what the limitations are. VGJs were effective at maintaining approximately the same pitch-averaged total pressure loss with up 3 to half the total number of turbine blades. Alternatively, the blade shape itself can be modified to produce higher pressure loading with fewer blades. For example, considerable evidence suggests that front-loaded profiles experience lower separation losses.

4. Analysis

A. Analysis Procedures

Step 1: At first we are going to get our L1A blade coordinates using ADVANCEDAEROFOIL SECTION GENERATION software from the details we have about L1A blade(e.g.: Axial Chord length(Cx),true chord length, inlet and exit flow angles) .
Step 2: Using GAMBIT software we are going to create the geometry of L1A blade using the Coordinates.
Step 3: In GAMBIT we create FARFIELD BOUNDARY and MESH process.
Step 4: Then using FLUENT software we are going to analyze the behavior of the aerofoil for different low Re (25000, 50000 and 100000).
Step 5: From the previous work we can find the flow separation range present on the suction surface of the aerofoil at low Re.
Step 6: Positioning the vortex generator in different places within the range of flow separation on the aerofoil using GAMBIT will be done and Step 1 & Step 2 will be repeated for these models.
Step 7: Then the Analyzing work for the aerofoil models with VG will be done in FLUENT.
Step 8: Then the comparison of performance between the aerofoil with VG models and aerofoil without VG model will be done.
Step 9: The VG model which gives best performance will be chosen and it will taken to the DISCUSSION process along with the model without vortex based on their performance at various low Re no.title .

B. Analysis Results for Aerofoil without VG

From the above graphs we can find the flow separation range of an aerofoil surface. For our L1A blade profile The Separation range is start from the point 0.05 to 0.07 on the suction surface length (i.e.) 50% to 70% 0f the Axial Chord length (Cx) .So, we have decided to place the VORTEX GENERATOR in three different places within the range of 50% to 70% on the suction surface curve. We create three Blade Profiles models with VG placed in three different places (50%, 60% & 70% of the axial chord length Cx).

C. Performance Analysis of Aerofoil's With Vg

Analysis on Velocity Magnitude along the Blade Profile at Low Re No 25000

D. Analysis on Dynamic Pressure Along the Aerofoil at Low Re No: 25000

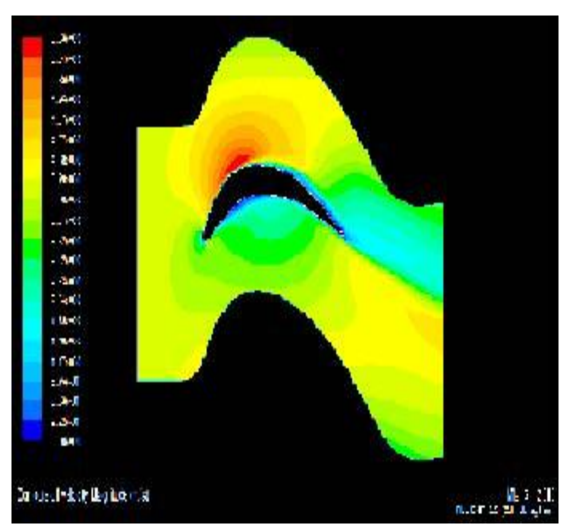


Fig-4.a: Aerofoil with VG at its 50%Cx (Axial chord)

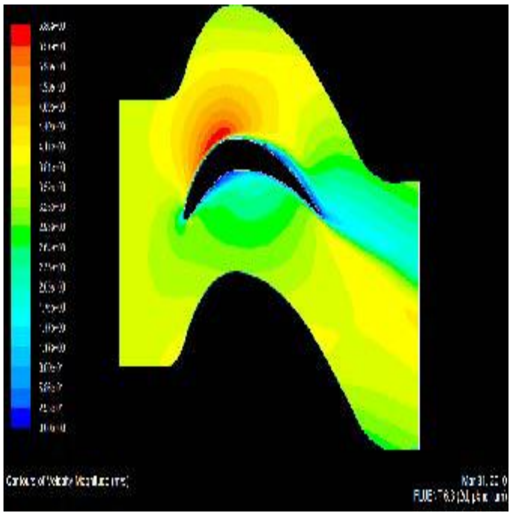


Fig-4.b: Aerofoil with VG at its 60%Cx

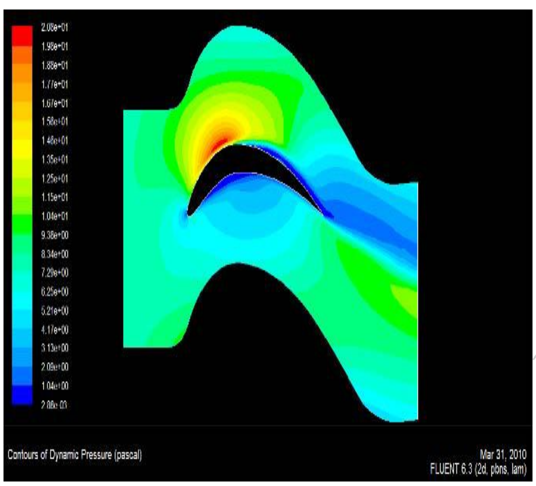


Fig-4c: Aerofoil with VG at its 50% Cx.

5. Tables and Graphs

Aerofoil	Without VG	VG at 50% Cx	VG at 60% Cx	VG at 70% Cx
Drag	-0.091	-0.055535665	-0.062131298	-0.080287
C_D	-0.00976	-0.006798972	-0.007606444	-0.009829
Lift	1.206966	1.2159022	1.2196748	1.2039107

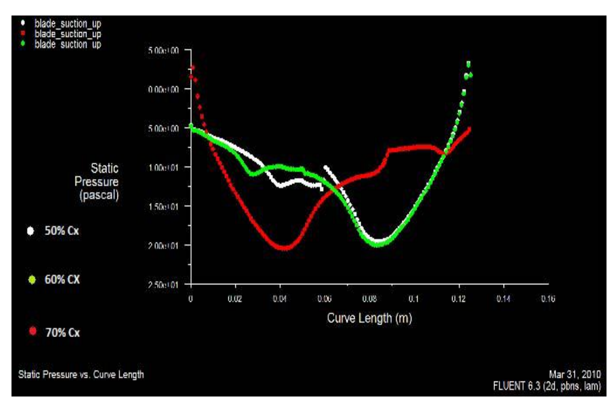
Table 5.1.1 Reynolds number at 25000

Aerofoil	Without VG	VG at 50%Cx	VG at 60% Cx	VG at 70% Cx
Drag	-0.38764	-0.22711265	-0.27148597	-0.34390584
Drag coefficient	-0.01186	-0.00695108	-0.008309189	-0.010525696
Lift	4.856173	4.907022	4.911755	4.8604085
Lift coefficient	0.148629	0.15002313	0.15033081	0.14875928

Table 5.1.2 Reynolds number at 50000

Aerofoil	Without VG	VG at 50% Cx	VG at 60% Cx	VG at 70% Cx
Drag	-1.668765	-0.91552999	-1.1141727	-1.390674
Drag coefficient	-0.001276	-0.007005214	-0.008525184	-0.01064087
Lift	19.582018	19.687808	19.730137	19.569756
Lift coefficient	0.1498325	0.15064204	0.15096677	0.14973961

Table 5.1.3 Reynolds number at 100000



Graph 5.1Static pressure Vs Curve length.

6. Results and Discussion

By evaluating the graphs and performance parameters values obtained above, it is assured that the aerofoil models with VG will increase flow suction length by delaying the flow separation along the suction surface of the aerofoil.

Particularly, the aerofoil which is having VG at its 60%Cx gives the best performance than other models .The Percentage of increased value of Cl is given below:

Aerofoil	VG at 50% Cx	VG at 60% Cx	VG at 70% Cx
Re = 25000	0.74 % increase	1.05 % increase	0.25 % decrease
Re = 50000	0.93 % increase	1.14 % increase	0.08 % increase
Re = 100000	0.54 % increase	0.74 % increase	0.06 % decrease

We conclude that flow separation can delayed by using vortex generator. Vortex generator is fixed on the suction surface of the L1A turbine blade profile. If we fit the vortex generator on the upper surface of the blade it will delay the boundary layer separation and it will energies the boundary layer. The efficiency of the blade becomes higher. Lift forces will increases. Aerofoil can easily recover from the Boundary Layer Separation problem and the aircraft performance also increases in high altitudes at Low Reynolds number.

Especially, when the VG positioned at 60% of Cx the performance of the blade is good than others. It is calculated that the efficiency of the blade is increased nearly (0.54 to 1.14) at low Reynolds number between(25000 to 100000).

Fluent is successfully used for computing the flow properties over the aerofoil and performance coefficients like (lift coefficient, drag coefficient). These values are taken for different Re No. Contours of Flow properties and values of coefficients are taken and graphs were plotted for Aerofoil with and without VG.

7. Reference

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