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# Reduction of Stall in Axial Flow Compressor

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***Abstract:*-Aircraft axial flow compressors have been an important subject to study as the blades of compressor encounter stalling and other off design performances during various angles of attack of an aircraft. The objectives are to suppress rotating stall and surge further to extend stable operating range of the compressor system. Using moveable inlet guide vanes, the uniform flow into compressor inlet can be achieved and thereby to improve stability and fuel efficiency. The improper airflow creates stalling, surging and chocking. This project is to study the effect of angle of attack on inlet guide vanes and analysed with both experimentally and using software. An experimental procedure started with fabrication of inlet guide vanes and tested them in our wind tunnel. The flow directions are measured using five holePitot tube. Results wasexperimental method.**

## INTRODUCTION

A compressor is a part of gas turbine engine especially sensitive on changes their technical state during operation process. Compressor stability and control research parallels the early days of aircraft stability and control research in various ways. Compressor rotating stall and surge are primary design constraints which effectively reduce engine performance, and which consume major fraction of a development program. One reason that these unsteady aerodynamic instabilities can lead to large penalties in performance is that they are difficult to predict accurately during design. Axial flow compressors are working in an unfavourable pressure gradient and therefore the disturbances caused in the working In order to reduce the stall and surge in axial flow compressor by the implementation moving inlet Guide vanes. Due to the moving action of inlet guide vanes there will be proper flow pattern obtained to the compressor at various angle of attack. The reduction of stall and surge is estimated by various methodologies some of them flow analysis and the design calculation. In these project is used to analyses the flow properties of inlet guide vanes and improve the engine performance also.

### *1.2 Need and scope*

- The stability analysis and estimation of axial flow compressor is very much important for each and every aircraft jet engine.
- The instability of compressor in the form of surge and stall is the major cause for engine failure (siege) and in turn accident.

### *1.3 Gas Turbine Engine*

Aircrafts mostly use either a turbofan or turbojet for the purpose of propelling the aircraft. The gas turbine engine consist of various module used are,

- Inlet diffuser
- Axial flow compressor
- Combustion chamber
- Turbine
- Nozzle

### *1.4 Inlet diffuser*

An engine’s air inlet duct is normally considered an airframe part and made by aircraft manufacture. During flight operation, it is very important to engine performance

### *1.5 Compressors:*

Compressors are the basic unit of any gas turbine engines which compresses air into the gas turbine engine from the diffuser to the combustion chamber by with its rotating action by rotor blades. The combustion of fuel and air at normal atmospheric pressure will not produce sufficient energy enough to produce useful work.

*1.5.1 Compressor classification*

The compressor are classified into two categories are

- Centrifugal compressor
- Axial flow compressor

*1.6 Combustion section*

There are three basic types of burner systems in use today. They are can type, annular type, can annular type. Fuel is introduced at the front end of the burner. Air flows in around the fuel nozzle and through the first row of combustion air holes in the linear. The air entering the forward section of the linear tends to recirculate and move up stream against the fuel spray

*1.6.1 Combustion process*

There are usually has only two 2ignite plugs in an engine. The 2ignite plug is usually located in the upstream region of the burner. About 25 percentage of the air actually takes part in the combustion process. The gases that result from the combustion have temperature of 3500 degree F.

*1.7 Turbine section*

. In a turbine as the gas passes through it expands. It parts of the energy of the gas during expansion is converted into kinetic energy in the flow of nozzles

*1.8 Nozzle section*

Exhaust nozzle are to collect and straighten the gas flow and to increase the velocity of the exhaust gas before discharge from the nozzle. The expansion process is controlled by the pressure ratio across the nozzle. Two types of nozzle used in jet engine are the convergent and convergent-divergent (C-D) nozzle.

## 2. STABILITY OF COMPRESSOR

*2.1System stability*

System stability is an important science to deal with especially for systems which rotate at very high speeds.
Stability can be classified majorly under two heads namely,
1. Static stability and
2. Dynamic stability

*2.1.1 Static Stability*

In order to explain the static stability, consider a ball within a convex vessel, concave vessel and a plain flat plate respectively. If a force is applied on the ball located wit in the convex vessel and the force is withdrawn immediately, the figure 2.1 shows that the static stability of ball undergoes an oscillation due to variation in the potential energy

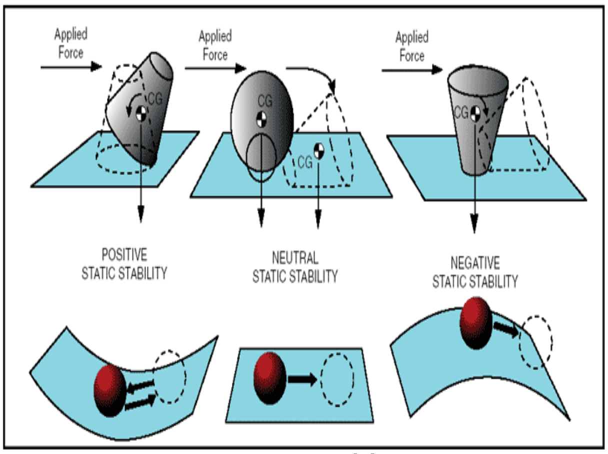



Fig 2.1 Static stability

*2.1.2 Dynamic Stability*

Dynamic stability the motion of an object after it is disturbed from the equilibrium point.

This dynamic stability analysis as follows.

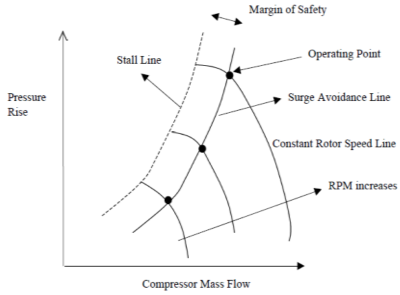
1. Non-oscillatory

*2.1.3 Non-oscillatory:*

In a non-oscillatory motion, the object does not exhibit any oscillation after a force is applied on it and withdrawn but takes its original position

*2.2 Compressor stability*

Stability in a compressor is the ability of a compressor to recover from disturbances that alter the compressor operation about an operational equilibrium point. Disturbances may be considered as transient or deliberate changes to the operating point. In the case of transient disturbances, the system is stable if it returns to its original operating point.




In looking at a map of the characteristic performance of a compressor. Rotating stall and surge usually occur at low flow rates, but may still occur on the right side of the surge line if the flow becomes unstable as a result of the instability

*2.3 Stall*

Separation of flow from the blade surfaces called stalling. If a flow Instability is somehow introduced into the system. Instabilities may develop and the compressor performance may deteriorate. It often takes only a few seconds for rotating stall to build up, and the compressor can operate under rotating stall for several minutes before damage develops. Rotating stall can occur in both compressible and incompressible flow.

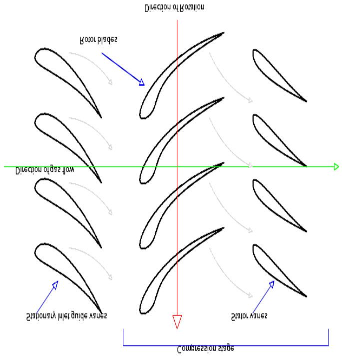


Fig 2.5 Blade arrangement

These imperfections would cause the inlet air to see these blades at slightly different angles of attack as compared to the other blades. When one of the blades stalls, as a consequence of some instability, the angle of the flow relative to the shaft increases. This increase in flow angle, in addition to blockage attributed to stall, cause part of the oncoming flow to be diverted towards the neighboring blades, thus causing an increase in their angles of attack and leading them to stall. As the blade rotates away from the disturbances, the angle of attack decreases.. Rotating stall moves in a direction opposite to the blade motion at a fraction of the rotor speed. One of the characteristics of pure rotating stall is that the average flow is steady with respect to time, but the flow has a circumferentially non-uniform mass deficit. During rotating stall, the cyclical variation of the pressures on the blades can cause them to fatigue and eventually break. The flow temperature may also increase due to uneven distribution of shaft work, reducing blade life.

*2.4 Surge*

Complete breakdown of the steady through flow called surging. Surge is a global instability that can affect the whole compression system. Surge is characterized by large amplitude limit cycle oscillations in mass flow rate, and pressure rise. The behavior of surge depends on both the compressor characteristic and the characteristics of the diffuser.

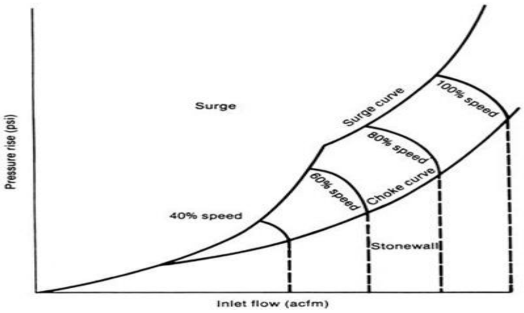



Fig 2.7 Graph between inlet flow and pressure

In contrast to rotating stall, the average flow through the compressor is unsteady but the flow is circumferentially uniform. Many of the conditions that a compression system experiences during rotating stall are also present in surge.

*2.5 Compressor map*

- A map shows the performance of a compressor and allows determination of optimal operating conditions.
- Operating margins can be illustrated by a compressor map.

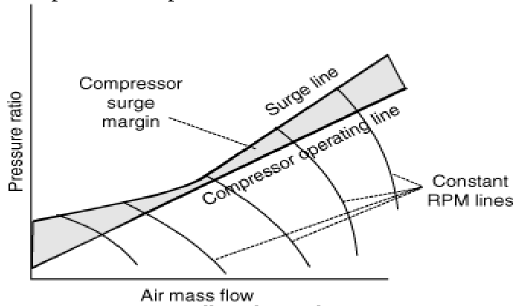



Fig 2.8 Stalls and surge line

*2.6 Aircraft crashes due to compressor stall*

- *U.S. Navy F-14 crash*

In 1994, a compressor stall contributed to the death of Lt. Kara Huitgreen, the first female carrier-based United States Navy fighter pilot.

- *ScSandinavian Airlines Flight 752*

In December 1991 Scandinavian Airlines Flight 751, a McDonnell Douglas MD-81 on a flight Stockholm to Copenhagen, crashed after losing both engines due to ice ingestion leading to compressor stall shortly after take –off.

*2.7 Remedy and control of stall and surge*

- Several measures are presently used to cope with surge. They can be classified as followsSurge control, surge protection, where the machine is prevented to operate in a region near and beyond the surge life.
- Surge detection and control, where the surge avoidance system starts acting if (the one set of) surge is detected

.

*2.8 Purposes of researches*

- Purpose of investigation made on real engines was determination influence of incorrect operation of axial compressor inlet guide variable stator vanes control system of a gas turbine engine parameters of compressor and engine work.
- For a critical values of air stream inlet angle by formulated vortex region of lower pressure, can occur air stream back off in inlet compressor direction. It could cause rapid rise of stream fluctuation transmitted on engine construction.

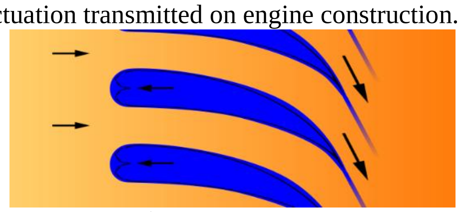


Fig 2.9 flow over Guide vanes

Compressor characteristics are relationship between compression ratio, compressor efficiency and air flow mass and compressor rotational speed. It makes possible to determine the best condition of compressor and another engine units mating. The figure 2.9 estimates the flow over guide vanes. Decrease of airflow intensity circumferential speed causes decrease axial component of air stream absolute speed.One of the most popular ways of axial compressor controls is changing their flow duct geometry by application of inlet guide stator vanes or variable stator vanes of several first compressor stages

*2.9 Methods of reduction*

1. Guide vanes
2. Air-injection method
3. Recirculation control
4. Movable plenum walls
5. Bleed valves

These are all the methods are basically used to avoid a stall and surge. But in this project used guide vanes to avoid a stall and surge.

*2.8.1 Inlet guide vanes*

Inlet guide vanes (IGVs) are used to deliver a uniform airflow for the following rotor and stator can be used to adjust this stage's aero dynamic performance. Using variable inlet guide vanes (VIGVs) can be varied in a wide range in order to control the compressor's operating point.

Variable inlet guide vanes are used to improve compressor performance through a range of operating conditions. The use of a circulation control inlet guide vanes was suggested by lord et al. as a means to replace complex flapped inlet guide vanes with a simpler configuration to reduce weight and cost. One such method of circulation control is by means of the coanda effect on the trailing edge of an air foil. The coanda effect process is used to control the inlet guide vanes. The movable inlet guide vanes are moved based up on the angle of attack. So the guide vanes operating process due to avoid stalling process into the axial flow compressor.

*Guide vanes related terms*

- Inlet guide vanes
- Toroidal-intake guide vanes
- Impeller intake guide vanes
- Nozzle guide vanesAir intake guide vanes

*2.9.2 Bleed valves*

Gas turbine engine employs compressor bleed valves to protect the axial compressor during start-up and shut down against stalling and surging conditions Compressor bleed valves during very light loading to limit the amount of air entering the combustor

*2.9.3 Recirculation control*

A controller for rotating stall in axial flow compressors using pulsed air injection is considered. Theory is developed for the combination of this air injection controller with a bleed valve controller for the system's surge dynamicsThe controller analysis is based on the surge dynamics acting on a slow time scale relative to the rotating stall dynamics.

*2.9.4 Movable plenum walls*

The first plenum carries cooling medium across an entrance and thence into a first heat-producing device located on a first side of the partition facing the first plenum. The second plenum carries cooling medium away from a second heat-producing device located on a second side of the partition facing the second plenum and thence across an exit. The second plenum becomes larger in cross sectional area as distance decreases toward the exit.

*2.9.5 Air injection method*

Injection mass flow rate in order to optimize the injection performance for stabilizing the compressor and increasing the surge margin. It was found that injecting air at an angle less than the diffuser vane angle weakens the effect of injection and doesn't increase kinetic energy of the fluid at diffuser inlet..

## 3. DESIGN CALCULATION OF INLET GUIDE VANES

*3.1 Design and analysis of inlet guide vanes*

During the design therefore, efforts are made by the designer for analyzing the modules both for static forces and dynamic forces in order to establish the susceptibility and with standing ability for all these known loads. Besides it is also mandatory to accommodate unknown loads for which the margin of safety is built-in which could cater for all these unknown loads whose magnitude could not be very high as visualized from the operational experience of the engines over the years.

*3.2 Solid modelling of guide vanes*

The analysing of inlet guide vanes is attached with turbo jet engine. Using MIG-23 engine consist of following details.

| Type | Turbo jet |
|---|---|
| Length | 4.991mm |
| Diameter | 968mm |
| Dry weight | 1,760kg |
| Compressor | Five stage low pressure, six stage high pressure. |
| Combustors | Annular |
| Turbine | Two stage high pressure, single stage low pressure. |
| Maximum power output | 12,480kg |
| Over all pressure ratio | 12.9:1 |
| Air mass flow | 105 kg/s |
| Number of blades | 36 |

Table 3.1Turbo jet engine properties

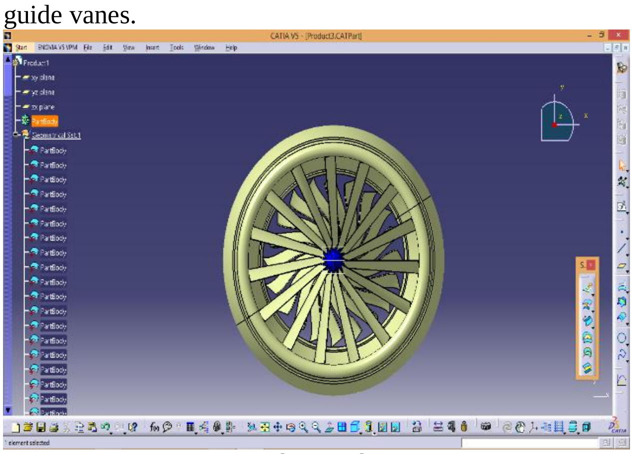
*3.3 Inlet guide vanes control*

A radial vane inlet controller (sometimes known as a vortex damper) consists of a number of segment shaped blades enclosed in a circular casing; each pivoted along its axis of symmetry and linked in such a way that all blades maintain an identical angle to the axis of the device. In this way the unit imparts a variable amount of swirl to the air (or gas) stream. Its normal application is therefore the regulation of centrifugal fans. The blades are connected via an external ring. Rotation of the ring causes the blades to open, each blade moving at the same rate as the others. The linkage between the ring and blades is designed so that, with blades almost shut, large Movements of the ring cause small blade movements. This results in fine control at large turn downs. At near full open settings where the position of the blades is less critical, the effect is reversed. The mechanical advantage of the linkage in the near closed position is also enhanced providing maximum torque where the requirement is greatest. The blades have minimum cross section area consistent with the mechanical strength required, so that pressure losses through the controller are restricted to a minimum.

## 4 DESIGNING OF GUIDE VANES

*4.1 Designing of air foil*

In this paper NACA 2412 air foil is consider as an inlet guide vanes of gas turbine engine. The geometry of the air foil is created by using the software CATIA V5. By using this CATIA V5 we designed air foil shaped inlet guide vanes.

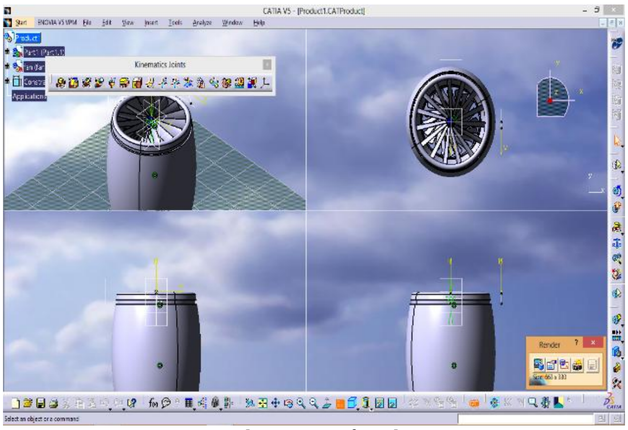



4.1 Guide vanes design

The picture shows that the air foil 2412 designed in CATIA V5. The designing of air foil section used to assume the flow over inlet guide vanes. The air foil is considered as the inlet guide vanes.We consider an air foil shaped inlet guide vanes are fixed behind the gas turbine engine (MIG 21). It will provide a significant effect to the flow to pass through the inlet of the gas turbine engine. The figure 5.1 shows that the design are made by using CATIA V5

*4.2 Solid modelling of inlet guide vanes*

The 3d modelling of the four different cases of axial pitch and present pitch in inlet guide vanes arrangements of the research in axial flow compressor design were made with CAD tools CATIA V5.The design parameters were used to make the models. The figure 5.2 estimate the using circular pattern are used in inlet guide vanes.




4.2Circular pattern of guide vanes

## 5. EXPERIMENTAL ANALYSIS OF INLET GUIDE VANES

*5.1 Low speed wind tunnel*

A wind tunnel consists of a tubular passage with the object under test mounted in the middle.. Air velocity through test section is determined by measurement of dynamic pressure and static pressure The pressure distribution across the test model has historically been measured by drilling many small holes along the airflow path. Using multi tube manometers to measure the pressure at each hole.Pressure distributions on a test model can also be determined by performing in which either a single pitot tube is used to obtain multiple readings downstream of the test model, or a multiple-tube manometer is mounted downstream and all its readings are takenPressure across the surfaces of the model can be measured if the model includes pressure taps

*5.2 Classification*

- low speed wind tunnel
- high speed wind tunnel
- supersonic wind tunnel
- hypersonic wind tunnel
- Subsonic and transonic wind tunnel.

*5.3 Five holes Pitot tube*

The five holes Pitot tube is used for diagnostic wind tunnel testing and in flight testing to determine the flow direction or angularity. The probe is bundle of five holes. A centre tube surrounded by four tubes in the shape of a cross. The leading edge of the four outside tubes is cut at 45 degree angle to the centre tube.

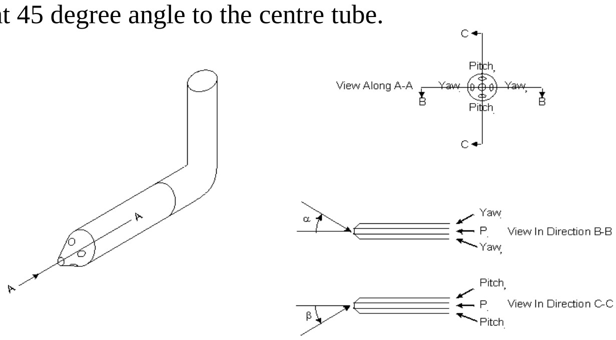



Fig 7.2 Five holes pitot tube

The flow of air past the probe makes an angle **a** with the centreline of the centre probe

p1 — p2 = f (a)

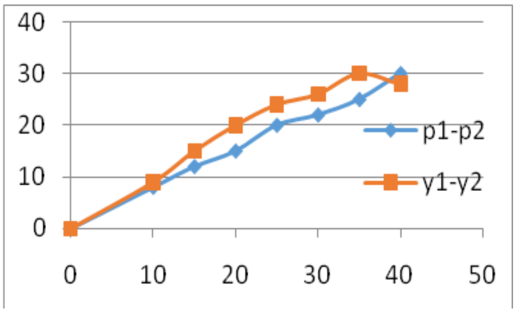
.The diagram at the left shows a vertical cut through three of the tubes. The angle of the flow is then related to the angle of attack of an aircraft. A similar horizontal cut can be made through the two remaining tubes and the angle of the flow is then related to the yaw angle of an aircraft. A five holes probe can therefore be used to simultaneously provide both pitch and yaw information in a flight test, or to provide the flow angularity in two perpendicular planes in a wind tunnel test.. The flow angularity he probe calibration procedure is to place the probe and vary the pitch and yaw of the probe over a matrix of angles with exceed the flow angles expected in the flow field to be measured. The five hole probe measure the total pressure, static pressure, and side slip angle are calculated.

5.4 Grammatical explanation of inlet guide vanes

| **Angle of attack** | **$P_1$-$P_2$** | **$Y_1$-$Y_2$** |
|---|---|---|
| 0 | 0 | 0 |
| 10 | 7 | 5 |
| 15 | 9 | 8 |
| 20 | 12 | 10 |
| 25 | 15 | 15 |
| 30 | 18 | 18 |
| 35 | 20 | 22 |
| 40 | 25 | 24 |

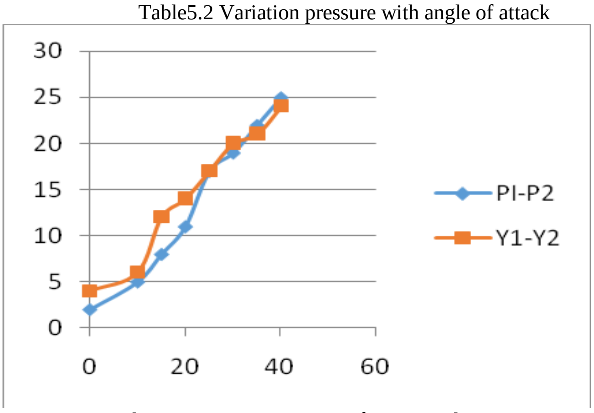
Table 5.1 Variation of pressure with angle of attack

| Angle of attack | $P_1$-$P_2$ | $Y_1$-Y2 |
|---|---|---|
| 0 | 2 | 4 |
| 10 | 5 | 6 |
| 15 | 8 | 12 |
| 20 | 11 | 14 |
| 25 | 17 | 17 |
| 30 | 19 | 20 |
| 35 | 22 | 21 |
| 40 | 25 | 24 |




Graph 5.1 Pressure variations of 30 m/s velocity

Table5.2 Variation pressure with angle of attack




Graph 5.2 Pressure variations of 35 m/s velocity

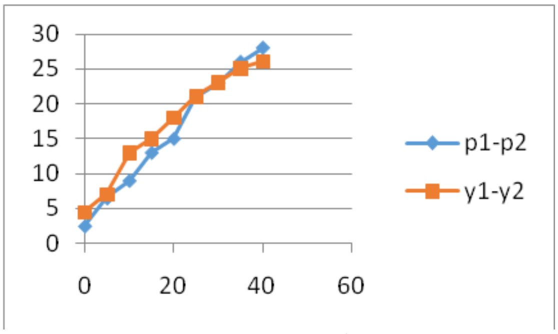
| **Angle of attack** | **$P_1$-$P_2$** | **$Y_1$-$Y_2$** |
|---|---|---|
| 0 | 3 | 5 |
| 5 | 6 | 7 |
| | | |
| 10 | 8 | 13 |
| 15 | 13 | 17 |
| 20 | 15 | 22 |
| 25 | 19 | 25 |
| 30 | 22 | 27 |
| 35 | 25 | 30 |
| 40 | 26 | 32 |

Table 5.3 Variation of pressure with angle of attack

Graph 5.3 Pressure variations of 40 m/s velocity

| **Angle of attack** | **$P_1$-$P_2$** | **$Y_1$-$Y_2$** |
|---|---|---|
| 0 | 2.5 | 4.5 |
| 5 | 6.5 | 7 |
| 10 | 9 | 13 |
| 15 | 13 | 15 |
| 20 | 15 | 18 |
| 25 | 21 | 21 |
| 30 | 23 | 23 |
| 35 | 26 | 25 |
| 40 | 28 | 26 |

Table 5.4 Variation of pressure with angle of




Graph 5.5 Pressure variations of 45 m/s velocity

## 6. RESULT AND DISCUSSION

The result and discussion are based on the made in this project. Analysing process is made by using experimentally based wind tunnel testing process used in pitot static holes. The comparison between the experimental process as follows. The methods to analyse pressure variation are followed.

- Experimental analysis through Wind tunnel testing's.

*6.1 Experimental analysing through wind tunnel testing*

Using low speed wind tunnel testing method is used to testing the guide vanes various boundary conditions. The boundary condition based up on the wind tunnel condition. In this project to design guide vanes to attached with test section area.

The figure estimates the guide vanes are attached with the test section area. The forces are measured by the five holes Pitot tube are used. The figure estimates the five holes Pitot tube placed with the test section area.Using multi tube manometer is used to measure the forces of the inlet guide vanes. The following graph are estimate various speed variation due angle of attack variation.

Fig 6.2 Five holes pitot tube

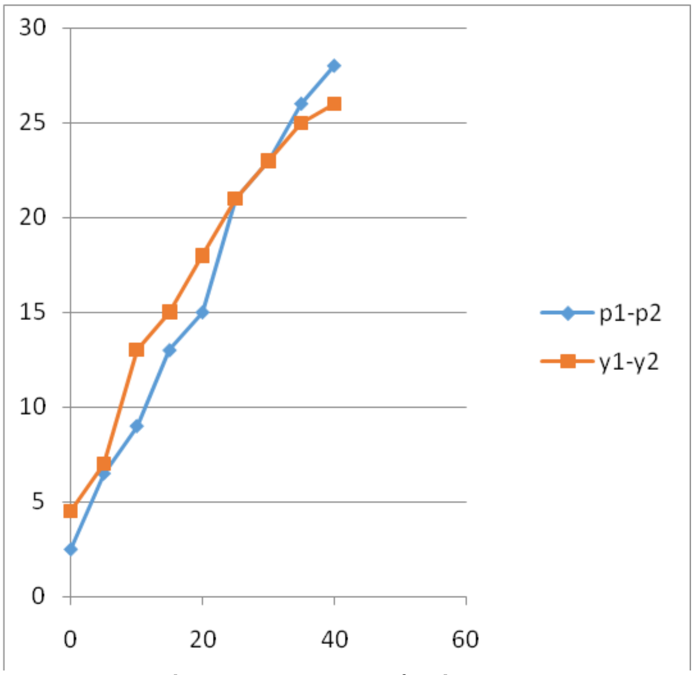
Fig 6.3 Guide vanes attached with test section area

*6.3 Wind tunnel testing process*

Using wind tunnel testing process based on the forces is measured like pitching and yawing. The guide vanes are attached with test section area figure 8.3. The wind tunnel is operated with the various velocity conditions the following table and graph estimated various boundary conditions.

| Angle of attack | $P_1$-$P_2$ | $Y_1$-$Y_2$ |
|---|---|---|
| 0 | 2.5 | 4.5 |
| 5 | 6.5 | 7 |
| 10 | 9 | 13 |
| 15 | 13 | 15 |
| 20 | 15 | 18 |
| 25 | 21 | 21 |
| 30 | 23 | 23 |
| 35 | 26 | 25 |
| 40 | 28 | 26 |

Table 6.1 Different angle of attack and forces




Graph 6.2 pressure variations of guide vanes

## 7. CONCLUSIONS

The results obtain from the plots value are tabulated. Through this study it has been clearly brought out that the inlet guide vanes arrangements, the airflow conditions with respect to different angle attack of gas turbine engines by flow separation. The inlet guide vanes will experience the different airflow separation in different angle of attack is estimated by this project.

- The model of the Inlet guide vanes.
- Identification of Inlet guide vanes of the blade under various conditions of the engine at different angle of attack is given
- The above processes are applied for inlet guide vanes.

## 8. FUTURE WORK

The work has thrown open multiple avenues which are nothing but the off-shoot of the work carried out on the Inlet guide vanes. There could be many marks which could not be carried out during the project. But it has opened up many visit as which are as follows:

- Inlet guide vanes could be used with methodology after obtaining the different angle of attack which is used as indices in the flow separation.
- An exercise could be attempted for the gas turbine engines at various angles of attack.
- This effect could have been one of the avenues for future work.

One could get a picture of the design efficacy of the blade if the above points are covered.

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