The design and analysis of axial flow compressor has become core area of interest to many researchers due to its wide applicability in areas like aero space, marine, power generation etc. Many analytical and experimental techniques are developed to design and analyze the axial flow compressors. Numerous mathematical optimization techniques are developed to optimize the design parameters of axial flow compressor stage.

In this chapter a review of literature related to design and analysis of axial flow compressors are discussed. Further, literature related to various single and multi objective optimization techniques and sensitivity analysis techniques applicable for optimizing the axial flow compressor stage are presented.

2.1 A study on Design and Analysis of Axial Flow Compressor

J H Horlock (1958), presented the two dimensional or pitch line design analysis of compressor cascades. Thermodynamic stage design relations and fluid flow relations including free and forced vortex flows, radial
equilibrium conditions etc. were presented based on several experimental test procedures. These correlations are very useful in determining the important stage performance measuring parameters like stage efficiency.

S Lieblin (1958), conducted loss and stall condition analysis in axial flow compressor cascades to determine various loss coefficients such as profile loss, skin friction loss, end wall loss etc. Quantitative measurements to determine the magnitude of losses were carried out.

S Lieblin (1960), carried out the analysis of low speed air compressor with conventional blades to determine the fluid flow characteristics in terms of incidence and deviation angles for minimum loss. Cascade theory of compressors and blade aerodynamic relations were utilized to bring insight into the behavior of fluid at different incidence and deviation angles.

B. Lakshmi narayana and J H Horlock (1963), developed the expression for flow model to determine the clearance between the tip of the blades and compressor casing wall during a blocked flow condition. The model predicts the decrease in stage efficiency due to tip clearance effect.

B. Lakshminarayana (1970), presented a review on secondary flows and various loss sources that cause profile loss, skin friction loss, end
compressor annulus region. These losses were estimated by conducting wind tunnel tests on compressors with different geometrical configurations.

C C Koch and L H Smith (Jr) (1976), determined various loss sources causing skin friction loss, end wall loss, profile loss etc., and their influence on the performance of axial flow compressor stage.

Tesch W.A, Moszee R.H et al (1976), applied stability and frequency response analysis techniques to provide a more economical approach to surge line and frequency response determination in blade rows of turbo machinery. The model was extended for compressors with inter stage cross flows.

Steinke R J (1976), presented an aerodynamic design of five stage core compressor with 9.271:1 pressure ratio and 29.17 kg/sec of mass flow rate. The first three stages in the design of core compressor were fabricated and tested experimentally. An optimal inlet guide vane set was determined to improve the adiabatic efficiency.

MC Kenzie AB (1980), formulated the Semi empirical relations and correlations for axial flow compressor blades, based on the tests conducted on a low speed axial flow compressor.
E. Macchi and A. Perdichizzi (1981), presented a reliable method for estimation of efficiency of a turbine stage. The turbine stage performance was found to be a function of three main parameters, i.e.; the expansion ratio, specific speed and a dimension less parameter which accounts for actual turbine dimensions.

C C Koch (1981), presented an engineering approach to the problem of predicting maximum pressure rise capability (or) predicting the maximum value of stall margin coefficient. A semi-empirical model was developed based on the tests conducted on a low speed axial flow compressor.

EM Greitzer and F K Moore (1986), presented a theory based on rotating stall and surge phenomena in case of axial flow compressors was proposed. A theoretical compression model was presented in that work.

A Sehra, J Bettner et al (1992), applied the design techniques developed for aircraft compressors to the compressors used in low utility gas turbine. The objective was to develop an aero dynamic design with a level of stage efficiency, which is higher than that of the compressors used in large gas turbines.
I J Day (1993), analyzed the occurrence of stall phenomena including rotating stall and surge in case of axial flow compressors. He described the discovery and importance of short length scale disturbances in the stall inception process.

Mansoux, C.A, Gysling, D.L et al (1994), developed a nonlinear Moore-Greitzer rotating stall model suitable for control, analysis and design of axial flow compressor against rotating stall and surge phenomena. The nonlinear compressor characteristic obtained from the model was shown to be the primary determinant of stall inception transient behavior.

Adnan M. Abdel Fattah and Peter.C.Frith (1995), proposed an approximate procedure for the derivation of individual stage characteristics of a multi stage axial flow compressor. The stage characteristics were derived from the steady state overall performance map, geometry of compressor annulus and blade section profile data. The one dimensional simulation model developed by NASA-LEWIS research centre was used in predicting the overall performance of compressor by applying the stage stacking technique.

Schobeiri, M.T (1997), presented reliable efficiency calculations for high sub-sonic and transonic axial flow compressors based on a new shock
model developed were presented. The correlations for the efficiency calculation were based on the loss coefficients estimated.

R.Schulze and D.K.Hennecke (1998), developed a simple and robust stall detection and control system. The system was developed based on the experiments conducted on a single stage subsonic axial flow compressor. On the basis of experimental results, a sensor/actuator was chosen for the control system. A significant improvement in the compressor stability was achieved through the newly developed control system.

S J Gallimore (1999), discussed the basic principles and rules associated with the design of axial flow compressors; primarily for aero space applications. The thrust was basically to develop the aero dynamic design correlations with minimum emphasis on empirical relations.

Calvert WJ and Ginder RB (1999), conducted the design of fans and compressors used for transonic applications. One and two dimensional transonic flow relations and techniques were employed to determine parameters such as specific flow, mean stage loading, axial matching between stages at key operating conditions etc. Finally detailed three dimensional CFD techniques were employed to refine the design process.
H Cohen, GFC Roger et al (2001), discussed the axial flow compressor characteristics, factors affecting performance, stage design relations, mean line and off-design calculations. A procedure for stage wise design of axial flow compressor was presented.

T W Song, T Skim et al (2001), proposed a new method for predicting the performance of multi stage axial flow compressors. The proposed method utilized the stage performance curves of axial flow compressor. Unlike the conventional stage stacking method it employed a consistent functional formulation method of governing equations to calculate simultaneously all the inter stage variables like temperature, pressure and flow velocity of working fluid.

N.Ananth Krishnan, U.G.Vaidya et al (2003), presented a novel bifurcation based stall/surge controller. The controller stabilizes the axial flow compressor for safe operation at peak pressure points. The controller prevents the axial flow compressor from abruptly entering the rotating stall zone. The controller maintains system stability even under large perturbations.

Tomita JT and Barbosa JR (2004), carried out the design and analysis of an axial flow compressor which can be utilized for 1 MW gas turbine applications. The compressor stage performance was analyzed based on
mean line flow properties. Stage stacking was used to analyze the multiple stages of the compressor.

Sieverding Frank and Meyer Micheal et al (2004), developed a new design system for the blade sections used for industrial compressors. The design system introduced new controlled diffusion air foils for wide surge range and high volume requirements. The design method combines the parametric geometry definition method, blade to blade flow solver and a new breeder genetic algorithm. The system was tested on the middle stages of an industrial axial flow compressor.

M Javed hyder and M Omair khan (2007), presented a novel method for selection of blade material for axial flow compressors. The method is based on the centrifugal stresses developed at the root of the blade in the first stage of the compressor. Blade tip speed, rotational speed, blade height and blade material were found to be the most important parameters that determine the magnitude of stresses developed inside the blades.

Niclas Falck (2008), developed a method for analyzing the axial flow compressor based on the mean line design principles. Mass flow rate, pressure ratios, various loss coefficients, stage loading factors, rotational
speeds etc. were considered for the analysis of compressor cascades. Results were determined using programs developed in MAT LAB.

Shuzhen hu, Xingen lu et al (2010), analyzed the fundamental mechanisms of non-axi symmetric hub end wall and its effect on end wall flow fields. Experimental and numerical data for the application of a non axi symmetric hub end wall in a high sub-sonic axial flow compressor was obtained.

EA Ogbonnaya, H U ugwu et al (2010), analyzed the effect of vibration based on surge and stall phenomenon in case of gas turbine compressors through a computer based simulation was carried out. An industrial duty gas turbine plant for electricity generation was used to actualize the results obtained.

P.V.Rama krishna and M.Govardhan (2010), presented a detailed study of rotor tip leakage related phenomena in low speed axial flow compressor passages. Fifteen compressor configurations were studied with five sweep patterns and three tip clearances of the blade chord. Results obtained were validated with the previous experimental data.

J L lu, W Chu et al (2010), conducted blade tip high response static pressure measurements and three dimensional flow simulation on an
isolated sub sonic compressor rotor to understand the inception of stall phenomenon in compressor cascades. Runga-kutta integration scheme was used to attain convergence to three dimensional flow field models.

Tony Dickens and Ivor Day (2011), developed a new design strategy for increasing the stage pressure rise by increasing the stage loading coefficient. Detailed experimental measurements of three highly loaded compressor stages were used to validate the results. The design strategy also explained the sources of additional losses specific to highly loaded compressor stages.

Tsuguji Nakano and Andy breeze stringfellow (2011), derived a stall margin parameter to evaluate the stability of multi stage axial flow compressors. The stall parameter was derived based on the assumption that the flow field is two dimensional and incompressible between the blade rows. The derived stall parameter was in good agreement with the test data.

J F Hu, H Ou-Yang et al (2011), presented an improved stream line curvature through flow analysis method to simulate flow fields of certain transonic axial flow compressors. The proposed method integrated the total pressure loss model and minimum loss incidence angle model to predict accurate and reliable design and off design performance of axial
flow compressor. The proposed method was setup as a function of inlet mach number, solidity thickness, blade camber angle etc.

### 2.2 A Review on Conventional Optimization Techniques

S.S. Rao and R.S. Guptha (1980), formulated the nonlinear mathematical programming problem of optimizing the gas turbine stage with the objective of minimizing aerodynamic losses and mass of the stage. Davidson-Fletcher-Powell variable metric unconstrained minimization technique along with cubic interpolation method was used to optimize the problem.

Jin Shik Lim and Myung kyon ching (1989), presented the design point optimization of an axial flow compressor stage with the objective of maximizing stage total to total pressure ratio and minimizing stage weight at a given stage pressure ratio. The gradient projection method was used to solve the optimization problem. The sensitivities of the objective functions in the whole feasible range of design variables were analyzed.

A Massado and A Satta (PART-I) (1990), formulated the axial flow compressor stage optimum design problem as a non linear mathematical programming problem with the objective of minimizing the aero dynamic
losses, weight of the stage and maximizing the stall margin coefficient. Davidson-Fletcher-Powell method was used as the optimization technique.

A Massardo and A Satta (PART-II) (1990), presented a new technique for design optimization of axial flow compressor stage based on through flow analysis procedure. The multi variable optimization function estimations were carried out based on pitch line calculations of the axial flow compressor.

J Sun and R L Elder (1998), implemented the sequential weight increasing factor technique to numerically optimize a stator vane in a multi stage axial flow compressor. A stage by stage model was used to stack the stages together using a dynamic surge prediction method. The method incorporates simultaneous setting of several rows of blades which influence the performance of the compressor.

Jeffrey C. Lagarias, James A. reeds et al (1998), studied the convergence properties of the Nelder-Mead simplex technique applied to strictly convex functions in one and two dimensions. A counter example given by Mc Kinnon was chosen to evaluate a family of strictly two dimensional convex functions for a set of initial conditions. The Nelder-Mead
technique in case of two dimensional convex functions converged to non-minimized functional values.

K.I.M, Mckinnon (1998), analyzed the behavior of the Nelder-Mead simplex method for a family of test cases, which caused the simplex method to converge to a non-stationary point. All the examples used continuous functions of two variables. The functions used were strictly convex with up to three continuous derivatives. In all the test cases, the simplex method applied the contraction step with best simplex point (vertex) remaining fixed.

Sang Yun lee and Kwang Yong Kim (2000), presented numerical optimization techniques which incorporate the three dimensional Navier-Stokes solver to find the optimum shape of axial flow compressor stator blade. Through flow calculations on single stage rotor-stator flow model were carried out. The optimum search directions were found by using steepest descent and conjugate gradient methods. The objective was to maximize the efficiency.

Akira Oyama and Meng-Sing Liou (2002), developed a multi objective optimization tool for multi stage compressors. The performances of the compressors were evaluated using the axi-symmetric through flow coding system that employs the stream line curvature method. The tool was implemented on the multi objective optimization problem of a four stage
axial compressor. The objectives considered were maximization of overall isentropic efficiency and total pressure ratio developed.

Qiang Xiong and Arthur Jutan (2003), presented a modified version of Nelder-Mead simplex technique called the dynamic simplex algorithm. This algorithm allows tracking of moving optimal point. This algorithm was applied to a chemical process whose operating conditions change continuously with time. Various simulation examples were demonstrated to understand the capability and flexibility of the new algorithm.

Behrooz Farshi, Reza Taghavi-Zenouz et al (2004), performed numerical optimization for the preliminary aerodynamic design of axial compressors based on mean line calculations. The compressor efficiency was treated as the objective function of non linear design variables. The optimization process was carried out using reduced gradient projection method. Overall pressure ratio, mass flow rate and rotational speed were considered as the main input data to the optimization problem.

Marco A Luersen and Rodolphe Le Riche (2004), developed a global bounded Nelder-Mead algorithm based on probabilistic restart concept. A spatial probability of starting a local search was built based on the past searches. This method was particularly adapted to tackle multi model
and discontinuous optimization problems. Many analytical test functions were tested using the improved method.

Francisco De Sousa junior, Rogerio Jose Da Silva et al (2005), implemented the single objective optimization of a multi stage compressor using a gradient based method i.e.; using a sequential programming technique. The stage efficiency was chosen as the objective function of an eight stage axial flow compressor.

Lingen Chen, Fengrui Sun et al (2005), performed the optimization of a subsonic axial flow compressor stage with the objective of minimizing the aero dynamic losses and mass of the stage. Different loss sources like pressure loss, skin friction losses etc were considered. The optimization problem was solved using the lagrangian function approach.

MC Duta and MD Duta (2007), developed a new improved gradient enhanced response surface method for multi objective optimization of turbo machinery. To illustrate the advantage of the new improved gradient response method, an enhanced neural network model is implemented in a multi objective transonic fan blade optimization problem.
Hoda Maleki (2008), presented the design optimization of axial flow compressor stage, which is formulated as a non linear mathematical programming problem with the objective of improving the stage efficiency, stall margin coefficient and minimizing the stage weight. The optimization problem was solved using interior penalty function method with Davidson-Fletcher-Powell method for direction vector and cubic interpolation method for optimal step-length. A computer program was developed to incorporate different sets of weightages.

Sang Won Hong, Hyungmin Kang et al (2009), carried out the aerodynamic and structural design optimization of a three stage axial flow compressor using response surface method. The experimental values for the response surface method were obtained through both aerodynamic and structural considerations were considered simultaneously. Later, based on the initial design results that were established, a sensitivity analysis was carried out on selected critical design variables.

2.3 A Review on Evolutionary Optimization Techniques

Etter D M, Hicks M J et al (1982), developed an adaptive genetic algorithm for determining the optimum filter coefficients in a recursive adaptive filter. In this technique the probability of selecting the string or
chromosome for the next generation was inversely proportional to the estimated mean squared error value. The algorithm was inspired by adaptive process present in nature.

Mauldin M L (1984), conducted a study on several heuristic mechanisms to maintain diversity in a simple genetic algorithm is presented. Adaptive genetic algorithms were utilized for maintaining diversity in search process which can search large domains, thus preventing pre-mature convergence.

England A C (1985), conducted the selection process of identifying a detector to classify known images by utilizing the concepts of genetic algorithm. The machine learning via genetic algorithms for visual recognition of images was presented.

Goldberg DE and Smith RE (1987), performed a non stationary function optimization using the domination and diploid principles of an adaptive genetic algorithm. In the diploid genetic algorithm two sets of binary chromosomes representing the design variable are mapped for dominance and a phenotype is created.

Jenkins W M (1991), conducted optimization of structures using genetic algorithm. Stochastic processes were utilized to generate initial
population of design vectors. Along with basic selection, cross over and mutation operations the parameter scaling was also incorporated.

S Rajeev and C S Krishna murthy (1992), presented the optimization of structural systems using simple genetic algorithms. The objective of the problem was to minimize the weight of the steel truss by determining the optimal material and geometric parameter configuration subject to a set of displacement and stress constraints.

Carlos M Fonesca and Peter J Fleming (1993), discussed the formulation and generalization of multi objective optimization problems using genetic algorithms. The objective of the work was to propose a fitness assignment scheme for selection of design solution vectors for multi criterion problems involving conflicting objective functions.

Jeffry horn, Nicholas Nafpliotis et al (1994), introduced the Niched Pareto Genetic Algorithm to find the pareto optimal trade off surface for the multi objective optimization problems. To achieve the distribution of solutions along the Pareto front, the individual objective fitness for solution vectors was divided by the niche count factor. Different test cases were used to demonstrate the working of the algorithm.
Kalyanmoy Deb (1995), discussed the optimization of single and multi objective problems with and without the effect of constraints taking different test cases. Multiple single objective function approach, bottom up approach and constraint surface approach methodologies were adopted to solve different multi objective optimization problems. Pareto solution fronts were determined both for discrete and continuous search spaces.

C Mares and C Surace (1996), developed a novel technique employing genetic algorithm for the detection of macroscopic structural damage in elastic structures. A location quantification study was performed to determine the extent of damage.

Shigeru Obayashi, Takanori Tsukahara et al (1997), applied the multi objective genetic algorithm based on the pareto ranking and fitness sharing techniques to the aerodynamic shape optimization of compressor cascade airfoil. The multi objective design aimed at developing higher pressures, higher flow angles and lower total pressure loss at a low machnumber.

Kalyanmoy Deb (1998), presented a report on construction of multi objective genetic algorithms and associated difficulties considering different test cases. The multi objective problem features that may cause
difficulties in convergence to a true Pareto optimal front were discussed. Multi objective optimization problems were constructed from the single objective optimization problems which allow known difficulties to be incorporated such as multi-modality, isolation etc.

Carlos M Fonesca and Peter J Fleming (1998), applied the multi objective optimization and multi constraint handling strategies based on genetic algorithm technique to optimize the vital design parameters of a gas turbine engine model.

S Vijayrangan, V Alagappan et al (1999), carried out the design optimization of leaf springs used for automotive applications using genetic algorithm technique. The optimization of dimensions of the leaf springs was considered as the objective function.

Kalyanmoy Deb (2000), presented a fast and elitist multi objective genetic algorithm using NSGA-II technique. A new non-dominated sorted genetic algorithm called NSGA-II was proposed which eliminates the difficulties associated with NSGA-I such as computational complexity, sensitivity to sharing parameter and lack of Elite individual preservation strategy.

Kameshki ES and Saka MP (2000), implemented a genetic algorithm based optimum design method for multi storey non swaying steel frames
with different types of bracings. The objective was to design a frame and bracing system with least weight by selecting appropriate sections for beams, columns and bracing members for steel sections. The algorithm also takes into account the lateral torsion buckling of frame members.

R Saravanan, K Rama krishnan et al (2001), carried out optimal design of gears to improve transmission effect and to reduce composite errors using genetic algorithm and simulated annealing techniques. The optimization process also considered various transmission losses incurred due to friction.

J L Marcelin (2001), presented the optimization of stiffened plates and shells based on application of two stochastic techniques. One of the techniques utilizes the finite element calculations and the other technique was based on Ritz method in creating function approximations, which can be utilized in computationally intense design optimization using Genetic Algorithms.

B K Chai and B S Yang (2001), developed a combined optimization algorithm by introducing the concept of immune system to a simple genetic algorithm. This technique then was implemented to minimize the total weight of the shaft and transmitted forces at the bearings.
E Zitzler, Kalyanmoy Deb et al (2001), delivered a lecture note on evolutionary multi criterion optimization using improved strength Pareto genetic algorithm. The performance of the algorithm was tested against other evolutionary multi criterion algorithms such as the non elitist non dominated genetic algorithm (NSGA-I).

Brian H Dennis, Igor N Egorov et al (2001), presented a robust stochastic algorithm for multi objective optimization of turbo machinery cascades. Minimization of loss, maximization of loading capacity and maximization of gap to chord ratio were considered as the objective functions to the problem.

Alexandre H Dias and Joao A De Vasconcelos (2002), compared the performance efficiency of non elitist non dominated genetic algorithm (NSGA-I) to other evolutionary optimization techniques taking two test cases.

Dazhi Sun, Rahim F Benekohal et al (2003), studied applicability of NSGA-II technique for multi objective traffic signal timing optimization problem. A three signal timing optimization problem with two objective functions and three constraints was analyzed.

Shantanu Guptha (2004), presented the multi objective design optimization of rolling element bearings using NSGA-II technique.
Maximization Static and dynamic loading capacity, minimization of film thickness were considered as the objective functions to the problem. The results obtained were compared with the classical multi objective optimization techniques.

J.F.Aguilarmadeira, H.Rodrigues et al (2005), developed a model for topology optimization of linear elastic structures where more than one objective function was required. A method based on genetic algorithm to generate an evenly distributed population of solutions to find Pareto optimal solution set to the problem was developed.

Akinkeskin and Dieter Bestle (2006), applied the Stochastic programming techniques to the multi objective optimization of an axial flow compressor stage. Maximization of efficiency, surge margin and pressure ratio of the stage were considered as the objective functions for the problem.

Levitin G, Rubinovitz J et al (2006), presented a genetic algorithm approach for the line balancing problem of robotic assembly. The objective was to maximize the production rate of the assembly line. The genetic algorithm results were compared with the truncated branch and bound algorithm.
Abdullah Konak, David W Coit et al (2006), presented a tutorial on implementation of genetic algorithm techniques for multi objective optimization problems. Several evolutionary multi objective algorithms like Niche Pareto genetic algorithm, Strength Pareto evolutionary algorithm, non dominated sorted genetic algorithm etc. were discussed.

Daming xu, Long yun kang et al (2006), conducted the multi objective optimization of a standalone hybrid wind system considering the maximization of power reliability and minimization of cost as the objective functions. The Pareto optimal solution fronts were found using the elitist non-dominated sorted genetic algorithm i.e. ; NSGA-II.

Daisuke Sasaki and Andy J.Keane (2006), optimized the single stage rotor and stator blades of a multi stage compressor for improving the efficiency and reducing blockage and losses using an adaptive range multi objective genetic algorithm for finding the optimal trade-off solution. A grid enabled computing software which can simulate the effect was incorporated.

Kim Y and Walton E K (2006), carried out an automobile antenna design optimization using NSGA-I technique. The geometrical parameters of the existing antennas were modified to improve the performance. Results based on actual measurements and simulations were analyzed. A set of
Pareto solutions conformal to FM-radio antenna geometry were developed based on NSGA-I technique.

Kalyanmoy Deb, Udaya Bhaskara Rao et al (2006), presented a technical report on dynamic decision making and multi objective optimization of hydro thermal power scheduling using a modified version of NSGA-II algorithm.

Md Atiquzzaman, Shie Yuiliong et al (2006), studied applicability of the NSGA-II technique for multi objective optimization of water distribution network for achieving the much desired Pareto optimal front of solutions. The study showed the scheme employed to select the solutions that yield acceptable total pressure deficit distributed equally at several nodes of the distribution system.

S Favuzza, M G Ippolito et al (2006), employed an improved crowd comparison operator based NSGA-II algorithm for handling multiple constraints in the optimal design of electrical distribution networks. The problem aimed at optimal capacitor placement in power distribution networks. The efficiency of proposed crowd comparison operator based NSGA-II technique was tested taking several other test cases.
Ding wei, Liu Bo, et al (2006), implemented a multi objective design optimization method for multi stage compressors using genetic algorithm and stream line curvature methods. The optimization of a two stage axial flow compressor was performed to maximize the overall adiabatic efficiency and total pressure ratio. The rotor and stator trailing edges and absolute flow angles were considered as design parameters.

N.Amanifard, N.Nariman-Zadeh et al (2006), applied the NSGA-II multi objective genetic algorithm with a new diversity preserving mechanism for pareto optimization of axial flow compressor. The objectives considered in the optimization problem were, compressor stage total efficiency and pressure ratio. The input parameters considered were, the stage inlet angle, inlet mach number and diffusion factor.

E G Berkele and J W Nicklow (2007), presented the multi objective strategic optimization of water resources using NSGA-II technique. The uncertainty in the availability of resources was also considered by implementing the stochastic techniques.

Chung Kwan, Fan YanG et al (2007), implemented the differential evolutionary version of NSGA-II algorithm which replaces the cross over and mutation operations in multi objective real world optimization problems taking three different test cases.
Abdus Samad, Kwang Yong Kim et al (2007), conducted the optimization of total efficiency, total torque and total pressure developed in turbo machinery was by applying the NSGA-II technique. The objective functions were optimized using three design variables related to skew, lean and sweep of the blade. The NSGA-II technique adopted an e-constraint local search strategy for multi objective optimization.

Shahrokh Shahpar, Andrew Polynkin et al (2008), presented the multi point approximation method for shape optimization of axial flow compressor rotor blades. The analysis included parameterization of blade shape, meshing, CFD analysis, post processing and objective/constraint evaluation. The parameterization was performed using five independent blade parameters.

Hiwa Khaledi, Mohammad Bagher Ghofrani et al (2008), applied a model for simulating an axial flow compressor using the stage stacking procedure with the aid of genetic algorithm. In the proposed method, the genetic algorithm used the constraints based on the qualitative and quantitative information obtained from turbo-machinery rules of axial flow compressor.
S Behzadi and Ali A Alesheikh (2008), implemented a pseudo genetic algorithm for sorting out the best optimal path. Large databases like geological information systems (GIS) involving complex spatial problems with large search spaces were handled using this technique. In this algorithm, the raw fitness scaling of each individual solution vector was implemented to select the population of chromosomes.

P N Hrishikesha and Jay Dev Sharma (2008), implemented the NSGA-I technique for optimal voltage control in power distribution networks with dispersed generation scheme. The objectives considered for the problem were minimization of voltage deviation and minimization of losses. The objective functions were modeled with four independent parameters that control voltage and current.

OmaR Al Jadaan, Lakshmi Rajamani et al (2008), developed an improved non dominated genetic algorithm for multi objective optimization problem considering different test cases. A new non dominated ranking approach combined with parameter less penalty approach was implemented to alleviate the difficulties in handling constraints in case of multi objective constraint problems.

Kodali SP, Kudikala R et al (2008), presented the implementation of NSGA-II algorithm for selection of optimal machining parameters for
surface grinding operation involving two conflicting objective functions. The objective functions were modeled using ten process variables and were subjected to four constraints. The Pareto optimal front of solutions obtained was compared with different classical approaches.

Afzal Husain and Kwang Yong Kim (2008), conducted the multi objective design optimization of micro channel heat sink by applying NSGA-II technique. Micro channel width, depth and fin width were chosen as design variables. The thermal resistance of the sink and pumping power were chosen as objective functions to the problem.

Xintaocui, Shuxin Wang et al (2008), carried out the optimal assembly design of automotive body involving multi material construction methodology by applying NSGA-II algorithm. The design problem was formulated as a multi objective non linear programming problem involving both continuous and discrete variables.

Xingtao Liao, Quing Li et al (2008), applied the NSGA-II optimization technique in the multi objective optimization of crash safety vehicles using step wise regression model. The work presented a two stage approach to cope with structure crash worthiness and occupant safety. A full scale vehicle model was developed to demonstrate the two stage approach.
Miquing Li, Jinhua Zheng et al (2008), delivered a lecture note on improving the NSGA-II technique by applying the concept of minimum spanning tree. The fitness assignment scheme and external population maintenance were based on the minimum spanning tree concept. Moreover a novel minimum spanning tree crowding distance comparator was used to estimate the solution density.

K.K. Mishra, Brajesh Kumar Singh et al (2008), implemented the NSGA-II optimization algorithm to optimize the melting rate and fuel consumption of a rotary furnace. The results obtained using NSGA-II techniques were validated with various experimental results. The regression model technique was implemented to mathematically model the melting rate.

U Siller, C Vob et al (2009), implemented an automated approach for multi disciplinary optimization of a transonic axial flow compressor. The compressor considered for analysis was a high loaded transonic stage compressor designed for very high pressure ratios with a single row of rotor and a tandem stator. The aerodynamic performance parameters were optimized considering the finite element structural parameters simultaneously using AUTO OPTI software.
Diab Mokeddem and Abdelhafid Khellaf (2009), determined the optimal solutions for multi product batch chemical process using NSGA-II technique. The selection of best compromise solution set from the Pareto fronts generated using NSGA-II technique was made using PROMTHEE II algorithm.

P Dibara and M E Mognaschi (2009), implemented the NSGA-II optimization technique to optimize the permanent magnet alternator used in automobile applications. The objective of the work was to test the applicability of multi criteria algorithm like NSGA-II to industrial electromagnetic design optimization. The optimized results obtained using the NSGA-II technique were compared to the optimization based software called MOESTRA.

Luis Felipe Gonzalez, Dong Seop Lee et al (2009), conducted the motion path optimization of an unmanned aerial system by implementing the NSGA-II optimization algorithm. The NSGA-II technique was implemented to determine three dimensional optimal collision free trajectories. The performance of the NSGA-II algorithm was compared against a hybrid game strategy algorithm.

Asish Kumar Sharma, Kyung Hyun son et al (2010), performed the Simultaneous optimization of luminance and chromaticity of phosphors
using NSGA-I optimization technique. The NSGA operations like Pareto sorting and niche sharing were implemented. The objective was to identify the phosphor that simultaneously exhibited the desired color intensity and chromaticity.

C Chitra and P Subba raj (2010), implemented the NSGA-II optimization technique to determine the shortest route. The quality of service parameters, delay and cost were considered as the objectives to the problem. A priority based encoding scheme was proposed for population initialization.

Bingquan huang, B Buckley et al (2010), presented the Multi objective feature selection for telecommunication applications by implementing the NSGA-II optimization technique. The work proposes a new multi objective feature selection for churn prediction in telecommunication service field. A method which yields fitness to choose global solutions with lowest ranks was proposed.

Rio GL D’souza, K Chandra Sekaran et al (2010), developed an improvised version of NSGA-II optimization technique based on a novel ranking scheme to handle multi objective and multi constraint problems. The run time of the algorithm was successfully reduced using the simple
principle of space-time tradeoff. The improvised NSGA-II algorithm was applied to the problem of classifying leukemia based on micro array data.

R Saravanan, S Ramabalan et al (2010), presented a novel NSGA-II algorithm for optimizing the motion of an industrial robotic manipulator. A method for computing optimal motions of an industrial robotic manipulator in the presence of fixed and oscillating obstacles was proposed. The model considers non-linear manipulator dynamics, actuator constraints and joint degrees of freedom.

Biswaajit Purkayastha and Nidul Sinha (2010), implemented an adaptive crowding distance mechanism of NSGA-II optimization technique for solving optimal economic emission dispatch problems in electrical power systems.

Maocai Wang, Guangming Dai et al (2010), developed an improved NSGA-II optimization algorithm for handling constrained optimization functions. A partial order relation and cross over operation using Cauchy distribution is setup. Bench mark functions were used to test the algorithm performance.

Pietari Pulkkinen and Hannu Koivisto (2010), presented a multi objective genetic fuzzy system to learn fuzzy partitions which tune the
membership functions. It uses dynamic constraints and enables three parameter tuning to improve the accuracy.

Shibo He, Jimming Chen et al (2010), adopted a stochastic algorithm that decomposes the multi objective optimization problem through Lagrange dual decomposition method and implements a stochastic quasi gradient method to solve the problem in a distributed manner.

Abolfazal Khalkhali, Mohamadhosein Sadafi et al (2010), implemented a modified version of NSGA-II optimization technique to simultaneously optimize the objective functions net energy stored and discharge time in a solar power system. The geometrical parameters of the solar power system were chosen as the design variables.

Ajoy Kumar Dey, Susmit Saha et al (2010), presented a dynamic method for conducting design optimization of impulse response filters by an efficient genetic algorithm technique. The coefficient coding scheme was implemented to obtain high efficiency of finite impulse response filters.

R Shafaghat, S.M. Hosseinalipour et al (2010), optimized the axi-symmetric cavitor shape of submergible bodies using NSGA-II algorithm in order to reduce the drag coefficient for a specified length. The design
objectives and constraints were correlated according to the supercavitational flow characteristics.

Sangwon hong, Saeil lee et al (2011), performed a reliability based design optimization of a multi stage axial flow compressor using an uncertainty model for stall margin. In this method, the mass flow rate and pressure ratio in stall margin calculation are defined as statistical models with normal distribution for consideration of uncertainty in stall margin estimation.

Y P Ju and CH Zhang (2011), developed a multipoint and multi objective optimization method for compressor cascades. The aim was to increase the operating range while maintaining performance at acceptable expense of computational load. The multi objective genetic algorithm was used to search the pareto optimal solutions. The established optimum design method can be extended to three dimensional aerodynamic design of compressor blade.

2.4 A Study on Sensitivity Analysis

Antony V Fiacco (1976), developed a technique using combination of penalty methods and Lagrange multipliers for conducting sensitivity analysis of non linear programming problems. The analysis technique
concentrated on the first order partial derivative sensitivity information, which could be explicitly expressed in terms of problem functions.

T.H. Pierce and R.I.Cukier (1981), proposed a new global nonlinear sensitivity analysis method to investigate the solutions of mathematical models vowing to large uncertainties in the parameters. The proposed model was found to be exact for continuous and discrete parameter variations. The analysis involved statistical characterization of data similar to the Fourier expansion method.

Alejandro Diaz (1987), implemented a strategy of compromise programming in conducting sensitivity analysis on multi objective optimization problems. In this approach the trade-off solutions of multi objective optimization problem were obtained by an analysis of sensitivity of solutions. An implementation based on sequential quadratic programming was provided.

Jerzy ky Parisis (1990), performed the Sensitivity analysis based on non-unique Lagrange multipliers method on non linear programming problems. In this approach the sensitivity analysis results for parametric nonlinear problems and variation inequalities were extended. Sufficient conditions were derived for continuity and directional differentiability of a local unique perturbed solution.
Karen Chan, Andrea Saltelli et al (1997), reviewed a number of variance based methods in sensitivity analysis to ascertain how much the mathematical models depended on each or some of its input parameters. The objectives of the work were, to assign probability density functions to each input parameter, to generate an input matrix through an appropriate random sampling method and to assess the relative importance of each of the input parameters on the output values of the mathematical model.

I.M. Sobol (2001), computed global sensitivity indices for rather complex mathematical models efficiently using Monte-Carlo methods. These indices were used to estimate the influence of individual variables or a group of variables on the model output. The indices were estimated by ranking the variables according to the Fourier amplitude sensitivity test.

Avila SL, Lisboa AC et al (2006), presented a novel approach to perform sensitivity analysis directly from data generated through stochastic optimization process of the problem. This novel technique was adopted to solve many multi objective optimization problems concerning electromagnetic devices.
Volker Schwieger (2007), presented the general characteristics of variance based sensitivity analysis techniques and their advantages with respect to other concepts of sensitivity analysis. The main advantage identified was that the qualitative and quantitative results could be predicted accurately independent of model characteristics. As an example, the optimal trajectory estimation of vehicle was carried out using the variance based sensitivity analysis technique.

J Hamel, M Li et al (2010), developed a novel sensitivity analysis technique called “Design improvement by sensitivity analysis” (DSA), which analyzes the interval of uncertainty of input parameters and determines the optimal combination of design improvements that will ensure minimal objective function variations.

Petrovic S, Fayad C et al (2010), presented the sensitivity analysis of complex job shop scheduling problems which are characterized as large problems with many machines, jobs and uncertain processing times. The aim of the proposed sensitivity analysis was to investigate consequences of prolonged job processing times. The base schedule was generated by applying a new fuzzy multi objective genetic algorithm.
Yang liu and Fan sun (2010), conducted the sensitivity analysis of a rainfall runoff model using the Morris method of sensitivity analysis. Formulation of sensitivity analysis methodology for the rainfall runoff model was the strategy. Overall influence and parameter interaction of multiple objective functions was studied.

Saeed Khorram and Mustafa Ergil (2010), studied the total load sediment flux equations developed for various water resources and conducted sensitivity analysis. He considered three hundred different parameters to identify the factors that control the errors in measurements. The gravitational effect was found to be the most influencing parameter.

Dylan Jones (2011), presented a weight sensitivity algorithm that can investigate the range of interest in multi objective optimization problems for conducting sensitivity analysis. The methodology was demonstrated on various multi objective optimization problems.

2.5 Scope of the present work

Many empirical and mathematical programming techniques are developed to design and optimize the axial flow compressor stage. However, the optimum design of axial flow compressor stage still remains a thrust area of research for many designers. This is due to the presence of
a large number of conflicting parameters which require the implementation of efficient algorithms.

In order to optimize the multiple conflicting objective functions, the conventional optimization techniques are not quite suitable. The review of literature presents evolutionary multi objective optimization techniques such as NSGA-I, NSGA-II etc. These techniques are efficient in determining non-dominated solution fronts that are best with respect to all the objective functions.

From the review of literature, it is found that much work is not reported on the inlet stage multi objective optimization of axial flow compressor. From the optimal design stand point, the inlet stage optimization is very important to develop high overall pressure ratios and high output power. Therefore, the present work aims at optimizing the performance influencing parameters of the compressor inlet stage. The optimization of the multi objective problem of axial flow compressor inlet stage is carried out using the evolutionary optimization techniques reviewed from literature like NSGA-I, NSGA-II, classical Genetic algorithm etc.