Engineering
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CFD for Aero Engines

WHITE PAPER

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HCL

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Abstract

The rapid progress and implementation of Computational Fluid Dynamics (CFD) has contributed to substantial improvements in the performance and efficiency of Gas Turbine engine components through enhanced understanding of the complex viscous flow and heat transfer phenomena involved. For this reason, CFD is one of the key computational tool used in Design & development of gas turbine engines. The document gives a fundamental understanding of Computational Fluid Dynamics as applied to the analysis and design of components that are being executed in aerospace industries using commercially available CFD tools.

Abbreviations

Sl. No.	Acronyms (Page No.)	Full form
1	CFD (4)	Computational Fluid Dynamics
2	HTC (6)	Heat Transfer Coefficient
3	TEC (6)	Turbine Exhaust Case

Market trend/ Challenges

Aerospace companies are exploring radical solutions that could alleviate the impact of air travel on global warming. Industry is looking at new technologies that could also result in huge fuel cost savings, some which are listed below

- Pratt & Whitney's new geared turbofan engine appears to be leading the field at present. Pratt & Whitney has already invested $1bn in the geared turbofan technology and Airbus plans to fly one of its A340 aircraft using Pratt & Whitney's new engine later this year[1]
- Number of engine manufacturers are working on even more radical new engines that promise significant advances in efficiency. The most complicated of these is the so-called open-rotor engine, which could cut fuel burn by up to 30%
- Boeing and Airbus are also seeking to develop more advanced aerodynamic planes. Both are looking at blended wing-body (BWB) aircraft, which have the potential to carry more than 1,000 passengers a flight and hold significant advantages over conventional aircraft in terms of performance and weight
- Boeing has announced perhaps the most dramatic technological breakthrough in the race to reduce the impact of air travel on the environment. According to Boeing, fuel-cell technology could be used to power small manned and unmanned air vehicles
- In the Rolls-Royce Vision technology program, further environmentally-friendly technologies are being developed for applications up to 20 years in the future. Rolls-Royce will spend over $1.5bn on research and development. The majority of this expenditure goes to make our products cleaner, more efficient and quieter[2]

Solution

For the concerns over carbon emissions and the high cost of fuel initiated, focus for improved efficiency. Noise impact on the world triggered another environmental concern. The aerodynamic drag is the key for efficient and high speed cruise, in the mean time high lift is essential for safe takeoff and landing. CFD plays a major role in aircraft aerodynamics, where the requirements continue to push the capabilities of CFD technology.

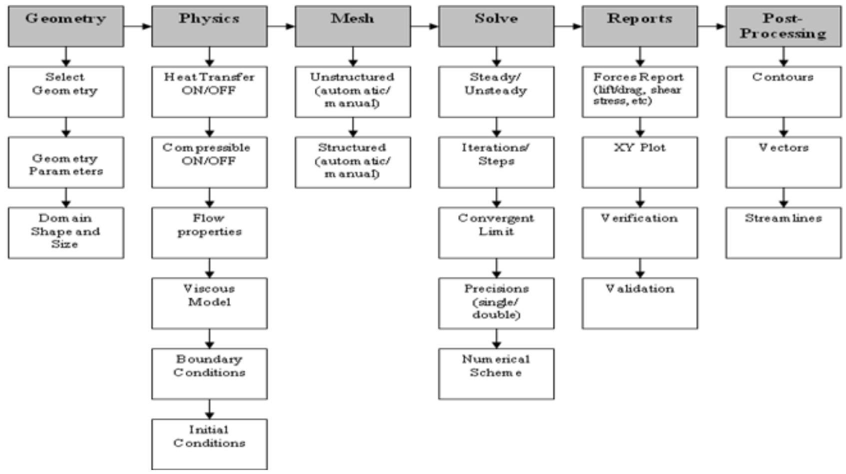
In the area of internal aerodynamic studies applied to gas turbine engines, the components like guide vanes, rotor blades and combustor are supposed to manage main gas flow with least possible pressure loss apart from taking care of the structural aspects. In this scenario, CFD tool helps the designer in optimizing the vane profiles more efficiently.

Gas turbine combustion is the key phenomenon which governs the performance of the engine. In addition to the efficiency, the emission norms are the major challenge for the designers. CFD helps the designers in optimizing the combustion supporting devices, development of innovative fuel injectors/atomizers for liquid-fueled and dual-fueled combustion systems, development of low NOx, gaseous and liquid-fueled combustion systems. Also, there are several activities happening around the world in areas of inter-stage turbine burners, advanced Spray/atomization models & validation, low emission fuel injectors where CFD has been very instrumental.

There are numerous gas turbine components that are being designed and developed are experiencing excessive thermal stress and must be prevented from failing by evenly cooling areas around hot components. For this purpose, uniform flow of cooling air must be ensured throughout the component vicinity. Strut internal cooling, thermal management of Combustors and Turbine parts, Turbine Mid Structure internal cooling, TEC lower cavities, p-flange pocket regions of the TEC, test rig setups, etc, are the typical areas where industries are focusing.

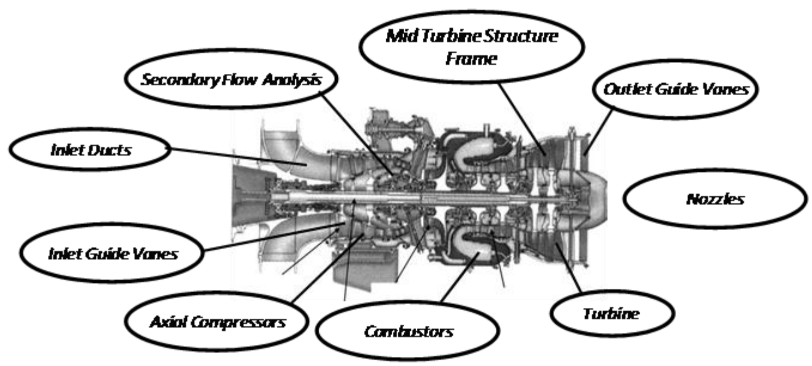
CFD tools are being used increasingly in gas turbine development with positive results and are able to solve these problems cost effectively. Here focus is mainly on analysis of such situations where temperature and heat transfer co-efficient (HTC) mapping are the key criterion.

CFD simulation of any fluid system approaches the problem with the following path.



Overview of CFD Solutions in Aero Engines domain at HCL

HCL's vast experience in serving the aerospace clients has helped in building the competence in CFD application to major components of the gas turbine engine programs namely GEnx, GP7000, PW1000, etc. HCL has been involved in providing services to aero clients in almost all the segments of the aeroengines as detailed below.



Inlet Ducts and Guide vanes: High Mach number & dynamic pressure distortion are believed to be created by the combination of acceleration through the flow abstructions and the high curvature of the downstream geometry. CFD tools are used by HCL to predict the total pressure loss from inlet to the exit plane and uniformity of flow at the plane adjacent to leading edge of the compressor. By optimizing the curvature profile of the casing, could achieve the least possible pressure drop and uniformity of the flow.

Secondary flow analysis: In modern aero-engines approximately twenty percent of the of the main working gas is tapped off to feed secondary air systems such as cooling and sealing flows. Their optimization is considered one of the most promising techniques to increase global engine efficiency. The accurate prediction of the stator, rotor and disc metal temperature is crucial for the reliable layout of such air systems. HCL CFD team has been supporting clients in predicting various performance measurement parameters viz., temperature and heat transfer co efficients on rotating disc walls of high/low pressure compressors, turbines and turbine exhaust casings.

Axial compressors: Gas turbine's overall performance is governed by the efficiency of the compressor, hence the designa nd evaluation of the compressor has been a challenging task ever. Designers have been more dependent on CFD tools to improve the aerodynamic efficiency. HCL has expertise in applying CFD for the overall compressor performance prediction, blade profile optimisation, tip clearance sensitivity and blade loading estimations.

Combustor: Combustor is the heart of the gas turbine as the gas turbines essentially work on the mechanism of extracting energy from the flow of combuston gas. Performance of the combustor is very crucial in gas turbines. Performance is dectated by parameters such as pressure drop across the combustor, air-fuel mixing efficiency, flame stability, etc. CFD tools have been extensively used at HCL to discretise and analyse the flow physics involved in the combustors.

Turbines, NGVs and Mid Turbine structures: In order to increase the efficiency and specific power of the gas turbine engine, temperature at the inlet of the turbine to be increased. This causes the increase in the thermal load on the nozzle guide vane and the first set of the rotor blade and results in decrease in the life of the component. One way to increase the life of the vane is by cooling the blade. Film cooling is commonly used along with the internal cooling to increase the life of the vane. Film cooling provides the thermal protection by forming a layer of cold air around the vane surface. HCL CFD team has significant amount of work in providing solutions in the area of conjugate heat transfer analysis and calculation of external flow and heat transfer between the fluid and the component. Proposing and evaluating several design concepts to improve the performance of the cooling systems for NGVs and MTS.

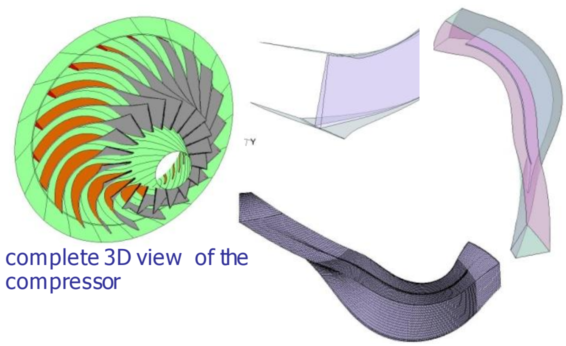
Nozzles: All gas turbine engines have a nozzle to produce thrust, to conduct the exhaust gases back to the free stream, and to set the mass flow rate through the engine. The nozzle sits downstream of the power turbine. A nozzle is a relatively simple device, just a specially shaped tube through which hot gases flow. However, the mathematics which describe the operation of the nozzle takes some careful thought. CFD has been instrumental in predicting the perofrmance of the nozzles at different flow conditions through out the operation of the gas turbine where the flow conditions may be from sub sonic, transonic and super sonic. At HCL, efforts have put in to understand and provide solutions in the area of nozzle performance optimisation and fluidic thrust vectoring.

Few case studies are presented in the paper which gives the glimpse of the CFD solutions provided at HCL.

HCL Case Study #1: Tip clearance sensitivity of a centrifugal compressor

Centrifugal compressors have wide range of utility ranging from process industry to the aerospace. Based on the requirements either shrouded or unshrouded at the blade tip are chosen.

Centrifugal compressors with very high speed are ususlly designed unshrouded due to structural constraints but from the aerodynamics aspects the shrouded impellers high better performance. The unshrouded machines will have a small radial gap between the impeller blade and the stationary casing and there will be a leakage flow enforced due to the pressure drop from pressure side to suction side To demonstrate the difference in performance between the two types of compressors a detailed CFD study is carried out.

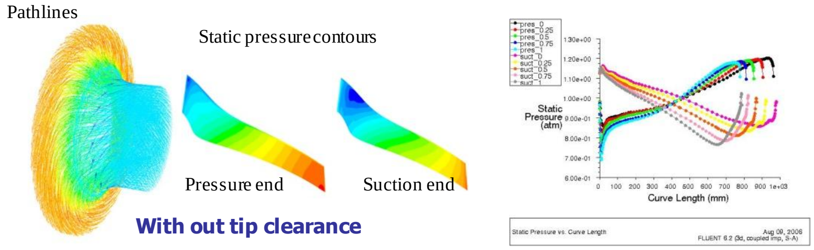


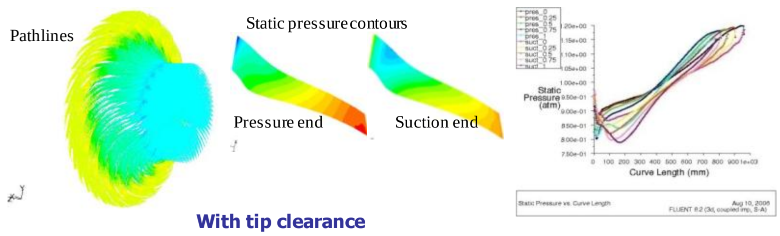
Challenges:

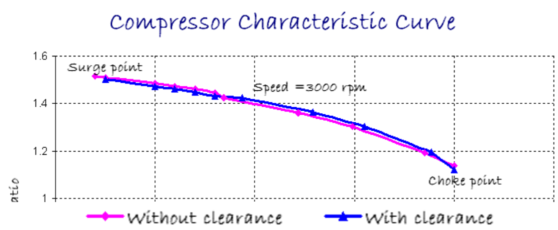
- Geometric complexities like highly curved 3D impeller vane, on which the boundary layer needs to be modeled to capture the viscous effects accurately
- Small clearance between the rotating blade and the stationary casing with suffiecient number of cell layers to capture the leakage

Solution:

- Two cases , one with the tip clearance and the other without tip clearance is modeled for the study.
- The steady state analysis is carried out for different mass flow rates till the choke and surge points are found
- Consideration of the tip clearance will have the expected pressure distribution over the suction and the pressure surfaces
- The surge point (first point in the characteristic curve) for the case with tip clearance is behind the case of without tip clearance
- Study showed significant difference in the blade loading between the two types which is the major factor that influence the structural aspects of the blades

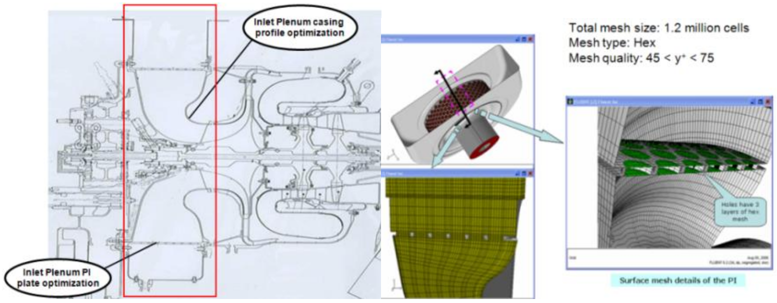






HCL Case Study #2: CFD analysis of the Inlet Plenum to achieve the flow uniformity at the outlet of the plenum (Leading Edge of the centrifugal compressor)

Inlet plenum is the entry port of the Auxiliary Power Unit which has a perforated plate intended for foreign object damage. Due to which the flow entering the compressor is bound to get disturbed. It is the High Mach number & dynamic pressure distortion are believed to be created by the combination of acceleration through the PI holes and the high curvature of the plenum shroud. CFD is used to predict the total pressure loss from inlet to the exit plane and total pressure loss across the perforated plate and uniformity of flow at the plane adjacent to leading edge of the compressor. By optimizing the no of holes, hole diameters, curvature profile of the casing we could achieve the targeted pressure drop and expected uniformity of the flow is achieved.

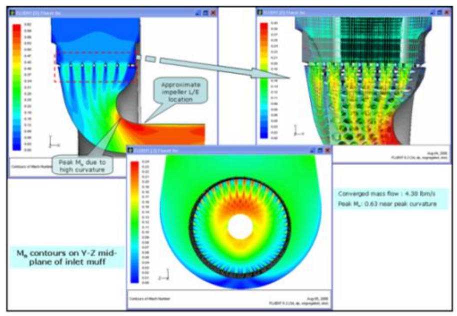


Challenges:

- Geometric complexities like highly curved shroud, perforated plate with numerous holes,
- High turbulent flow which leads convergence issues
- Many design iterations with less turnaround time till the targeted flow uniformity is achieved

Solution:

Mach Number contours & velocity vector fields



- Complete hexahedral, resolved boundary layer mesh which leads to stable solution is built
- Studied the base design for the specified altitude conditions
- Suggested design changes were studied to find out the impact on the performance
- Iterations were continued till the intended flow uniformity is achieved at the exit of the plenum

Conclusion

The wide application of the CFD tool in the aerospace industry has resulted in the advancement of the tool towards more accuracy and reliability. This paper has highlighted the potential of the CFD tools and application of it to various aerospace problems. Also, scope for the CFD is understood and it is known that during the past two decades, CFD has steadily moved from its strong existence in the aerospace industry to be a valuable analysis tool for engineers in many other disciplines.

Reference

[1]http://www.aerospace-technology.com/features/feature40264/ as on 23rd February 2010

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[3] Modern Aircraft Design and CFD by Hrvoje Jasak

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