Graduate Research in Engineering and Technology (GRET)

Volume 1
Issue 7 *Rockets and Missiles Technologies.*

Article 19

June 2022

Film Cooling in Gas Turbine and Nozzle

Manideep Uduta Engineer-Graduate Aerospace
Sandip University, Maharashtra, Nashik, INDIA, manideepudutha111@gmail.com

Vaibhav Naiknavre Engineer-Graduate Aerospace
Sandip University, Nashik, Maharashtra, INDIA, vaibhavn1000@gmail.com

Recommended Citation

Uduta, Manideep Engineer-Graduate Aerospace and Naiknavre, Vaibhav Engineer-Graduate Aerospace (2022) "Film Cooling in Gas Turbine and Nozzle," *Graduate Research in Engineering and Technology (GRET)*: Vol. 1: Iss. 7, Article 19.
DOI: 10.47893/GRET.2022.1128
Available at: https://www.interscience.in/gret/vol1/iss7/19

Film Cooling in Gas Turbine and Nozzle

Manideep Uduta[1] , Vaibhav Naiknavare[2]
[1,2]Department of Aerospace Engineering, Sandip University, Nashik, India
Corresponding Author Email: manideepudutha111@gmail.com

Abstract— **A gas turbine is a rotating engine that generates its power through the flow of combustion gases. With either an axial or centrifugal compressor, air from the surrounding environment is drawn into the engine intake, where it is compressed and heated before being sent to combustion chamber. Every gas turbine engine has a nozzle as a standard part. Among its many responsibilities include propelling the engine forward, returning exhaust gases to the free stream, and regulating mass flow through the engine. When the power turbine's exhaust exits, the nozzle is directly in the direction of the fumes. Simply put, nozzles are just tubes that allow hot gases to flow through them; they're not much more complicated than that. The highest point on each of these delas is around 2500 kelvin. This research illustrates the film cooling method for gas turbine and nozzle longevity. For film cooling to work, the temperature of the airfoil and nozzle case must be decreased.**

Keywords : Airfoil, Film Cooling, Nozzle, Turbines,

I. INTRODUCTION

Turbine intake temperatures of more than 1600°C can be achieved by cooling turbine components with 20–30% of the total flow through the engine. Film cooling is another technique used for turbine airfoils. Improvements in cooling performance that lower airfoil temperatures by just 25°C can significantly increase component life in the turbine operating range. Reduce the flow of coolant to obtain the same airfoil temperature, but the turbine's efficiency will rise, resulting in lower fuel expenditures for the same output. The primary goal of gas turbines is to use film cooling to decrease airfoil temperatures, but only a small fraction of the turbine flow bled from the compressor can be used as coolant before the overall system performance of the engine is compromised by using too much coolant. Convective cooling is a method of decreasing airfoil temperatures by lowering the temperature of the fluid near the airfoil surface and enabling it to cool as it travels through airfoil cooling holes.

II. FILM COOLING ANALYSIS METHODS

The blades of turbines are kept cool by a coolant that flows via holes in the blades. Laser drilling or electro discharge machining are the two methods that are most commonly utilised in the process of drilling holes into the surface of an airfoil (EDM). The machining of EDM holes offers greater creative leeway in terms of hole design and position. In most cases, the airfoils in engines need to be replaced or repaired because certain portions of the airfoil, such as the leading or trailing edges, have burned away but the airfoil's main body has not been compromised.

As a result of the fact that the need for airfoil replacements is caused by local variations in the temperatures of the metal, it is essential to make use of models that are founded on the flow physics of the relevant parameters in order to make predictions regarding the temperatures of the local airfoils. Because greater metal temperatures lead to a shorter component life, the goal of turbine cooling is to reduce the temperatures of the airfoils to the lowest possible level. The temperatures of the metals used in turbine airfoils are influenced not only by the interior but also by the external film cooling.

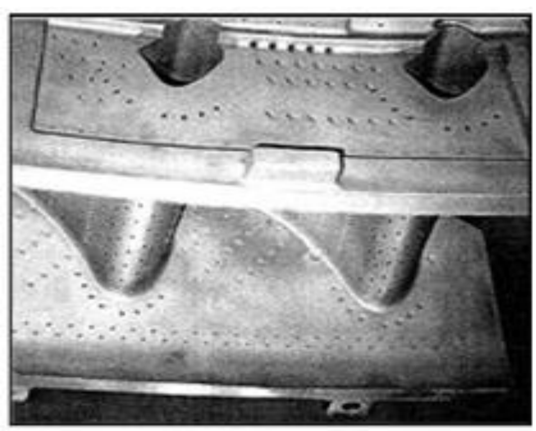


FIG [1] Film cooled turbine vane

III. Equations

The driving potential for heat transfer to occur can be reduced by lowering the temperature of the fluid immediately next to the surface of the airfoil. The heat is transferred from the air to the metal by a process known as conduction. This process is modelled with a mechanistic equation that incorporates a convective heat transfer coefficient, such as.

q’’ = h $(Tref - Tw)$

where, q’’ = heat flux, h = heat transfer coefficient, $Tref$ = driving temperature of the fluid, Tw = adiabatic wall temperature Consequently, the heat transfer coefficient with film cooling, hf is defined as follows:
$qf = hf(Tref - Taw)$

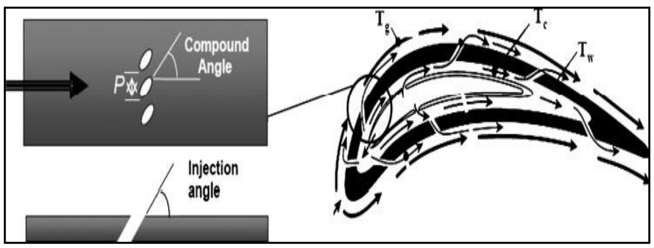


FIG [2] Schematics of typical film cooling configuration, three temperatures potential for film cooled surface

the adiabatic wall temperature and the local convective heat transfer vary widely over the airfoil surface given the discrete nature of the film-cooling holes. film effectiveness also referred to as adiabatic effectiveness defined as:
η = $(T\infty - Taw)/(T\infty - Tc,exit)$
where, $Tc,exit$ = coolant temperature at the coolant hole exit, $T\infty$ = freestream temperature.

IV. Cooling hole geometry & Configurations

A. Cooling Hole Spacing

Three hole diameters is the standard distance between adjacent coolant holes, although this distance can be adjusted up to a maximum of eight hole diameters in the horizontal direction if necessary. As the distance between the holes grows smaller, the coolant covers more of the surface area; more specifically, the coolant covers more of the surface area. In situations where the coolant holes are separated by a significant distance, each coolant jet can be considered to be functioning independently. Using the performance of a single hole as a baseline, it is feasible to accurately forecast how a group of holes would perform under similar conditions. Mainstream flow's interaction with coolant jets will be affected if holes are spaced closer together. Because of this, the flow of coolant between the coolant jets will be impeded.

B. Double Rows of Holes

Two rows of coolant holes positioned close together in a streamwise pattern can be used to cool turbine airfoils. There is no sacrifice in structural integrity or coolant coverage. If the performance of the two rows is overlaid, a film with two closely spaced rows of holes outperforms one with a single row of holes at bigger blowing ratios.

C. Full Coverage Configurations

Full coverage cooling consists of many rows of coolant holes distributed across the area to be cooled. This method is frequently used for combustor cooling. Full coverage film cooling resulted in the greatest net heat flow decrease.

D. Cooling Hole Angle Effects: Streamwise Oriented with Different Surface Angles

As a rule, coolant holes are positioned at shallow angles to the surface, although in some cases, higher injection angles are used. On flat surfaces, studies on the effect of hole injection angle on film efficiency have generally shown that film effectiveness reduces significantly as the injection angle increases. The coolant jet separation rises with increasing injection angle, resulting in decreased film effectiveness.

E. Cooling Hole Angle Effects: Compound Angle Injection

Coolant holes are typically oriented at an oblique angle to the major flow direction, known as a compound injection angle. The coolant jet has a broader jet profile as it passes over the main stream, resulting in a greater coverage area downstream of the hole. Because of the improved film effectiveness that may be projected, this orientation will produce a greater heat transfer coefficient.

F. Shape Holes with Streamwise Orientation

When the coolant hole is "curved" toward the hole's exit with an expansion that diffuses the flow leaving the hole, better film cooling performance is produced. The coolant jet is decelerated by expanding the hole exit, resulting in a reduced flux of momentum and, as a result, less inclination for the coolant jet to split. In terms of film efficacy for shaped holes, there has been an increase in performance.

G. Shaped Holes with Compound Angle Injections

There was a three-fold increase in exit area as a result of the formed holes. Shaped holes orientated with a 0-deg compound angle and double rows of cylindrical holes and double rows of discrete slots were tested for film efficacy, heat transfer coefficients, and net heat flux reduction. Compared to multiple rows of cylindrical holes and short slots, the film effectiveness performance for 35-degree compound angle holes was comparable to that of 0-degree compound holes. In contrast, the heat transfer coefficients of the shaped holes increased more, resulting in a lower net heat flux decrease than the heat flux reduction induced by the round holes.

V. Airfoils and Endwalls

A "showerhead" of coolant holes at the leading edge and more widely spaced rows of coolant holes surrounding the airfoil's main body are common in film cooling on vanes and blades. The tip of the blades may also be cooled by introducing coolant. The endwalls also include arrays of coolant holes.

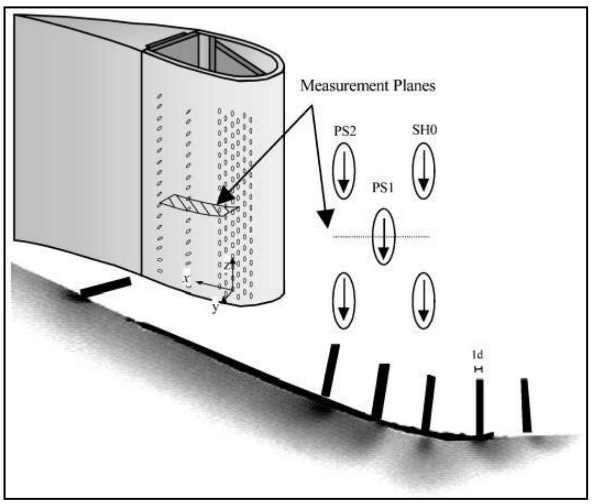


FIG [3] flow visualization of coolant flow in the showerhead

A. Leading Edges

Leading Edges for vanes and blades, the leading edge generally is subjected to the largest heat loads due the large heat transfer coefficients along the stagnation line. Consequently, film cooling of the leading edge is often accomplished using several closely spaced rows of coolant holes. Holes are typically aligned radially, that is, normal to the mainstream direction, with injection angles relative to the surface ranging from 20 to 45 deg.

B. Turbine Blade Tips

Heat transfer coefficients near a turbine blade tip are among the highest for turbine airfoil surfaces. Impingement cooling and film cooling improve the blade tip's thermal environment. Holes may be on the blade tip or pressure surface. The crossflow pushing the tip from the pressure to the suction surface helps distribute the coolant throughout the tip surface. Positioning the cooling holes along the pressure side of the blade ensures that coolant travels across the blade tip corner, where significant oxidation rates occur. If the perforation blowing is too high, coolant can blow off the airfoil and along the pressure surface rather than via the tip gap, or touch the outside shroud rather than stick to the blade tip. Smaller tip gaps cool better because more coolant fills the space than in larger gaps, where a higher mass flow of hot fluid mixes out the coolant.

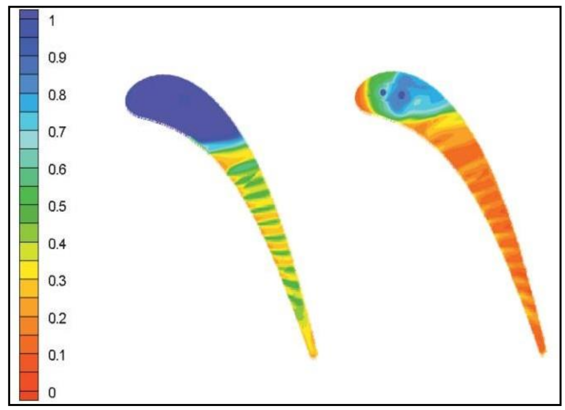


FIG [4] contours of film effectiveness for film cooled tips from pressure side holes for small (left) and large (right) tip gap, both using 0.68% coolant flow measured relative to passage flow

C. Airfoil Endwalls

Because of the flowfield's complexity, turbine endwalls are notoriously difficult to cool. Because they're at the blade tips. A large amount of the coolant injected via the cooling holes can be whisked off the endwall surface by leading edge and passage vortices. Leakage at the turbine-combustor junction causes cooling.

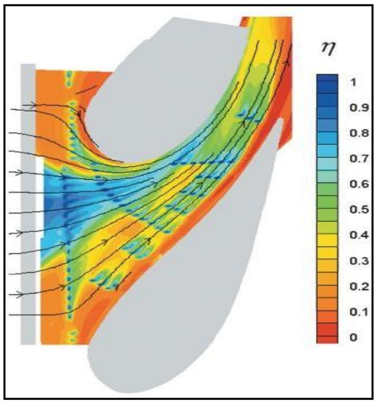


FIG [5] Measured film effectiveness levels for 0.5% slot and 0.5% film cooling flow, flow percentage measured relative to passage flow and predicted streamlines in near wall region

Coolant flow through leakage gaps between the combustor and first vane, or between vanes and blades, can considerably contribute to endwall cooling and influence the secondary flow pattern. Injection from a two-dimensional, flush slot immediately upstream of the vane causes endwall heat transfer. Film efficacy and heat transfer coefficients were measured for a variety of blowing ratios using a flush slit directly upstream of the leading edges of his single passage channel. One of the significant discoveries was that the distributions of endwall film efficacy varied greatly throughout the vane gap, with much of the coolant being swept across the endwall toward the suction-side corner.

VI. Film Cooling and Transfer in Nozzles

In this paper experimental and theoretical investigations on heat transfer and cooling film stability in a convergent-divergent nozzle are presented. Compressed air is injected into hot air in the inlet region of the nozzle and the influence of the strong favorable pressure gradient in the nozzle on turbulent heat transfer and mixing is examined. The experiments cover measurements of wall pressures, wall temperature, and wall heat flux.

A. Experimental Setup

The wind tunnel was used for the experimental research. Compressed air is employed as a hot medium as well as a coolant. A two-stage radial compressor compresses the hot air to a maximum stagnation pressure of 0.28 MPa and a maximum stagnation temperature of 485 K in the test section with a maximum mass flow rate of 2.8 kg/s. A smaller two-stage compressor with an intermediate heat exchanger compresses the cooling air. It enters the test portion with an estimated stagnation temperature of 305 K and a maximum mass flow rate of 0.25 kg/s. The entire equipment is kept in a constant state of motion.

B. Test Section

The maximum outlet Mach number of 2.25 is permitted by the test portion, which is an asymmetric rectangular water-cooled CD nozzle. This portion is designed to have a normal shock at its exit when the compressor is loaded to its maximum capacity, which allows for a maximum outlet Mach number of 2.25. The nozzle was constructed with 35

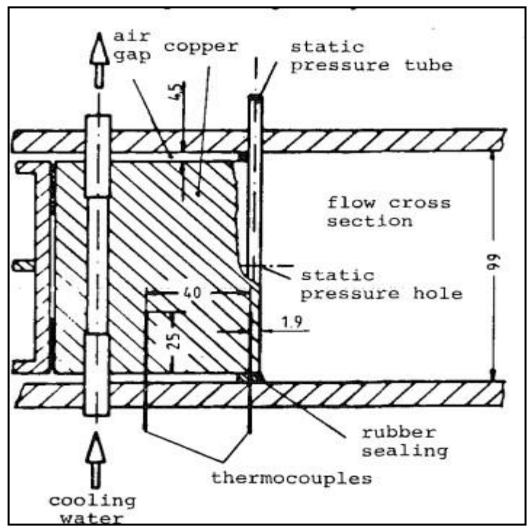


FIG [6] Sectional view; copper

segment individually water-cooled segments of copper that were placed on each of the two side walls. This enabled extremely precise measurements of the heat flux that was transferred from the air to the nozzle walls. It is possible to generate a thermal boundary condition that meets a certain specification if the rate at which cooling water flows through each portion is controlled.

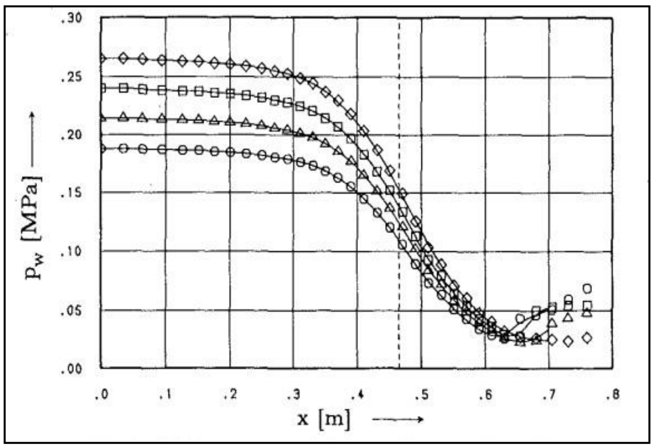
C. Measurement Techniques

pressures are taken from the small steel tubes between the copper segments and transferred to a Scan valve pressure scanning system. Total pressures and total temperatures are taken from combined probes. The mass flow rate of the hot air is calculated from one dimensional gas dynamics relations in the absence of a cooling film.

Symbol	O	Δ	□	◇	
$\dot{m}$	1.971	2.221	2.457	2.695	kg/s
p_o	190329	217227	242624	268616	Pa
T_o	447.4	458.6	467.8	476.3	K
u	55.34	56.02	59.02	59.60	m/s
T_w	309.5	309.5	318.0	323.0	K

FIG [7] Wall pressure Pw (x) along plane nozzle wall

The mass flow rate of the cold air is measured with a \standard orifice. The inlet velocities are computed from the inlet An HP 1000 Minicomputer was utilized to gather the data from the pressure scanning system and the digital voltmeter during the test run, allowing instantaneous examination of the mass flow rates and the distribution of pressure, wall temperature, and wall heat flux. By employing the computer for continually monitoring the wall temperature and the wall heat flux during scanning, it was feasible to produce isothermal wall conditions by manually modifying the cooling water control in an acceptable time.



III. CONCLUSION

Gas turbine airfoil film cooling is affected by a wide variety of factors, as discussed in the preceding sections. For cooling turbine airfoils and end walls, rows of discrete coolant holes are the most common film cooling design. This configuration has been the main focus of this review. Finding the factors that matter and those that don't was a top priority. In each example, we've attempted to offer a physical description of the interaction between coolant jets and the main stream as an explanation for the impact on film cooling performance. Using film effectiveness, heat transfer coefficients, and net heat flux decrease, we may calculate film cooling performance. All three of these variables must be considered in order to have a complete picture of the performance. In many circumstances, the efficacy of the film takes precedence, and this is the sole subject of many investigations. But in other circumstances, an increase in heat transfer coefficient reduces net heat flux by reducing the efficacy of the film. As a case in point, the film efficacy of compound angle injection is noticeably enhanced, although the net heat flow decrease is either equal to or worse than with streamwise oriented holes.

REFERENCES

[1] Film Cooling and Heat Transfer in Nozzles J. Stoll J. Straub Lehrstuhl A fur Thermodynamik, Technische Universitat Miinchen, Munich, Federal Republic of Germany.

[2] Gas Turbine Film Cooling D. G. Bogard University of Texas, Austin, Texas 78712-0292 and K. A. Thole Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24060.

[3] Cooling Methods in Combustion Chambers and Nozzles Department of Mechanichal Engineering and Aeronautics John Poulopoulos, Theodoros Chronopoulos This study is submitted for the project of Rocket Propulsion Systems.

[4] A DESIGN STUDY OF A REGENERATIVELY COOLED NOZZLE NUCLEAR ROCKET SYSTEM /- FOR A TUNGSTEN WATER-MODERATED by Richard Le Pzcthof Lewis Research Center CZeueZand, Ohio.

[5] The impact of nozzle configuration on the heat transfer coefficient K. Krupanek *, A. Staszczyk, J. Sawicki, P. Byczkowska Institute of Materials Science and Engineering, Lodz University of Technology, ul. Stefanowskiego 1,15, 90-924 Łódź, Poland * Corresponding e-mail address: krzysztof.krupanek@p.lodz.p