INFLUENCE OF HEIGHT TO DIAMETER RATIO ON IMPINGEMENT HEAT TRANSFER ON EFFUSED CONCAVE SURFACE

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The leading edge of a gas turbine engine nozzle guide vane or rotating blade is typically protected by a combined jet and effusion cooling. The compressed air jet, impinging on the interior surface of the leading edge, offers a high heat transfer coefficient. The coolant then exits partly through the effusion or film holes and partly along the edges or side ways of the gas turbine blade. Among various factors influencing the heat transfer rate, the ratio of the spacing (H) between the target plate and the jet exit and the diameter (D) of the jet plays a major role. Several researchers in the past analyzed the effect of H/D on the transport rate for single and multiple jets with and without film holes and ascertained its influence on a flat surface [1, 2]. However, very few studies are made on curved surfaces [3] and the effect of H/D on the combined jet impingement with effusion is not reported. The present work aims at computationally analyzing the influence of height to diameter ratio on flow and heat transfer by multiple impinging jets for an effused concave surface.

A typical computational domain (Fig. 1) consists of a 5x4 array of jet holes as an integral part of a plenum cylinder, and a concave target surface with 4x4 array of effusion holes positioned in a staggered fashion with respect to the jet holes. The air jets from the plenum impinge on the isothermal concave surface and exit through the effusion holes. The exit flow after impingement on the target surface to the ambient is provided by one of the two exit configurations for the spent air: (i) exit through all the edges (Fig. 1a) and (ii) exit only through the effusion holes (Fig. 1b). Steady state simulations are carried out with both the exit flow configurations and for H/D values of 0.5, 1, 3, and 5. Jet Reynolds number of 7500 is maintained. Fluent 6.3 is used for the simulations.

In the present configurations, the impinging flow is characterized by two stagnation zones on the target surface. The primary one is the stagnation zone along the jet center line. In this zone, the Nusselt number variation is akin to the flow and turbulence characteristics of the impinging jet. At lower H/D values (H/D = 3 or less), both potential core and shear layers distinctly impress on the target surface (refer Fig. 2), Corresponding to these, a dip in Nusselt number at the stagnation point is followed by two primary peaks symmetric about this point are noticed, Fig. 3. On the other hand, when the length of the potential core is smaller than the jet hole to target surface distance, say H/D = 5 or more, the primary peak remains at the stagnation point itself.

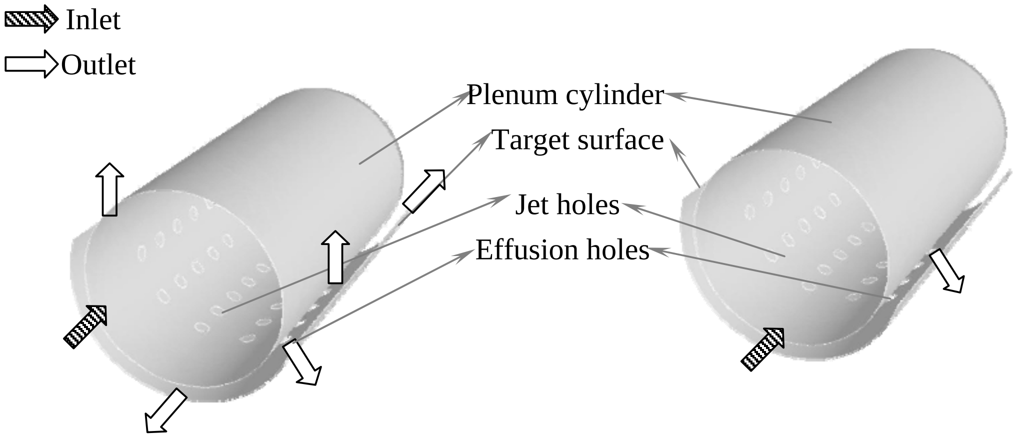
A secondary stagnation zone is formed by the up-wash region due to the interaction of neighboring jets. A second Nusselt number peak is noticed corresponding to the secondary stagnation point. It is evident that the secondary peak stagnation values of Nusselt number are also dependent on the H/D ratio, refer Fig. 3. The presence of film holes on the surface is also found to reduce the local pressure and enhance local heat transfer to a varying degree depending on the exit configurations. It is observed that the average heat transfer coefficient reduces as H/D increases for both the exit configurations, refer Fig. 4.

References:

[1] Behbahani, A. I., and Goldstein, R. J., 1983 “Local Heat Transfer to Staggered Arrays of Impinging Circular Air Jets,” Transaction of ASME Journal of Engineering for Power, **105**, pp. 354-360.

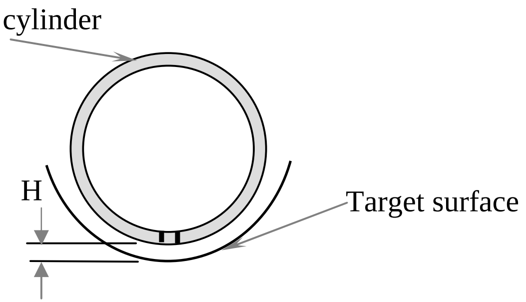
[2] Cho, H. H., and Rhee, D. H., 2001 “Local Heat/Mass Transfer Measurement on the Effusion Plate in Impingement/Effusion Cooling Systems,” ASME Journal of Turbomachinery,**123**, pp. 601 – 608.

[3] Bunker, R. S., and Metzger, D. E., 1990, “Local Heat Transfer in Internally Cooled Turbine Airfoil Leading Edge Regions: Part I Impingement Cooling Without Film Coolant Extraction,” Transactions of the ASME Journal of Turbomachinery, **112**, pp. 415-458.



(a) with exit through all the edges and effusion holes

(b) with exit only through effusion



(c) H/D ratio

Fig. 1 Physical and computational domain

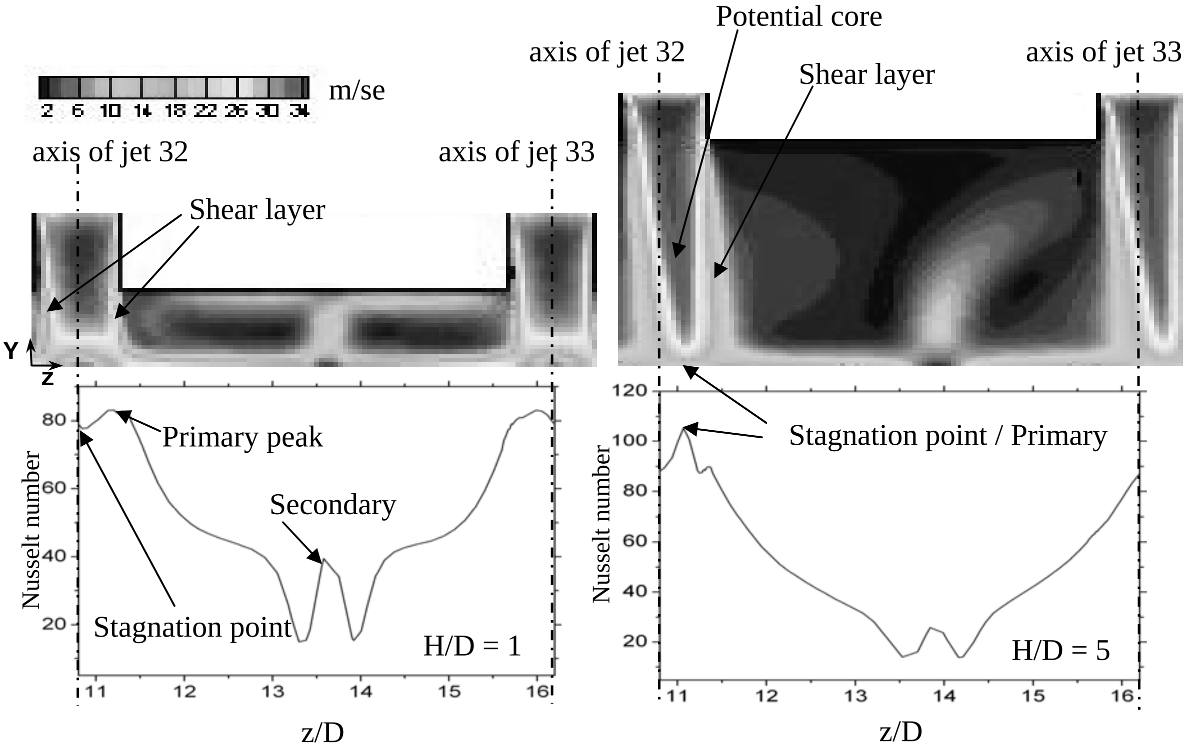


Fig. 2 Velocity magnitude and Nusselt number distribution for jet 32 interacting with jet 33.

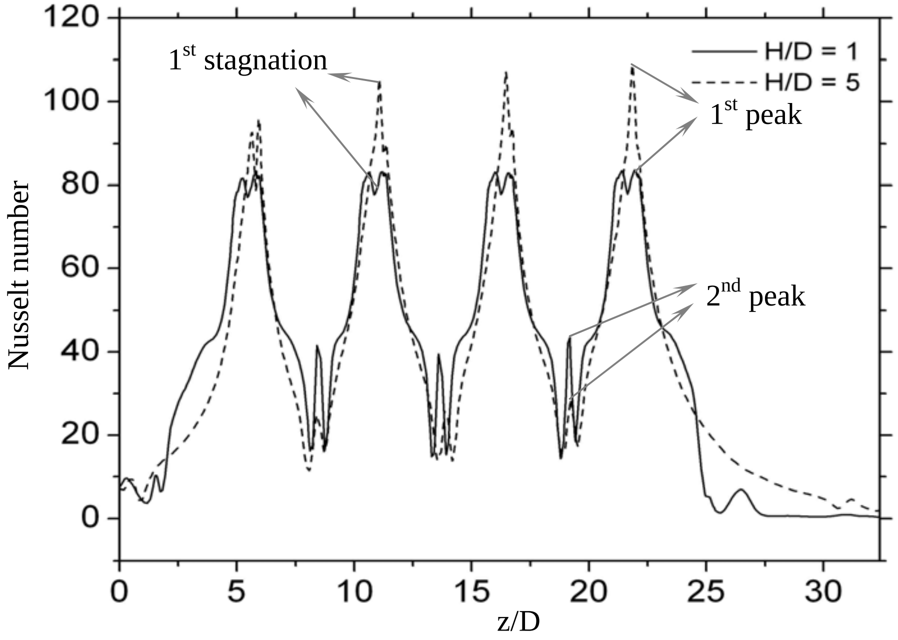


Fig. 3 Nusselt number distribution along stagnation line (showing interaction of all the jets)

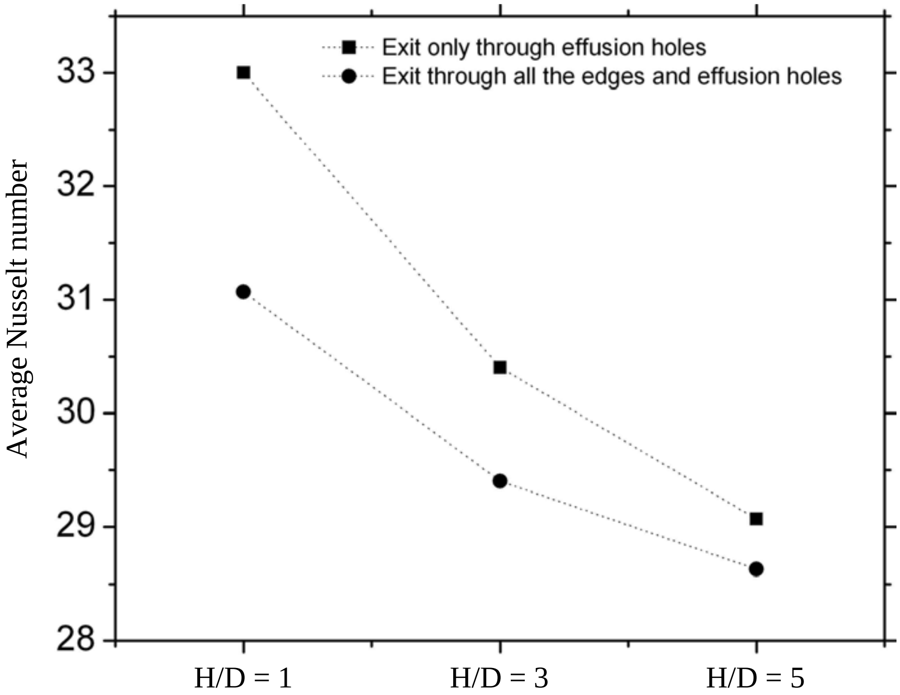


Fig. 4 Average Nusselt number variation with H/D for two exit configurations