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EXPERIMENTAL INVESTIGATION OF TURNING FLOW EFFECTS ON INNOVATIVE TRAILING EDGE COOLING CONFIGURATIONS WITH ELLIPTIC PIN FINS

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This paper describes a heat transfer experimental study of two trailing edge cooling configurations that reproduce two real geometries of aeronautical engine blades. The cooling systems consist of 5 rows of elliptical pin fins with the main axis that is streamwise or spanwise oriented inserted in a wedge shaped duct and followed by an array of circular pin fins with a fillet radius.
The test rig reproduces a real trailing edge layout: the airflow enters the trailing edge in the radial direction with a 90° tuning flow from the hub inlet to the trailing edge outlet; a tip outlet is also present to investigate its effects on heat transfer and pressure drop.

EXPERIMENTS

Test facility description. The test rig consists of a suction-type circuit that allows complete control of the air stream in terms of both temperature and massflow rate; vacuum conditions are required in such a way that Mach and Reynolds numbers are those typical of the real engines. As shown in Fig. 1, in G2.1 the major axis of the ellipse is oriented in the airflow direction (streamwise direction), while in G2.2 the ellipse is rotated of 90° (spanwise direction). Both the arrays are fitted in a 10° wedge shaped duct (L1), replicating the typical trailing edge shape. Ahead of the hub inlet the test article starts with a settling chamber, a grid and then the hub smooth constant height duct, which is 72.75x19.65mm. The main dimensions of L1 and L2 and pin fins are presented in Fig. 1. L2 consists of a constant height duct with a single row of circular pin fin with fillet radius r=H/2: in the real trailing edge duct the small height does not allow to accommodate cylindrical pin fins due to manufacturing constraints.

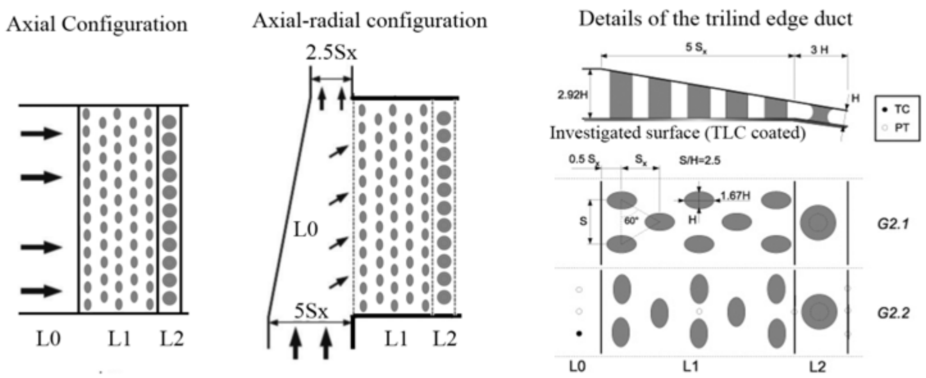


Figure 1. Axial and axial-radial geometry details - G2.1, G2.2

Experimental procedure. Detailed HTC distribution on the pressure side surface is obtained assuming 1D conduction over a semi-infinite solid [Ireland et al., 1993 and Camci, 1995]. The *Series of Steps* method [Ireland and Jones 2000] was implemented to take into account air temperature time history.

The uncertainty analysis was performed following the ASME [1985] standard based on the Kline and McClintock method [Kline and McClintock 1953]. Typical uncertainties of the most important parameters are: HTC = 12.2%, Re = 2.8%, f = 5.4%.

EXPERIMENTAL RESULTS

Heat transfer results. In Fig. 2Figure 2, G2.1 and G2.2 surface heat transfer coefficient maps are presented for the axial-radial configurations comparing to the axial setup and referring to Re=18000 tested flow condition.

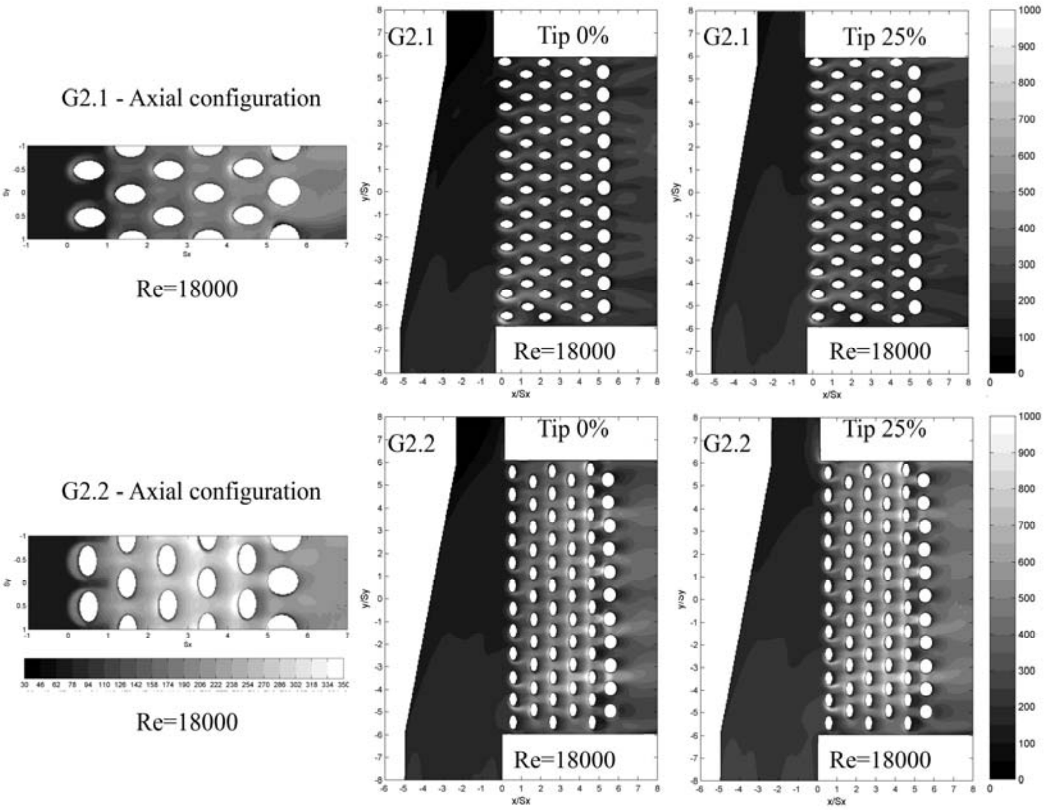


Figure 2. G2.1 and G2.2 HTC maps - Axial and axial-radial configurations - Re=18000 - [W/m^{2}K]

By comparison of G2.1 with G2.2 for both axial and axial-radial configurations, the spanwise oriented pin fins always generate a higher HTC value over the whole investigated surfaces L1 and L2, due to higher turbulence level induced by their disposition. For the axial configuration, see Fig. 2, previous results [Facchini et al., 2008], by comparison with the axial-radial geometries, show lower values of HTC over L1 and L2 surfaces and the HTC distribution is uniform along the spanwise direction. On the contrary with the axial redirection of inlet radial flow, the HTC distribution is dependent on massflow rate percentage flowing through the tip section and is independent from pin disposition. With a closed tip section there is a region, corresponding to $4 \leq y/S_y \leq 6$, with a low HTC value, while the higher HTC is measured near the hub inlet; with a blowing tip section, the radial HTC distribution becomes more and more uniform. Results of heat transfer measurements are also presented in terms of adimensional Nusselt and Reynolds numbers:

$$\mathrm{Re}_{L0} = \frac{\dot{m}_{L2outlet} \cdot D_{h-L1inlet}}{A_{L1inlet} \cdot \mu} \qquad Nu = \frac{h \cdot D_{h-L1inlet}}{k} \tag{1}$$

where Re is calculated referring to L1 inlet section area $A_{L1inlet}$ and hydraulic diameter $D_{h-L1inlet}$; h is the averaged HTC value over L1 or L2 and k is the thermal conductivity.
Over L1, averaged Nu plot (see Figure 3) shows a higher HTC value for the spanwise oriented pin fin arrays, as previously stated, while the depicted trend is similar. Moreover, the effect of an increasing massflow rate is negligible for G2.1, while this effect is visible for G2.2.

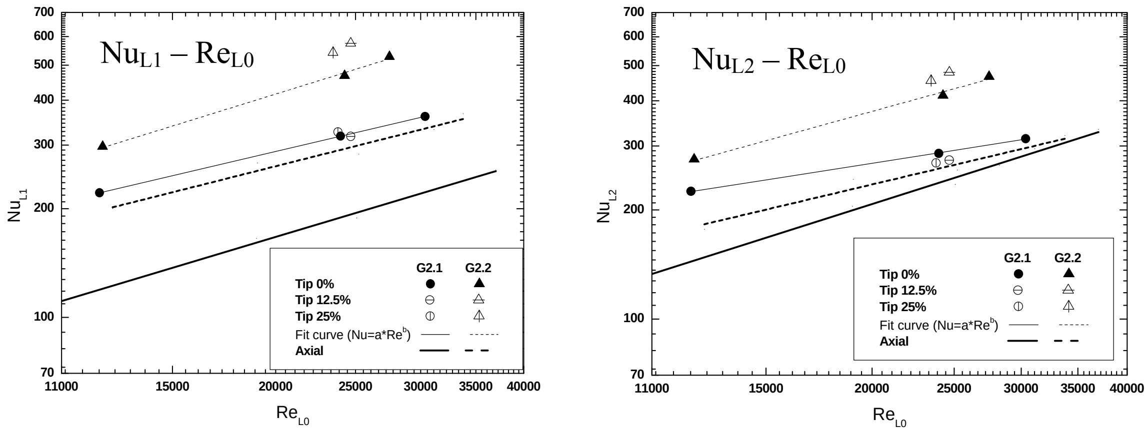


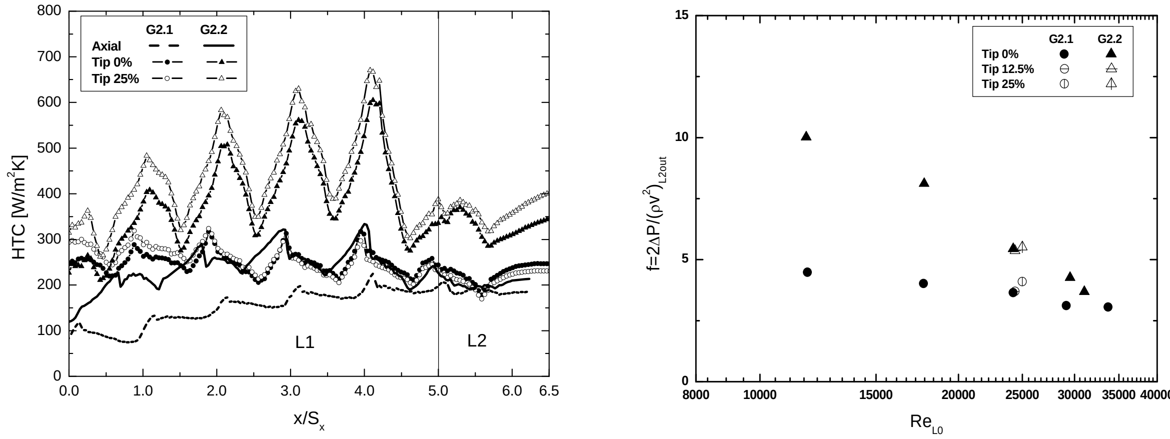
Figure 3. Averaged Nusselt number values over L1 and L2 for G2.1 and G2.2

In Figure 4a, the spanwise averaged HTC is presented for both the axial and axial-radial configurations. As previously stated, higher HTC values were measured for G2.2 regardless of test rig configuration and no remarkable differences can be highlighted for each geometries with a closed or a blowing tip outlet. However, for G2.2 the averaged HTC shows a remarkable growing due to the presence of HTC enhancement near the stagnation points of each pin fin row.
The effect of the circular pin fin array with a fillet radius (x/S_x=5.5) is negligible comparing to elliptic pin fins. Such a behavior is due to the reduction of the turbulence level caused by the flow acceleration in the TE throat section (x/S_x=5); this effect is reported by other authors too [Metzger et al., 1986].

Pressure drop. The experimental survey performed on G2.1 and G2.2 was completed evaluating the pressure drop in terms of the friction factor f defined as $f = 2 \cdot \Delta P_{tot} / (\rho v^2)_{L2out}$, where $\Delta P_{tot} = P_{tot-HUB} - P_{tot-L2outlet}$ is the total pressure drop between the hub inlet and the L2 outlet section.
As shown in Figure 4b, the friction factor for G2.2 has a remarkable dependence upon Reynolds number comparing to G2.1: when the main axis of the pin fins is spanwise oriented there is an area reduction that produces a relevant acceleration of the flow-field. Nevertheless, with a high Reynolds number the friction factor for both geometries is similar. The effect of a blowing tip outlet is negligible regardless of the elliptic pin fins disposition.

CONCLUSIONS

In the present article, an experimental investigation concerning pressure drop and heat transfer was performed, investigating the effect of elliptic and circular pin fin arrays in a wedge shaped duct for an axial-radial trailing edge cooling system geometry, comparing to the axial configuration of the same geometries. Heat transfer results shows that the HTC coefficient is higher for the spanwise oriented elliptic pin fins for both the axial and axial-radial configurations, while averaged Nusselt values over L1 and L2 shows similar trends comparing the investigated geometries.



a. Averaged spanwise HTC b. Pressure drop

Figure 4. Averaged spanwise HTC and pressure drop for G2.1 and G2.2

With flow redirection, HTC distribution over L1 and L2 surfaces depends on whether there is a closed or a blowing tip outlet: an increasing massflow rate through the tip outlet produces a more and more uniform distribution of HTC. However, for each geometry the mean HTC values are practically independent from tip massflow rate. Nevertheless, even though the spanwise oriented pin fin geometry has a better heat transfer behaviour, the friction factor measured for this geometry is globally higher comparing to the streamwise oriented pin fins; for high Re friction factor differences vanish.

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