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Effect of Gurney Flap Configuration on the Performance of a Centrifugal Fan

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ABSTRACT

The present investigation is conducted to study the effect of Gurney flap configuration on the performance of a centrifugal fan at different Reynolds numbers. Gurney flaps of different configurations, such as angle, quarter round and half round corresponding to a nominal height of 1.2 mm (1.94% of the impeller blade spacing at tip) height are attached to the pressure surface of the centrifugal fan impeller blade tip. Performance tests are carried out on the centrifugal fan with a vaneless diffuser at five Reynolds numbers viz. 0.30, 0.41, 0.55, 0.69 and 0.80×10^5 based on the impeller tip speed, impeller blade exit height and kinematic viscosity, both with and without Gurney flaps. From the performance curves it is found that fan performance improves significantly with Gurney flaps at low Reynolds numbers and improves marginally at high Reynolds numbers. Gurney flap of angle configuration of height as small as 1.94% of the impeller blade spacing at tip increases head coefficient by 5.2% and increases the volume flow rate across the fan by 5.4% at the lowest Reynolds number of 0.30×10^5. Even though there is increase in both head and flow coefficients with other Gurney flap configurations (quarter round and half round), they are always less than that for the angle Gurney flap. The effect of Reynolds number on the performance curves is found to be negligible with Gurney flaps, whereas the effect of Reynolds number on the performance curves of the impeller without Gurney flap is found to be considerable. Additional experiments conducted with Gurney flaps of two configurations, viz. angle and quarter round, with a larger height of 2.5 mm (4.05% of the impeller blade spacing at tip) attached on the pressure surface of the centrifugal fan impeller blade tip have shown that the performance of the fan with quarter round GF is better than the performance of the fan with angle GF.

Keywords: Centrifugal fan; Gurney flap; Effect of configuration; Experimental investigation.

NOMENCLATURE

A	cross sectional area
b_2	impeller blade height at exit
C_d	velocity in the discharge duct
C_s	impeller tip diameter
D_2	gurney flap
GF	height difference between suction and delivery duct pressure taps
H	gurney flap height
H_{GF}	half round GF
HR	rotational speed
N	Reynolds number based on b_2
Q	volume flow
QR	quarter round GF
U	blade speed
W	specific work
α	coefficient of discharge of inlet nozzle
ϕ	flow coefficient
ϕ_{max}	maximum flow coefficient
ϕ_{op}	operating range of the fan
ρ	density of air
ν	kinematic viscosity
ψ	head coefficient
ψ_{peak}	peak head coefficient

1. INTRODUCTION

Industrial fans are widely used for cooling, ventilation, vacuuming, dust removal, inflating, etc., and account for a large fraction of the worldwide industrial energy demand. Centrifugal fans are widely used for these applications, because of their low cost, ease of fabrication, robustness, higher pressure ratio and reasonable design and off-design efficiencies. The range of application of centrifugal fans has been extended to cool portable electronic devices where they must be run at very low Reynolds numbers (Tamagawa and Yoshida, 2006). Other examples include computer cooling fans, refrigeration fans, air conditioning fans, and automotive cooling fans as they are suitable when space is limited and when there is a high pressure drop environment. Because of their relatively low rotational speeds in these applications, they tend to have reduced efficiency.

In recent years, it has been recognized that effective energy conservation can play a major role in reducing energy consumption and can, thus, offset growth in energy supply required to keep up with industrial demand. Given a large fraction of the energy consumed by fans, even modest improvements applied to large quantities could result in significant energy savings. Hence, there is a need to understand and improve the performance of centrifugal fans at low Reynolds numbers. A simple and inexpensive passive means that had shown improved aerodynamic performance of aerofoils and wings is Gurney flap (GF).

A Gurney flap is not a sophisticated device. It is simply a short flat tab or plate attached to the trailing edge perpendicular to the chord line on the pressure side of an airfoil or a wing. Dan Gurney was the first person to use this type of flap in 1971 on his race car. The flap was rigidly fixed to the top trailing edge of the rear wing of the car and was pointing upwards to increase down force generated by the wing, and thus the traction generated by the inverted wing on the car. Gurney flaps are now used widely on airfoils, subsonic and supercritical wings, high lift devices, delta wings and helicopters. A review on their scope of applications is given by Wang *et al.* (2008). This review is updated by Suresh and Sitaram (2011) and included some applications of Gurney flaps for turbomachinery.

Despite their widespread use in aeronautics very little research work has been done on turbomachinery (Byerley *et al.*, 2003; Chen *et al.*, 2010; Greenblatt, 2011; Janus, 2000 and Myose *et al.*, 1996). A preliminary effort on the use of Gurney flaps in a centrifugal fan was made by Dundi *et al.*, 2012. Based on the encouraging results of this paper, further investigations are undertaken to optimize the height of Gurney flap for application in centrifugal fans. Kim *et al.*, 2013 has recently applied a 5% chord height Gurney flap to the tip a radial fan for air conditioner at 45 deg. to the trailing edge and the aerodynamic performance of radial fan has been investigated by using experimental and numerical methods. They had shown that both head coefficient and efficiency were increased when Gurney flap is used. Suresh and Sitaram (2018) presented experimental investigations on the effect of height and position of quarter round GFs on the performance of a centrifugal fan. However no systematic investigation is carried out on the effect of GF configuration on the performance of airfoils, turbomachinery. Hence the present investigation is undertaken.

2. OBJECTIVE

The objective of the present investigation is to find the effect of Gurney flap configuration on the performance of a centrifugal fan. Hence an experimental investigation is undertaken to find the Gurney flap configuration effect on the performance of a centrifugal impeller. Gurney flaps of angle, quarter round and half round of nominal heights of 1.2 mm (1.94% of the impeller blade spacing at tip) were tested at five Reynolds numbers viz. 0.30, 0.41, 0.55, 0.69 and 0.80×10^5 based on the impeller tip speed, impeller blade exit height and kinematic viscosity i.e., at five speeds 1100, 1500, 2000, 2500 and 2900 rpm. Additional experiments were conducted with Gurney flaps of two configurations, viz. angle and quarter round, with a larger height of 2.5 mm (4.05% of the impeller blade spacing at tip) attached on the pressure surface of the centrifugal fan impeller blade tip.

3. EXPERIMENTAL FACILITY, INSTRUMENTATION, GURNEY FLAPS TESTED, EXPERIMENTAL PROCEDURE AND UNCERTAINTY ANALYSIS

3.1 Experimental Facility

A low specific speed centrifugal fan test rig was used for the experimental investigation. The test rig is a single stage centrifugal fan driven by a 10 HP AC motor whose speed is controlled by a variable speed drive. The major geometric details of the fan are given in Table 1.

Table 1 Design Details of Centrifugal Fan Tested

Pressure ratio, P_{O2}/P_{O1}	1.036
Mass flow rate, m	0.56 kg/s
Speed, N	3,000 rpm
Shape number, $N_{sh}=NQ^{1/2}/60W^{3/4}$	0.076
Specific speed, $n_q=NQ^{1/2}/60H^{3/4}$	25.3 $m^{3/4}s^{3/2}$
Inducer hub diameter, D_{1h}	110 mm
Blade angle at inducer hub, β_{1h}	45 Deg.
Inducer tip diameter, D_{1t}	225 mm
Blade angle at inducer tip, β_{1t}	29 Deg.
Impeller exit diameter, D_2	393 mm
Blade angle at exit, β_2	90 Deg.
Blade height at impeller tip, b_2	20 mm
Number of impeller blades	20
Exit diameter of vaneless diffuser, D_3	600 mm
All angles are w.r.t. tangential direction	

3.2 Instrumentation

Each performance test of the fan was conducted at a constant rotational speed and the speed was measured using a non-contact type tachometer of range 0-9999 rpm with an accuracy of ±1 rpm. The pressure measurements were taken using a digital micro manometer (range ±200 mm of WC, accuracy ±0.1% full scale reading) and a 20 way scanning box.

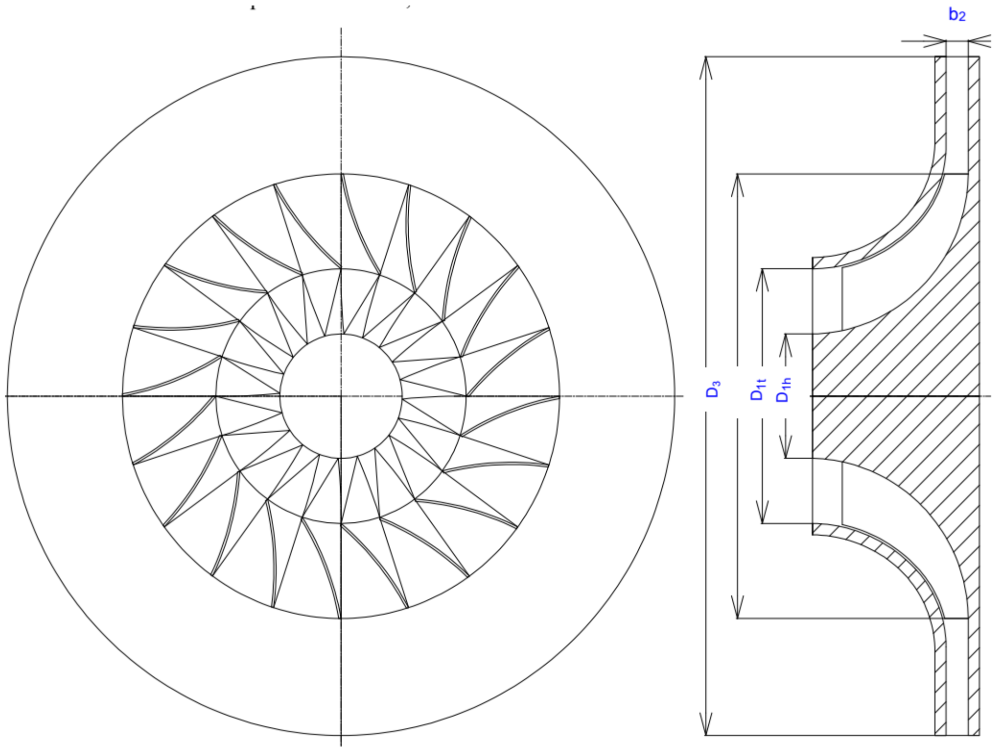

Fig. 1a AUTOCAD drawing of front and end views of the impeller.

3.3 Gurney Flaps Tested

Three different configurations of GFs were tested in the present investigation. The configurations tested were angle, quarter round and half round shape. Initial experiments are conducted with GFs of nominal size, i.e. 1.2 mm (1.94% of the impeller blade spacing at tip). As the GFs were chosen from commercially available brass and styrene material, the heights were slightly different. For angle GF, the height was 1.2 mm, for quarter round GF, the height was 1.0 mm and for half round GF, the height was 1.25 mm. From the experiments, it is found that both angle GF and quarter round GF gave almost identical performance with half round GF giving lower performance, although its performance was still superior to that of the compress without GF. As the height of angle GF was 20% more than that of quarter round GF, it was decided to conduct performance tests with angle and quarter round GFs of larger and same height i.e. 2.5 mm (4.05% of the impeller blade spacing at tip). The impeller frontal and end views with major dimensions are shown in Fig. 1(a). Photographs of the impeller and impeller blade tip with the angle GF attached are shown in Figs. 1(b) and 1(c) respectively. The tested GFs are shown in Fig. 2.

3.4 Experimental Procedure

The micro manometer has a 10% range, corresponding to ± 20 mm of WC. This range was used when the pressures to be measured were below 20 mm of WC. As the performance of the fan was to be measured at low rotational speeds (up to 1100 rpm), the coefficient of discharge of the inlet nozzle was to be determined for very low volume flows. However accurate measurement of very low pressures is difficult.

Hence the coefficient of discharge of the inlet nozzle was determined for a few low volume flows. The coefficient of discharge was plotted against the wall static pressure of the inlet nozzle. This plot was curve fitted and the curve fitted equation was used to determine the volume flow. Pressure difference across the pre-calibrated nozzle at the inlet of the test rig was used to calculate volume flow rate through the fan using the following equation,

$$Q=\alpha A(2\Delta P/\rho)^{0.5} \tag{1}$$

Volume flow rate was controlled using the throttle at the downstream of delivery duct. Two sets of static pressure tapings, one at the inlet duct (SS) and other at the delivery duct (PP) were used to measure the average static pressure developed cross the fan at each volume flow rate. These measurements were used in determining specific work, W of the fan using the relation

$$W = \frac{p_d - p_s}{\rho} + \frac{C_d^2 - C_s^2}{2} + gH \tag{2}$$

The two performance parameters, Head coefficient, ψ, vs. Flow coefficient, ϕ, that are measured in the experiments are subject to many measurement errors in the pressures. The magnitude of the expected errors in these measurements is presented in the next section.

The flow coefficient is defined as

$$\phi=C_m/U_2=(\text{constant})\ [2\Delta P/(P_a/RT_a)]^{0.5}/N \tag{3}$$

The head coefficient is defined as $\psi=(2W/U_2^2)$ (4)

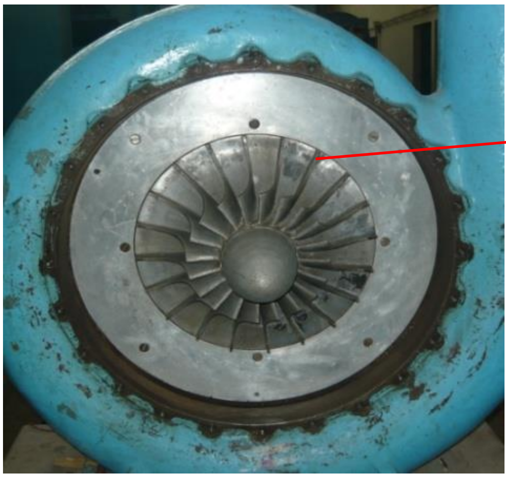

Fig. 1b Front view of impeller.

Fig. 1c Impeller blade with Gurney flap.

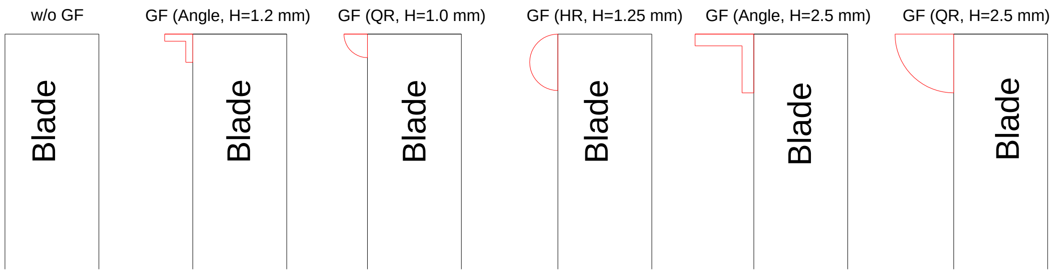

Fig. 2. Fan impeller blade with different configurations of Gurney flap.

3.5 Uncertainty Analysis

Based on the manufacturer's specifications of the instruments used, the total measurement error in the determination of flow coefficient can be estimated as 1% at high volume flows. However at low volume flows, particularly when the fan is operating at the lowest rotational speed, the total measurement error can be as high as 4%.

The error in measurement of head coefficient depends on the accuracy of measurement of static pressure across the fan, air density and impeller speed. Based on the manufacturer's specifications of different instruments used, the total measurement error in the determination of head coefficient can be estimated as 0.7% at low volume flows, when the pressure rise is high. However at high volume flows, particularly when the fan is operating at the lowest rotational speed, the total measurement error can be as high as 3%.

4. RESULTS AND DISCUSSION

4.1 Effect of Reynolds Number on the Performance of the Fan

The performance characteristics of the fan without and with GFs (H=1.2 mm) of different configurations in terms of non-dimensional parameters, ψ vs. ϕ at the five Reynolds numbers in the order of 0.30, 0.41, 0.55, 0.69 and 0.80×10^5 are presented in Fig. 3. There is significant reduction of head coefficient (ψ) from the highest Reynolds number (0.80×10^5) to the lowest Reynolds number (0.30×10^5). Other researchers (Wiesner, 1979; Simon and Bulskamper, 1984 and Casey, 1985). Table 2 gives the variation of ψ_{peak} and ψ at ϕ_{design} for all the five Reynolds numbers. The maximum variation of head coefficient (ψ_{peak}) is 4.3% and the maximum variation of head coefficient at the design flow coefficient (ϕ_{design}=0.34) is 3.6% for the fan with impeller without a Gurney flap.

However for the fan with GFs, the effect of Reynolds number on the performance is negligible (about 0.5% drop in ψ_{peak} and ψ at ϕ_{design} for angle GF, about 0.7% increase in ψ_{peak} and ψ at ϕ_{design} for quarter round GF and about 0.5% increase in ψ_{peak} and ψ at ϕ_{design} for half round GF, between the highest and lowest Reynolds numbers tested). The increase in ψ_{peak} and ψ at ϕ_{design} for quarter and half round GFs is surprising. The most possible reason is the smooth flow over these GFs.

4.2 Effect of Gurney Flap Configuration on the Performance of the Fan

Performance characteristics without and with the Gurney flap for Reynolds numbers viz. 0.30, 0.41, 0.55, 0.69 and 0.80×10^5 i.e., at five speeds 1100,

Table 2 Variation of Head Coefficient with Reynolds number

N (rpm)	Re_{b2}	ψ_{peak}				ψ at ϕ_{design}			
		Gurney flap configurations tested							
		w/o GF	Angle	QR	HR	w/o GF	Angle	QR	HR
1,100	0.286×10^5	1.318	1.387	1.363	1.369	1.317	1.382	1.362	1.369
1,500	0.390×10^5	1.323	1.387	1.356	1.361	1.321	1.380	1.357	1.358
2,000	0.522×10^5	1.342	1.391	1.368	1.371	1.340	1.386	1.360	1.363
2,500	0.651×10^5	1.362	1.394	1.359	1.371	1.348	1.384	1.359	1.352
2,900	0.781×10^5	1.375	1.394	1.355	1.361	1.365	1.385	1.353	1.356
% change in ψ from highest to lowest Re		-4.1	-0.5	0.6	0.6	-3.5	-0.2	0.7	1.0

1500, 2000, 2500 and 2900 rpm for the three Gurney flap configurations of height 1.2 mm (1.94% of the impeller blade spacing at tip) are shown in Fig. 4. The head coefficient for the fan with GF is always higher than that of the fan without the GF for the three GF configurations over almost the complete flow coefficient range at low Reynolds numbers. At low Reynolds numbers, the difference is higher, whereas only small increases are found at high Reynolds numbers for angle GF. The maximum flow coefficient increases for a fan with GF and these increases are again higher at low Reynolds numbers and increases marginally at high Reynolds numbers. For angle GF configuration, the maximum flow coefficient increases by 5.4% at the lowest Reynolds number.

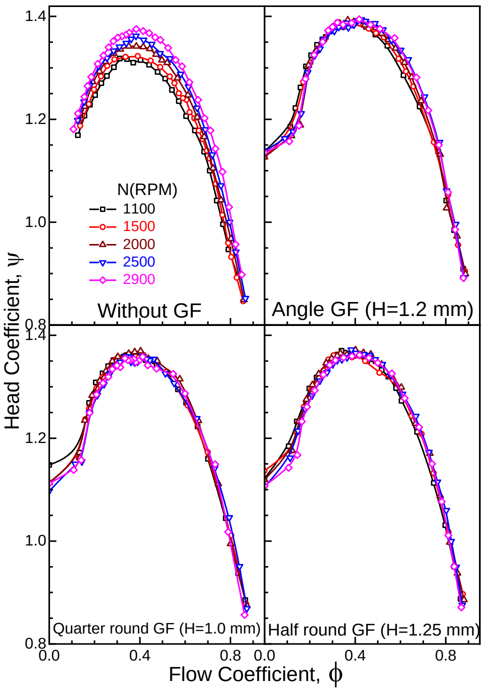

Fig. 3. Effect of Reynolds number on performance curves of centrifugal fan without and with GF.

The increase in the maximum flow coefficient is reduced as Reynolds number increases. The point of maximum head coefficient (ψ_{peak}) moves toward the higher flow coefficients for the fan with a GF at all five Reynolds numbers compared to the fan without a GF. For quarter round and half round GFs, similar observations are made. However the increase in maximum flow coefficient is slightly lower than that for angle GF. From Fig. 4 and Table 3, it is observed that the performance of the fan with angle GF is always higher followed by that of the fan with half round GF, the fan with quarter round GFs while the performance of the fan without GF is always lowest. The height of quarter round GF is only 1 mm, which is about 20% smaller than that of angle and half round GFs. For true comparison, the heights of the GFs should be same. Hence further performance tests are conducted with angle and quarter round GFs with a height of 2.5 mm corresponding to 4.05% of the impeller blade spacing at tip.

4.3 Effect of Large Gurney Flap on the Performance of the Fan

Performance characteristics without and with large Gurney flap for Reynolds numbers viz. 0.30, 0.41, 0.55, 0.69 and 0.80×10^5 i.e., at five speeds 1100, 1500, 2000, 2500 and 2900 rpm for the two Gurney flap configurations of height 2.5 mm (4.05% of the impeller blade spacing at tip) are shown in Fig. 5. The head coefficient for the fan with GF is always higher than that of the fan without the GF for both the GF configurations over almost the complete flow coefficient range at low Reynolds numbers. At low Reynolds numbers, the difference is higher, whereas only small increases are found at high Reynolds numbers for angle GF. The maximum flow coefficient increases for a fan with GF and these increases are again higher at low Reynolds numbers and increases marginally at high Reynolds numbers. For angle GF configuration, the maximum flow coefficient increases by 4.8% at the lowest Reynolds number. This increase in flow coefficient is reduced at high Reynolds numbers. For GF quarter round configuration, the maximum flow coefficient increase is slightly higher (5.4%) at the lowest Reynolds number.

The point of maximum head coefficient (ψ_{peak}) moves toward the higher flow coefficients for the fan with a GF at all five Reynolds numbers compared to the fan without a GF. The head coefficient of the fan with quarter round GF is always higher than that of the fan with angle GF. The difference in performance is maximum at the lowest Reynolds number. At Reynolds number of 0.69×10^5 and higher values the

Table 3 Variation of Head Coefficient with Reynolds number without and with large GF

N (rpm)	Re_{b2}	ψ_{peak}			ψ at ϕ_{design}		
		Gurney flap configurations tested					
		w/o GF	Angle	QR	w/o GF	Angle	QR
1,100	$0.286\text{x}10^5$	1.318	1.379	1.401	1.317	1.373	1.395
1,500	$0.390\text{x}10^5$	1.323	1.380	1.397	1.321	1.374	1.392
2,000	$0.522\text{x}10^5$	1.342	1.388	1.398	1.340	1.379	1.396
2,500	$0.651\text{x}10^5$	1.362	1.383	1.393	1.348	1.381	1.383
2,900	$0.781\text{x}10^5$	1.375	1.394	1.392	1.365	1.382	1.382
% change in ψ from highest to lowest Re		-4.1	-1.1	0.6	-3.5	-0.7	0.9

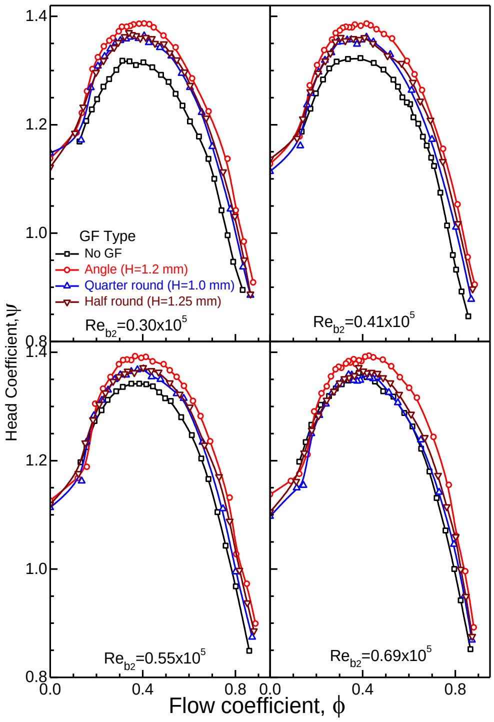

Fig. 4. Effect of GF configuration on performance curves of centrifugal fan.

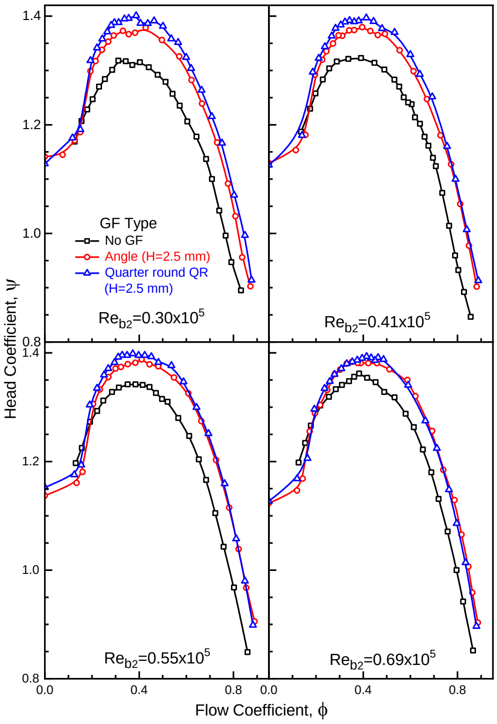

Fig. 5. Effect of large GF configuration on performance curves of centrifugal fan.

difference in the performances is almost negligible. Similar to the performance of the fan with GF of nominal height of 1.2 mm, the effect of Reynolds number on the performance is negligible (about 1% drop in ψ_{peak} and ψ at ϕ_{design} for angle GF, about 0.5% increase in ψ_{peak} and ψ at ϕ_{design} for quarter round GF between the highest and lowest Reynolds numbers tested). These values are slightly higher than the corresponding values of the fan with GF of nominal height of 1.2 mm. However the performance of the fan with height of 2.5 mm is always higher than that of the fan with GF of nominal height of 1.2 mm.

4. CONCLUSIONS

Experimental investigation on the effects of Gurney flap configuration on the performance of a centrifugal fan were conducted and the following major conclusions are drawn:

Reynolds number effect on the performance of the fan is negligible for the given fan with Gurney flap. Without Gurney flap, the maximum head coefficient of the fan reduces by about 5% at the lowest Reynolds number. Performance tests on the fan without and with Gurney flaps have shown that the fan performance improves with Gurney flaps and the maximum volume flow across the fan also increases with Gurney flap at low Reynolds numbers and increases slightly at higher Reynolds number. Gurney flaps of angle, quarter round and half round of height of 1.2 mm (1.94% of the impeller blade spacing at tip) are tested and from the performance curves it has been concluded that angle Gurney flap of smallest height (1.2 mm, equal to H/S_2 of 1.94%) improves the fan maximum head coefficient by 5.2% and increases maximum flow coefficient by 5.4% at lowest Reynolds number (0.30×10^5). Even though there is improvement in performance of the fan with quarter round and half round GFs for the same height, it is not significant.

The operating range of the fan improves with the GF at low Reynolds numbers of 0.30 and 0.41×10^5 for angle GF of height of 1.2 mm (H/S_2=1.94%) while the operating range deteriorates with the same GF type at high Reynolds numbers. For GF of 2.5 mm height (4.05% of the impeller blade spacing at tip), the performance of quarter round GF is superior for the entire operating range of the fan at all the five Reynolds numbers tested. The most probable reason is the smooth flow over these GFs, while still increasing the effective camber angle.

Overall it can be concluded that the performance of the centrifugal fan is superior with Quarter Round Gurney flap compared to that with angle or half round GF.

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