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Original Paper

Application of Gurney Flaps on a Centrifugal Fan Impeller

Thomas Manoj Kumar Dundi, Nekkanti Sitaram and Munivenkatareddy Suresh

Thermal Turbomachines Laboratory, Department of Mechanical Engineering,
Indian Institute of Technology Madras, Chennai – 600036, India
thisismanoj.t@gmail.com, nsitaram@iitm.ac.in, suremreddy@gmail.com

Abstract

The objective of the present investigation is to explore the possibility of improving the performance of a centrifugal fan at low Reynolds numbers using a simple passive means, namely Gurney flap (GF). GFs of 1/8th inch brass angle (3.175 mm) corresponding to 15.9% of blade exit height or 5.1% of blade spacing at the impeller tip are attached to the impeller blade tip on the pressure surface. Performance tests are carried out on the centrifugal fan with vaneless diffuser at five Reynolds numbers (viz., 0.30, 0.41, 0.55, 0.69, 0.82x10^5, i.e., at five speeds respectively at 1,100, 1,500, 2,000, 2,500 and 3,000 rpm) without and with GF. Static pressures on the vaneless diffuser hub and shroud are also measured for each speed at four flow coefficients [ϕ=0.23 (below design flow coefficient), ϕ=0.34 (design flow coefficient), ϕ=0.45 (above design flow coefficient) and ϕ=0.60 (above design flow coefficient)] with and without GF. From the performance curves it is found that the performance of the fan improves considerably with GFs at lower Reynolds numbers and improves marginally at higher Reynolds number. Similar improvements are observed for the static pressures on the diffuser hub and shroud. The effect of Reynolds number on the performance and static pressures is considerable. However the effect is reduced with GFs.

Keywords: Centrifugal fan, Gurney flap, Experimental investigation, Performance, Static pressure.

1. Introduction

Industrial fans are widely used for cooling, ventilation, vacuuming and 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 low cost, ease of fabrication, robustness, higher pressure ratio and reasonable design and off-design efficiency. The range of application of centrifugal fans has been extended to cool portable electronic devices where they have to be run at very low Reynolds numbers. 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, it results in 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 large fraction of the energy consumed by fans, even modest improvements applied at large scales 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 improving the aerodynamic performance of airfoils and wings is Gurney flap.

A Gurney flap is not a sophisticated device. It is a length of metal or plastic right-angle rigidly bolted, riveted or glued to the trailing edge of a wing. Dan Gurney's (All American Racing) team used this type of flap in 1971 while testing the team's new USAC car at Phoenix, prior to the season's first race. The team used this type of flap to increase the ''down force'' and thus the traction generated by the inverted wings on his race cars. Numerous wind tunnel tests on Gurney flaps attached to airfoils have been performed. These investigations have shown that the Gurney flap increases the effective camber of the airfoil. There is a significant increase in lift with only a small increase in drag as long as the flap height scales with the local boundary layer thickness. Despite their widespread use in aeronautics (Lee [1], Lee and Su [2] and Wang et al. [3]), very little research work has been done on turbomachinery (Byerley et al. [4], Chen et al. [5], Greenblatt [6], Janus [7] and Myose et al. [8]). An effort has been made here to find the effectiveness of Gurney flaps on the performance of centrifugal fan.

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Corresponding author: N. Sitaram, Professor, nsitaram@iitm.ac.in

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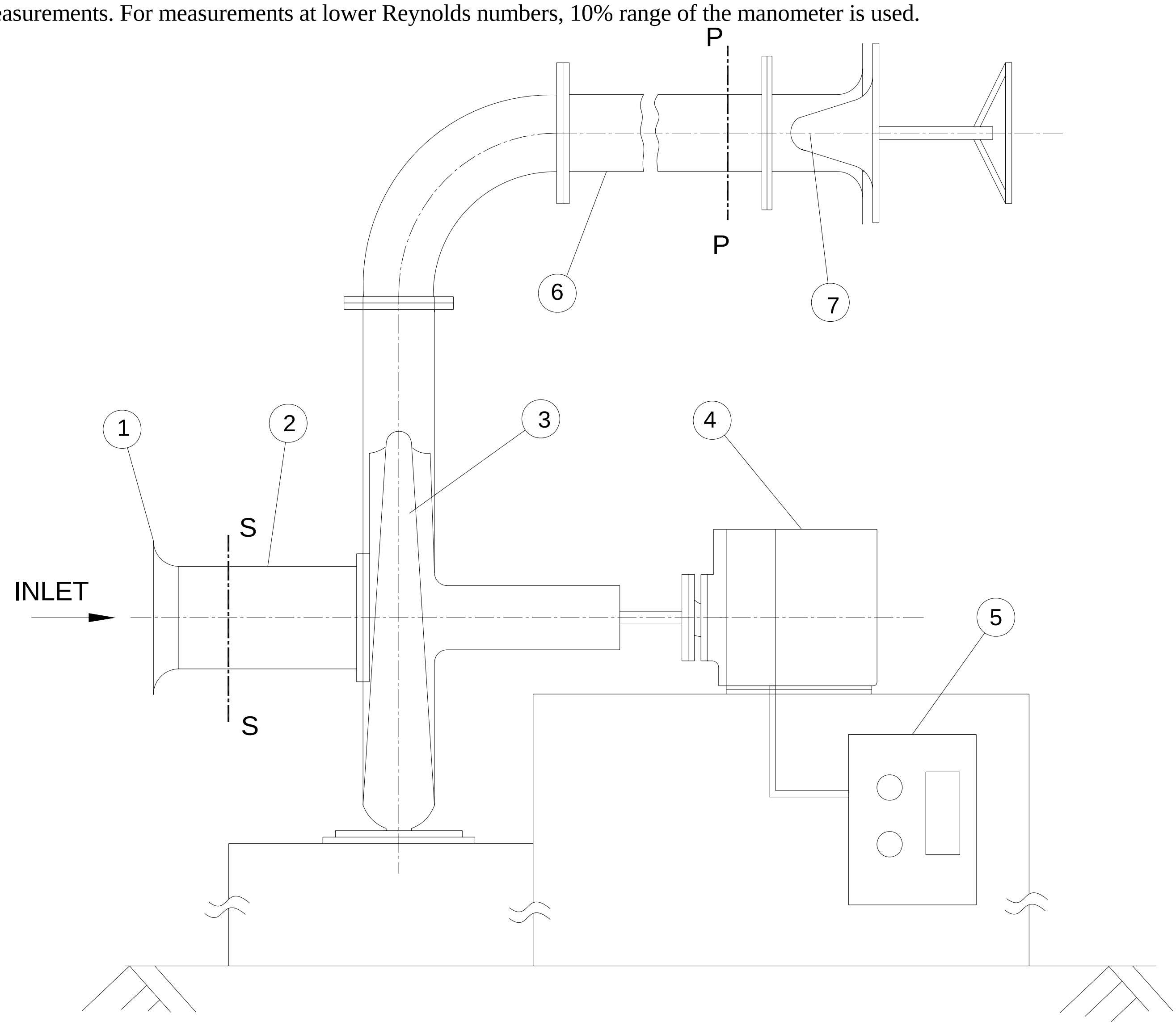
2. Experimental Facility, Instrumentation, Program and Procedure

The experiments are carried out on a low specific speed centrifugal fan available at the Thermal Turbomachines Laboratory, Department of Mechanical Engineering, IIT Madras. A schematic of the experimental facility is shown in Fig. 1. The experimental facility is a single stage centrifugal fan driven by a 10 HP AC motor, whose speed is controlled by a variable speed drive. The major design details of the fan are given in Table 1. A digital micro manometer (Model FCO012, range: $\pm$ 200 mm of water gage) and a 20 way scanning box (Model FCO091) manufactured by M/s. Furness Controls, Bexhill, U.K. are used for pressure measurements. For measurements at lower Reynolds numbers, 10% range of the manometer is used.



1 Inlet nozzle   2 Inlet duct   3 Centrifugal fan   4 Drive motor   5 VSD   6 Delivery duct   7 Throttle
SS Suction pressure   PP Delivery pressure

Fig. 1 Schematic layout of the experimental facility

Table 1 Design Details of the Centrifugal Fan

Pressure ratio, P_{02}/P_{01}	1.04	Mass flow rate, m	0.56 kg/s
Speed, N	3,000 rpm	Shape number, N_{sh}	0.076
Inducer hub diameter, D_{1h}	110 mm	Inducer tip diameter, D_{1t}	225 mm
Blade angle at inducer hub, β_{1h}	45 Deg.	Blade angle at inducer tip, β_{1t}	29 Deg.
Impeller exit diameter, D_2	393 mm	Number of impeller blades	20
Blade angle at exit, β_2	90 Deg.	Blade height, h_2	20 mm
Exit diameter of vaneless diffuser, D_3	600 mm	All angles are w.r.t. tangential direction	

Performance tests are carried out on the centrifugal fan with vaneless diffuser at five Reynolds numbers viz., 0.82, 0.69, 0.55, 0.41, $0.30\text{x}10^5$ i.e., at five speeds respectively at 3,000, 2,500, 2,000, 1,500 and 1,100 rpm without Gurney flap to investigate the effect of Reynolds number. Static pressures on the vaneless diffuser hub and shroud are also measured for each speed at the following four flow coefficients, viz. ϕ=0.23 (below design flow coefficient), ϕ=0.34 (design flow coefficient), ϕ=0.45 (above design flow coefficient) and ϕ=0.60 (above design flow coefficient).

A 30 cm long brass angle of 1/8th inch side (3.175 mm) manufactured by M/s Special Shapes and is supplied by M/s Small Parts is cut into pieces of 20 mm length. One surface of the brass pieces is roughened using emery paper. Similarly the pressure surface of the impeller blade near its tip is roughened using emery paper. These brass pieces are attached to the impeller blade pressure surface near tip using instant glue Anabond. As both the surfaces of the brass pieces and impeller pressure surface near the blade tip are roughened, the brass pieces are rigidly fixed to the impeller pressure surface. The brass pieces stayed in place up to an impeller speed of 3,000 rpm. These brass pieces are Gurney flaps as shown in Fig. 2. The height of the Gurney flaps corresponds to 15.9% of impeller blade height at exit or 5.1% of blade spacing at the impeller tip. Then the performance tests carried for baseline configuration without Gurney flap are repeated with Gurney flap to determine the effect of Gurney flap on the performance of centrifugal fan. Static pressures on the vaneless diffuser hub and shroud are also measured for Reynolds numbers 0.69, 0.55, 0.41, 0.30x10^5 (2,500, 2000, 1500, 1100 rpm) at four flow coefficients, viz. ϕ=0.23 (below design flow coefficient), ϕ=0.34 (design flow coefficient), ϕ=0.45 (above design flow coefficient) and ϕ=0.60 (above design flow coefficient) for configurations without and with Gurney flap.

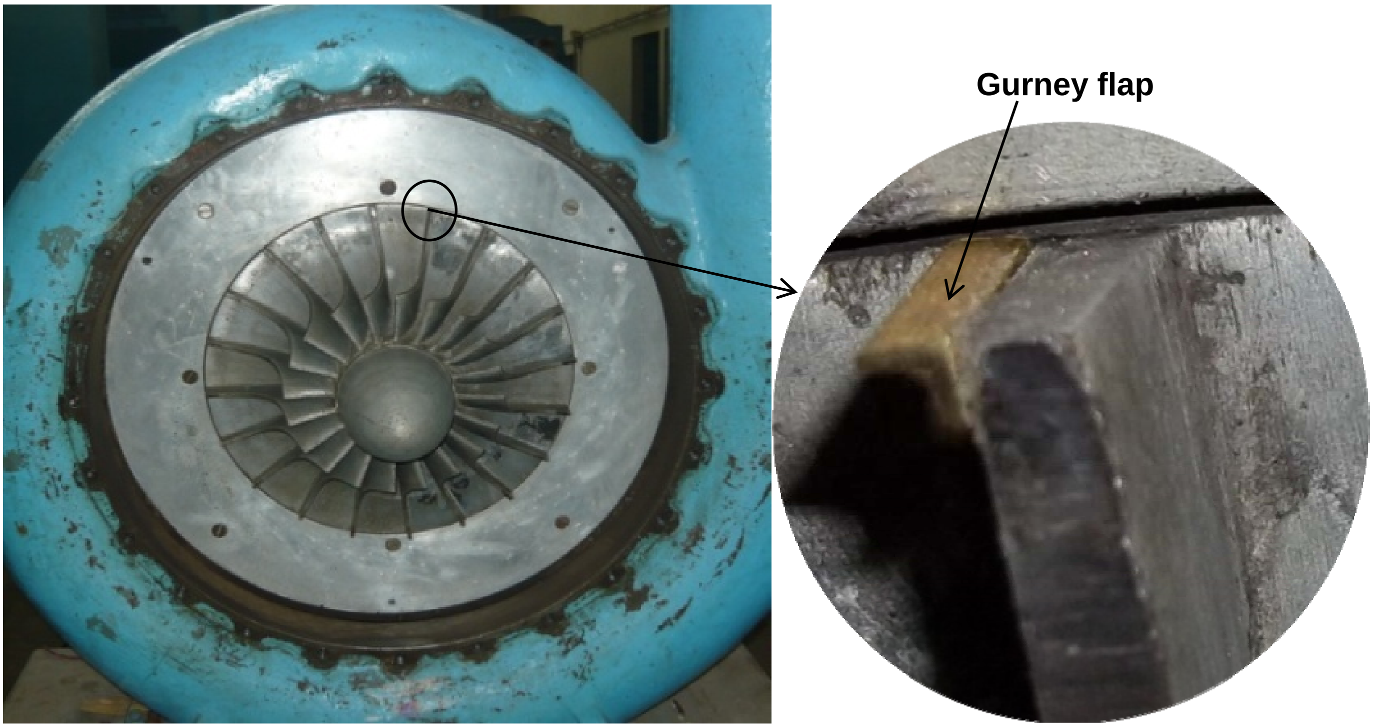


Fig. 2 Impeller blade tip with Gurney flap

3. Results and Discussion

3.1 Effect of Reynolds number on performance

Performance characteristics without Gurney flap: The performance characteristics for baseline configuration without Gurney flap in terms of non-dimensional parameters, energy coefficient (ψ) vs. flow coefficient (ϕ) at Reynolds numbers of 0.82, 0.69, 0.55, 0.41, 0.30x10^5 are presented in Fig. 3. There is a considerable effect of Reynolds number where the fan exhibits lower operating range w.r.t. $\phi_{\text{instability point}}$ at lower Reynolds numbers as shown in Table 2. The trends for all Reynolds numbers are similar in nature but higher differences in energy coefficient values can be observed at mid peak regions of the curves.

Performance characteristics with Gurney flap: The trends of performance parameters are similar in nature with Gurney flap as shown in Fig. 4. But the values of energy coefficient exhibited at the higher Reynolds number flows 0.82, 0.69x10^5 (3,000 and 2,500 rpm) are surprisingly lower compared to those at the lower Reynolds numbers of 0.55, 0.41, 0.30x10^5 (2,000, 1,500 and 1100 rpm respectively). It is also seen that the operating range exhibited at different Reynolds numbers varies significantly and does not follow any specific trend as shown in Table 2. However the fan exhibits highest operating range at the lowest Reynolds number of 0.30x10^5 (1,100 rpm) and lowest operating range at the highest Reynolds number of 0.82x10^5 (3,000 rpm).

3.2 Effect of GF on performance

Performance characteristics without and with Gurney flap for Reynolds numbers of 0.30, 0.41, 0.55, 0.69, 0.82x10^5 (1,100, 1,500, 2,000, 2,500, 3,000 rpm respectively) are presented in Fig. 5. The energy coefficient for the fan with GF is higher than that for the fan without GF for almost complete flow coefficient range. At low Reynolds number the difference is higher, whereas only small increase is found in case of high Reynolds numbers of 0.69x10^5 and 0.82x10^5 corresponding to 2,500 and 3,000 rpm.

Table 2 Comparison of important performance parameters without and with GF

N (rpm)	Re_{b2}	$\phi_{instability\ point}$		ϕ_{op}	
		w/o GF	with GF	w/o GF	with GF
1,100	$0.30x10^5$	0.311	0.252	0.521	0.612
1,500	$0.41x10^5$	0.291	0.295	0.563	0.584
2,000	$0.55x10^5$	0.311	0.312	0.550	0.578
2,500	$0.69x10^5$	0.281	0.282	0.584	0.600
3,000	$0.82x10^5$	0.262	0.290	0.588	0.574

ϕ_{op} : Operating range = ϕ_{max}-$\phi_{instability\ point}$

$\phi_{instability\ point}$: Flow coefficient where there is a sudden drop in energy coefficient

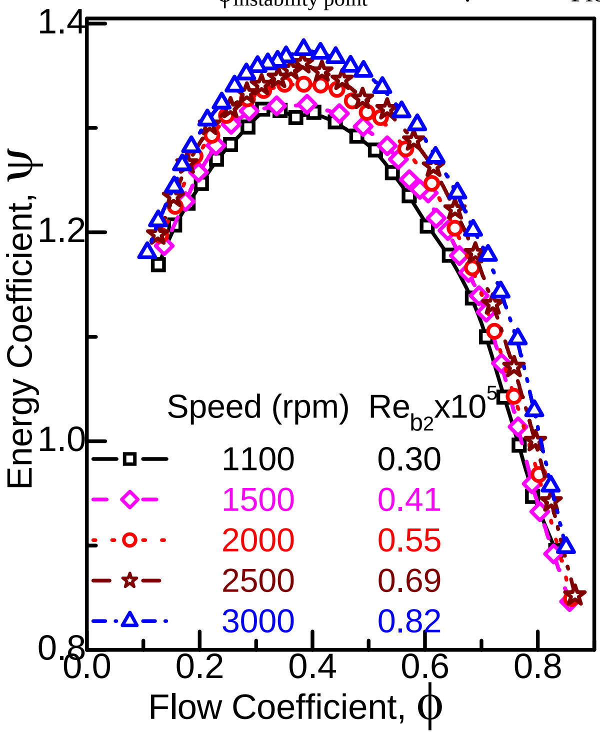


Fig. 3 Effect of Reynolds number on energy coefficient of centrifugal fan without GF

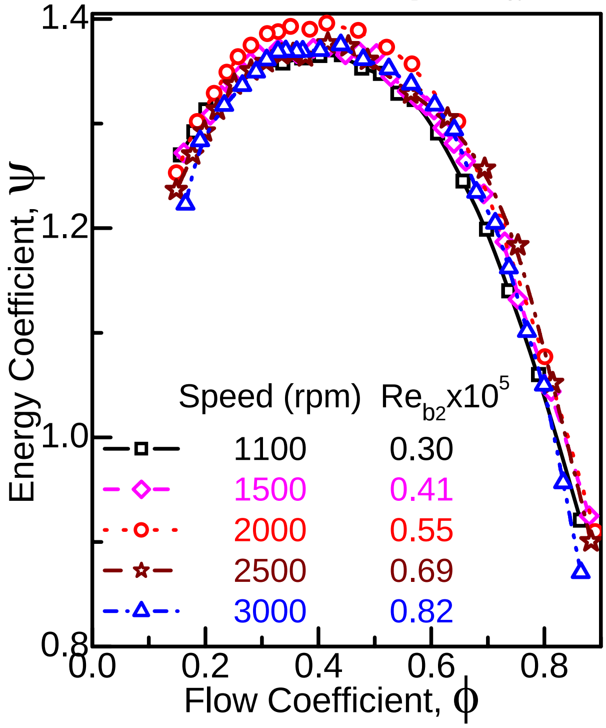


Fig. 4 Effect of Reynolds number on energy coefficient of centrifugal fan with GF

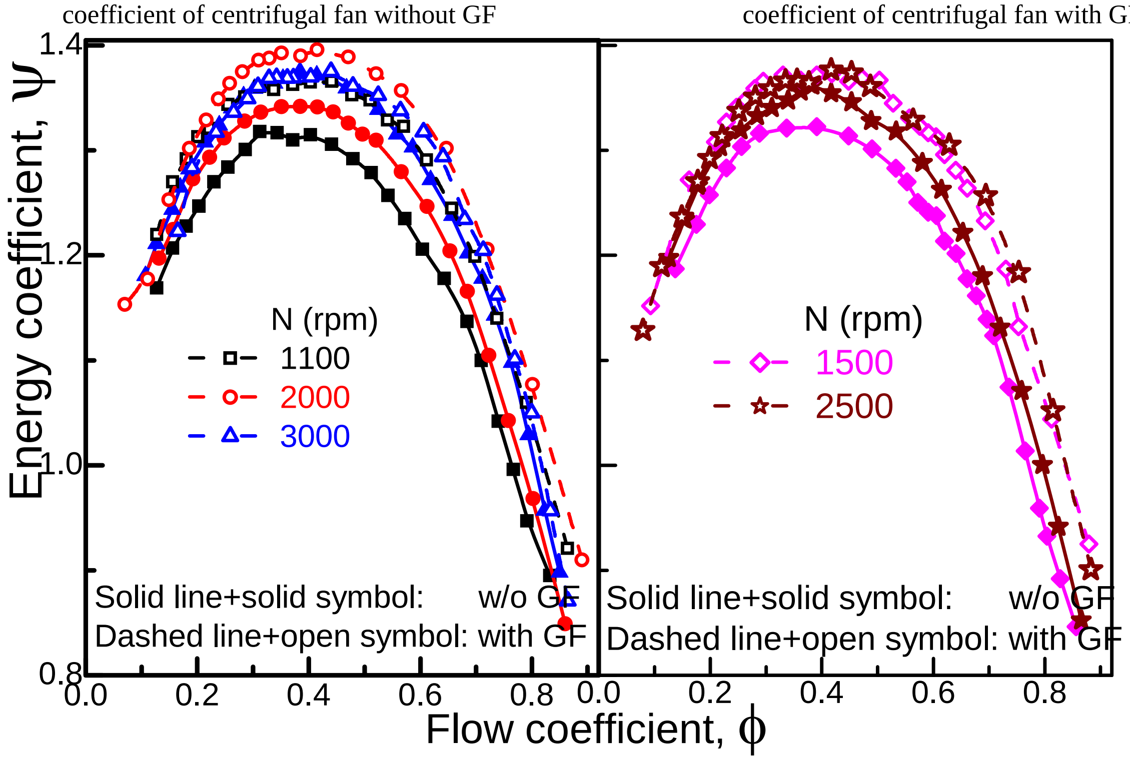


Fig. 5 Comparison of energy coefficient of the centrifugal fan without and with GF

3.3 Effect of Reynolds number on diffuser hub and shroud static pressures

Static pressure is measured on the diffuser hub and shroud at one circumferential location and seventeen radial locations at each speed for four flow coefficients, viz., ϕ=0.23 (below design flow coefficient), ϕ=0.34 (design flow coefficient), ϕ=0.45 (above design flow coefficient) and ϕ=0.60 (above design flow coefficient), without and with Gurney flaps. There is considerable effect of Reynolds number on static pressures on diffuser hub and shroud. For the sake of brevity, only representative results are presented. All the static pressure data are presented in Manoj Kumar Dundi [10]. More or less similar nature is exhibited for various Reynolds numbers for corresponding flow coefficients as shown in Fig. 6. Static pressure coefficient increases with radius for all flow coefficients at different speeds as flow diffusion occurs due to area increase. The values of static pressure coefficients on diffuser hub for corresponding flow coefficients for various speeds are higher than those on the diffuser shroud. However the difference is small at low flow coefficients. Static pressure increases continuously without any sudden change upto a radius ratio of about 1.25 on the diffuser hub and shroud. Then there is a sudden change in the slope of static pressure curve. Static pressure coefficient is generally higher as the Reynolds number increases. Trends for static pressure with GF configuration are similar as shown in Fig. 7.

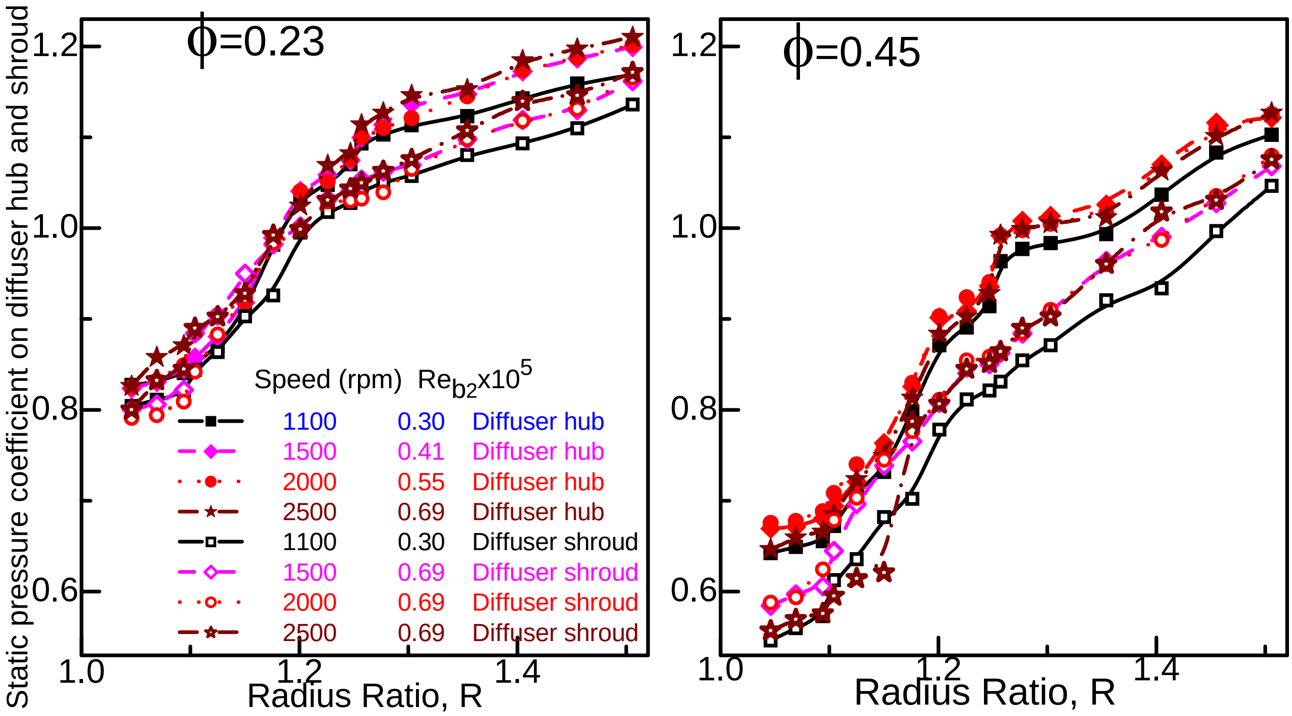


Fig. 6 Effect of Reynolds numbers on static pressure on diffuser hub and shroud without GF

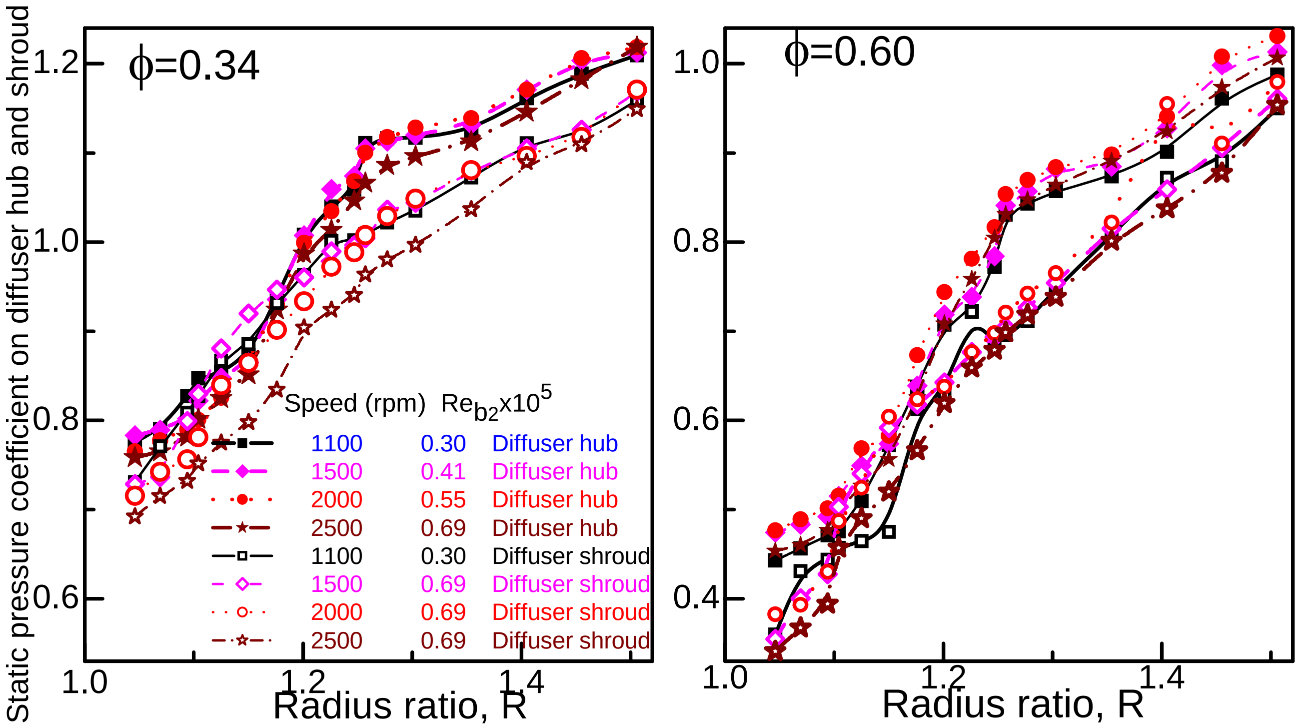


Fig. 7 Effect of Reynolds numbers on static pressure on diffuser hub and shroud with GF

3.4 Effect of Gurney flap on diffuser hub and shroud static pressures

The radial variation of static pressure coefficient on the diffuser hub and shroud is compared without and with Gurney flaps for representative flow coefficients and speeds in Fig. 8. In general static pressure on the diffuser hub and shroud is higher with Gurney flaps compared to the basic configuration of without Gurney flaps. However the difference is reduced as the Reynolds number increases with almost negligible difference at the speed of 2,500 rpm corresponding to a Reynolds number of 0.69×10^5. The results of static pressure correspond well with those of performance characteristics.

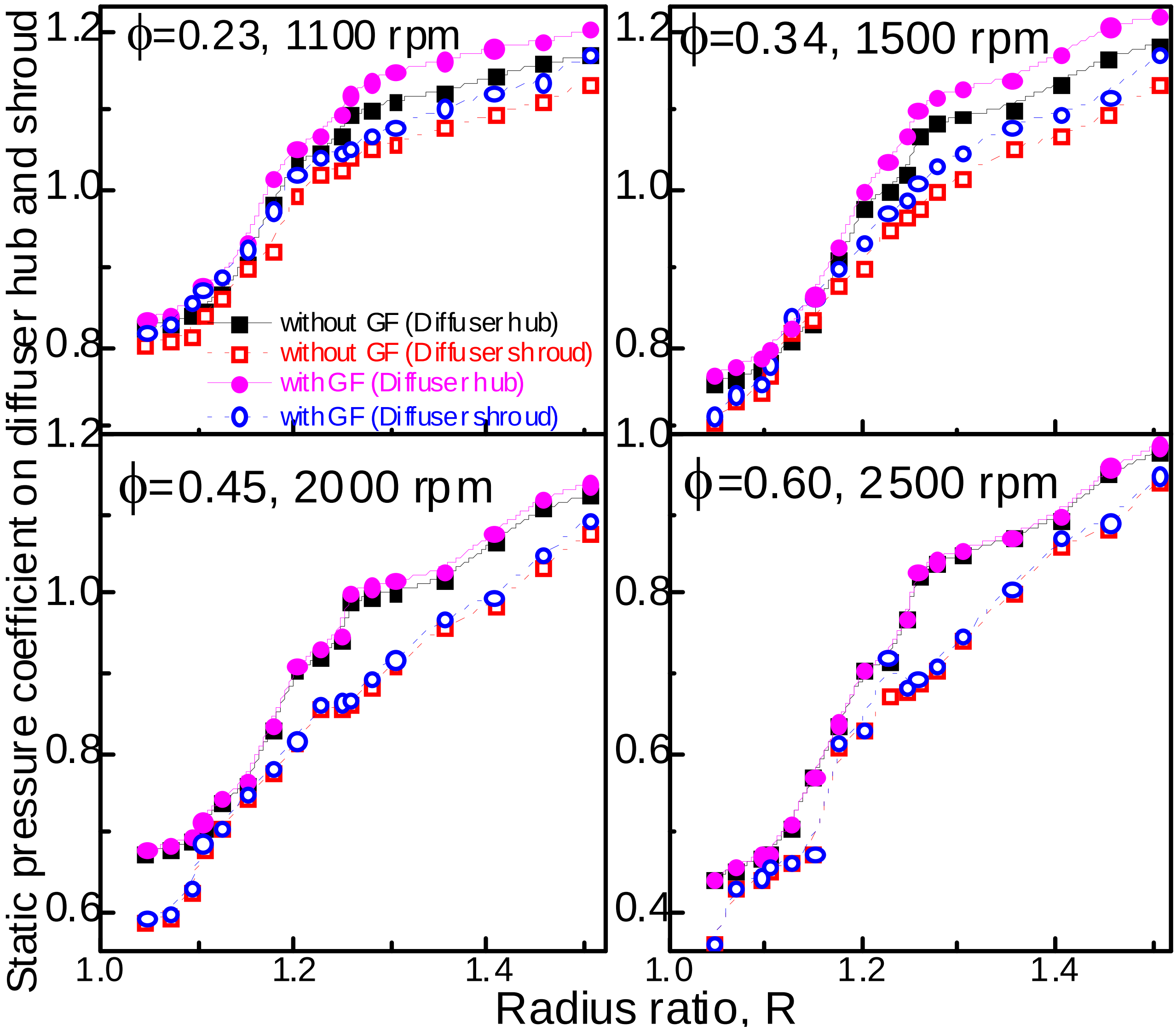


Fig. 8 Effect of Gurney flap on static pressure on diffuser hub and shroud

4. Conclusions

1. Performance tests on the centrifugal fan without and with Gurney flaps on the impeller blade tip have shown that the fan performance improves with Gurney flaps. In addition the maximum volume flow across the fan increases slightly with Gurney flaps. However the performance without and with Gurney flaps remains almost same at Reynolds number of 0.69×10^5 and higher Reynolds numbers.
2. The effect of Reynolds number on the performance parameters is as follows: At lower Reynolds numbers the impeller without Gurney flap shows lower operating range compared to the impeller with Gurney flaps. This difference decrease as the Reynolds number increases, with almost negligible difference at Reynolds number of 0.69×10^5 and higher Reynolds numbers.
3. Gurney flaps of 1/8th inch brass angle (3.175 mm), 15.9% of blade exit height are successful in producing higher values of energy coefficient for complete flow range at low Reynolds numbers. At the higher Reynolds number of 0.69×10^5 (2,500 rpm), the difference in static pressure without and with Gurney flaps is negligible.

Nomenclature

b_2	diffuser width (m)	W	specific work (m^2/s^2)
D_2	impeller tip diameter (m)	α	flow angle (Deg.)
GF	Gurney flap	ϕ	flow coefficient
N	speed (rpm)	ρ	density of air (kg/m^3)
r_2	impeller tip radius (m)	ν	kinematic viscosity (m^2/s)
r_3	diffuser outlet radius (m)	ψ	energy coefficient
R	radius ratio (r_3/r_2)	ψ_{ws}	static pressure coefficient on diffuser hub and shroud
Re_{b_2}	Reynolds number based on impeller blade height at exit (U_2b_2/ν)		
U	blade speed (m/s)		
V	volume flow (m^3/s)		

Subscript

1	impeller inlet
2	impeller exit

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