3rd Asian-Pacific International Symposium on Combustion and Energy Utilization

Geometrical Parameters for Flows Across Axial Swirlers

H.S. COUTO
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

W.F. MUNIZ
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

D. BASTOS-NETTO
Combustion and Propulsion Laboratory, National Space Research Institute, Cachoeira Paulista, SP, Brazil

Abstract

It is well know that the general trend in the design of modern industrial plants for energy generation, naval propulsion, incinerators and aircraft turbines is to employ swirlers as flame holding devices, as these equipaments do not suffer as much as the bluff bodies or screens from the exposure to elevated temperatures while still showing good behavior in the flame holding action. This paper presents expressions for the performance parameters of industrial axial swirlers with fixed (welded) blades and of those with continuously variable pitch angle.

Keywords: swirling flows, axial swirlers, flame holding.

INTRODUCTION

Although there exist a large number of devices being used as flame holders coupled to industrial burners which are blunt bodies such as spheres, inverted cones and cylinders or screens, there is no general theory available for the design of these equipments, which are then built from empirical techniques and rules[1,3]. Besides, the flame holding action achieved with these elements leads to large pressure losses and to a sure abrasive action and corrosion processes upon them[2]. Thus, the general trend in the design of modern industrial plants for energy generation, naval propulsion or incinerators is to employ swirlers as flame holding devices, as these

INPE
LCP - BIBLIOTECA

equipments do not impose large pressure losses in the flow field neither suffer as much as the blunt bodies from the exposure to elevated temperature while still showing good performance as flame holders[2,3]. Axial swirlers in particular are widely used in industry. This paper establishes analytical expressions for the permeability and the blockage coefficient[2] for industrial axial swirlers with fixed 'welded' blades as well as for axial swirlers with continuously variable pitch angle. It also shows the influence of the several geometrical variables upon these parameters.

SWIRLER CHARACTERISTICS

Consider a guide vane swirler in an axial tube flow as sketched in Figure 1, where r_h is the rub radius, r_3 is the duct inner radius, r_S is the swirler radius and α is the vane pitch angle. This is the usual case where only the secondary air flow is swirled, the primary flow (i.e., the fuel feeding system, if this were the case of a furnace air register) remaining unswirled.

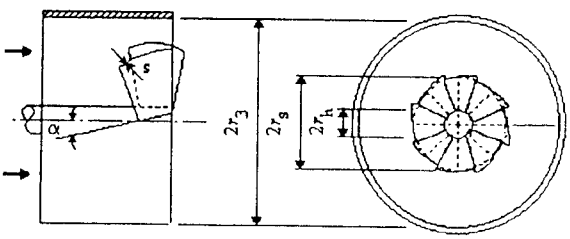

Fig.1 Axial Swirler

If A_S is the swirler swept cross-section, i.e.,

$$A_S = \pi\left(r_S^2 - r_h^2\right) \tag{1}$$

and A_{ef} is the effective air passage area through the swirler disk, then the swirler permeability μ, usually defined as the ratio between the actual mass flow through the swirler to the mass flow which would take place through it in the absence of blades, can be written as

$$\mu = \frac{A_{ef} - A_b}{A_S - A_b} \tag{2}$$

where A_b represents the existing air leakage area between the blades and the hub,

$$A_b = z\left\{\tan\frac{\pi}{z} - \frac{\pi}{z}\right\} r_h^2 \sin\alpha \tag{3}$$

For a swirler with z vanes of thickness s, the effective air passage area A_{ef}, can be calculated by subtracting from the air passage cross section, A_{SS}, the blocking area due to the blades finite thickness, A_f, and by adding A_b. Then:

$$A_{ef} = A_{SS} - A_f + A_b \tag{4}$$

where

$$A_{SS} = \pi\left(r_S^2 - r_h^2\right)\cos\alpha \tag{5}$$

and

$$A_f = z\,s(r_S - r_h)\cos\alpha \qquad (6)$$

If the flow Reynolds Number has small influence in the swirler blocking performance then one can also obtain C_B, a blockage coefficient, which will then depend on the problem geometry only. In this case:

$$C_B = \frac{1}{1-\sigma} \qquad (7)$$

where σ is a blockage factor,

$$\sigma = \left(\frac{A_S - A_{cf}}{A_3 + A_S}\right) \qquad (8)$$

A_3 being the air passage cross-section outside the swirler,

$$A_3 = \pi\left(r_3^2 - r_S^2\right) \qquad (9)$$

Notice that σ is the ratio between the swirler blocking area and the air duct cross-section.

Finally, the most usual way of characterizing the swirl intensity is through the dimensionless ratio known as the swirl number[2], which, for the secondary flow, can be written as

$$S_S = \frac{G_\phi}{G_x(r_3 - r_h)} \qquad (10)$$

where G_ϕ is the axial flux of angular momentum, G_x is the axial flux of axial momentum, quantities which are conserved in swirling free jets or flames, and $r_3 - r_h$ is the air passage radii difference.

As the evaluation of G_x requires the knowledge of the flow velocity and static pressure profiles the swirl number S_S is normally substituted by $\dot{S}_S$, the alternative swirl number, given by

$$\dot{S}_S = \frac{G_\phi}{G_x(r_3 - r_h)} \qquad (11)$$

where $\dot{G}_x$ is G_x less the static pressure term[4].

As the primary air flow is unswirled, an overall alternative swirl number, $\dot{S}$ can be written as[4],

$$\dot{S} = \frac{1}{1+M_R}\dot{S}_S \qquad (12)$$

where M_R, the axial momentum flux ratio, is given by:

$$M_R = \frac{\dot{m}_p U_p}{\dot{m}_S U_S} \qquad (13)$$

where $\dot{m}_{p,S}$ and $U_{p,S}$ are the mass flow rates and axial velocities (assumed uniform) of the primary and secondary flows, respectively. Equation (13) can also be written as:

$$M_R = \frac{\dot{m}_p^2}{\dot{m}_S^2}\left(\frac{\rho_S}{\rho_p}\right)\frac{\left(r_3^2 - r_h^2\right)}{r_i^2} \qquad (14)$$

where r_i is the fuel injection radius and $\rho_{p,S}$ are densities of the

primary and secondary flows, respectively.

Assuming that the tangential component of the secondary air flow velocity, W, is equal to $U\tan\alpha$ and taking the incompressible flow approximation, then G_ϕ and G_x can be written as:

$$G_\phi = \left(\frac{2\pi}{3}\right)\left(\rho C_B U^2 \tan\alpha\right)\left(r_S^3 - r_h^3\right) \quad (15)$$

$$G_x = \pi\rho U^2\left(r_3^2 - r_h^2\right) \quad (16)$$

where C_B is the blockage coefficient given by Equation (7). Then Equation (11) becomes

$$S_S = \frac{2C_B\left(r_S^3 - r_h^3\right)\tan\alpha}{3\left(r_3 - r_h\right)\left(r_3^2 - r_h^2\right)} \quad (17)$$

RESULTS AND CONCLUSIONS

Equations (2) and (7) yield the behavior of the permeability μ, and the blockage coefficient, C_B, which then can be used in the design of an axial swirler. Figures 2 and 3 show μ and C_B vs r_S and α and Figures 4 and 5 show μ and C_B vs α for a continuously variable pitch swirler of radius $r_S = 78.5\,mm$. These figures also depict five isolated points for equivalent industrial swirlers with pitch angles fixed at 15°, 30°, 45° 60° and 75° respectively. The slight difference shown there is due to the fact that the efective air passage area through their disks is not given by Equation (4) anymore, but instead by the following equation:

$$A_{eff} = A_{SS} - A_f \quad (4a)$$

as it can be easily seen, for those swirlers have their blades welded to the hub.

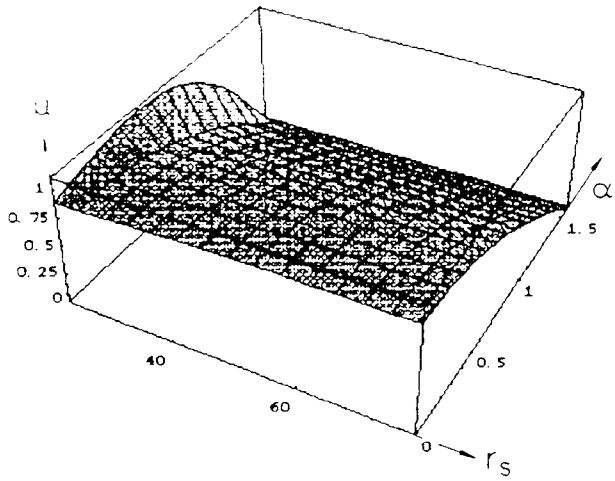

Fig.2 μ vs $r_S(mm)$ vs $\alpha(rad)$.

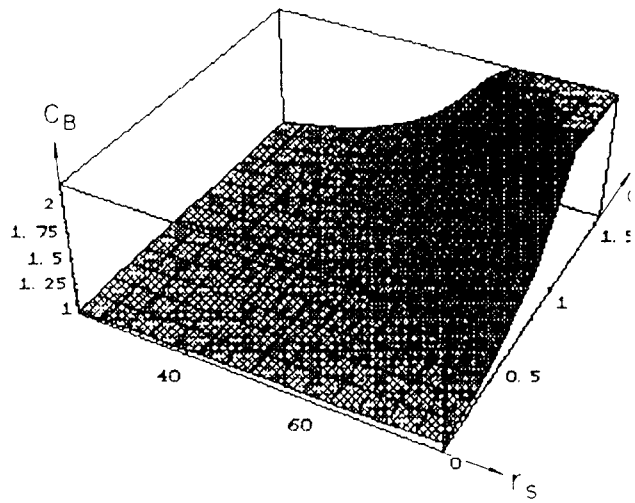

Fig.3 C_B vs $r_S(mm)$ vs $\alpha(rad)$.

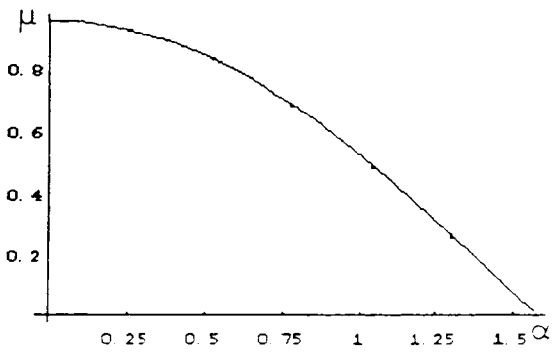

Fig.4 μ vs $\alpha(rad)$ for $r_S = 78.5\,mm$.

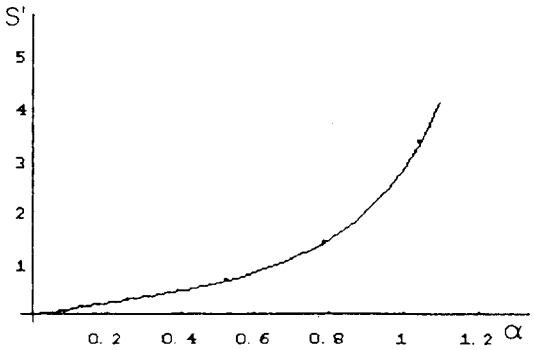

Fig.6 $\dot{S}$ vs $\alpha(rad)$ for $r_S = 78.5\,mm$.

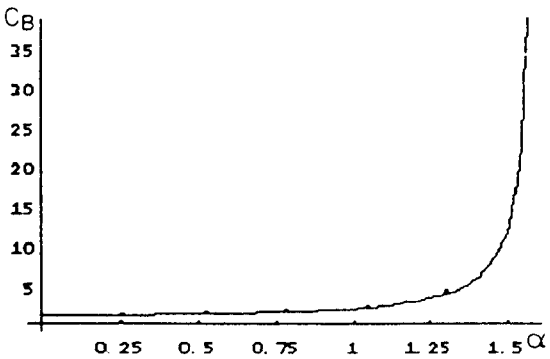

Fig.5 C_B vs $\alpha(rad)$, $r_S = 78.5\,mm$.

Equation (7) is then used in Equation (17) to obtain $\dot{S}_S$, and the alternative swirl number, $\dot{S}$, follows from Equation (12). Figure 6 shows the behavior of $\dot{S}$ vs the pitch angle, α, for the following conditions: $z = 8\,blades$, $s = 2.0\,mm$, $r_i = 2.5\,mm$, $r_h = 21.0\,mm$, $r_3 = 79.0\,mm$, $r_S = 78.5\,mm$, $\dot{m}_S = 180.0\,g/s$, $\dot{m}_p = 1.3\,g/s$, $\rho_S = 1.2\,Kg/m^3$ and $\rho_p = 2.1\,kg/m^3$. Those results led to the design and construction of an air register which performed precisely as predicted[5].

ACKNOWLEDGEMENT

The authors acknowledge the support received from CNPq (contracts No. 500140/92-8 and 301406/91-0) and FAPESP (contract No. 92/1138-8).

NOMENCLATURE

A_b - Air Leakage Area between Blades and the Hub Surface;

A_{ef} - Effective Air Passage Area across the Swirler;

A_{efi} - Effective Air Passage Area across a Swirler with Welded Blades;

A_f - Blocking Area due to Blades Finite Thickness;

A_S - Swirler Swept Cross-Section;

A_{SS} - Air Passage Area through the Swirler;

A_3 - Air Passage Area outside the Swirler Disk;

C_B - Blockage Coefficient;

G_ϕ, $\dot{G}_x$ - Axial Fluxes of Angular and Axial Momenta[4];

M_R - Axial Momentum Flux Ratio;

$\dot{m}_p$, $\dot{m}_S$ - Primary and Secondary Mass Flow Rates;

r_h, r_i, r_3, r_S - Hub, Injector, Duct and Swirler Radii;

$\dot{S}$ - Alternative Swirl Number

S_S - Swirl Number for the Secondary Flow;

$\dot{S}_S$ - Alternative Swirl Number for the Secondary Flow;

s - Vanes Thickness;

U_p, U_S - Axial Velocities of Primary and Secondary Flows;

W - Secondary Air Flow Velocity, Tangential Component;

Z - Vanes Number;

Greek Symbols:

α - Vane Angle;

ρ_S - Secondary Flow Density;

ρ_p - Primary Flow Density;

σ - Blockage Factor;

REFERENCES

[1] Winterfield, G., "On Processes of Turbulent Exchange behind Flame Holders", Tenth Symposium (International) on Combustion, The Combustion Institute, Pittsburg, Pa, pp. 1275, 1965.

[2] Beér, J.M. and Chigier, N.A. "Combustion Aerodynamics", John Wiley and Sons, New York, N.Y., 1972

[3] Syred, N., Chigier, N.A. and Beér, J.M. "Flame Stabilization in Recirculation Zones of Jets with Swirl",Thirteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pa., 617-624, 1970.

[4] Wall, T.F. "The Combustion of Coal as Pulverized Fuel through Swirl Burners", Principles of Combustion Engineering for Boilers, Lawn, C.J.,(Ed.), Academic Press, New York, N.Y., 197-335, 1987.

[5] Muniz, W.F.,"Study of a Vortical/ Axial Flameholder with Variable Angle Blades", (in portuguese), M.Sc. Thesis, INPE-5558-TDI/538, São José dos Campos, SP, Brasil, 1993.