GAS TURBINE MIXED JET FLOWS BASED ON THE COANDĂ EFFECT

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***Abstract**: In this paper are presented some analytical results regarding the mixing jet flow devices used in the gas turbine engines. Recent achievements in advanced ejectors, nozzles and air flow rate amplifiers are presented. Two cases of specific flows ejectors were studied: ejector with normal ejection and uniform speeds; ejector with peripheral ejection and non-uniform speeds in admission region. The analysis is based on the theoretically and experimentally characteristics of a typical axial flow engine elements. The paper deals with the theoretical quantitative and qualitative aspects of the Coandă phenomenon, in connection with the analytical Karman model.*

***Keywords:** Coandă ejector, Karman model, air amplifier, jet*

ρ = air density
H = force
φ = growth factor
C = a constant

A = surface
V, ,V_i ,V_e = speed
u = uniform speed
υ = distribution fact.

μ = coeff. of increase
α = unevenness
U = average speed
n = parameter

1. INTRODUCTION

The Coandă effect is a natural phenomenon. Since it occurs independently, it acts on the fluid flow in the vicinity of a divergent wall called airfoil and is characterized by strong asymmetry favored by the low pressure area in the rear of the airfoil [4]. According to specialized studies in aerospace, Coandă effect is successfully used to increase performance on lifting surfaces in morphing concept (flap, jet-slot), [7].

Henri Coandă identified an application of the effect during experiments with his Coandã-1910 aircraft. The motor-driven compressor pushed hot air rearward, and Coandă noticed that the airflow was attracted to the nearby surfaces. He discussed this matter with leading aerodynamicist Theodore von Kármán who named it the Coandă effect.

In 1934 Coandă obtained a patent in France for a "Method and apparatus for deviation of a fluid into another fluid".

The effect was described as the "Deviation of a plain jet of a fluid that penetrates another fluid in the vicinity of a convex wall" [4,9].

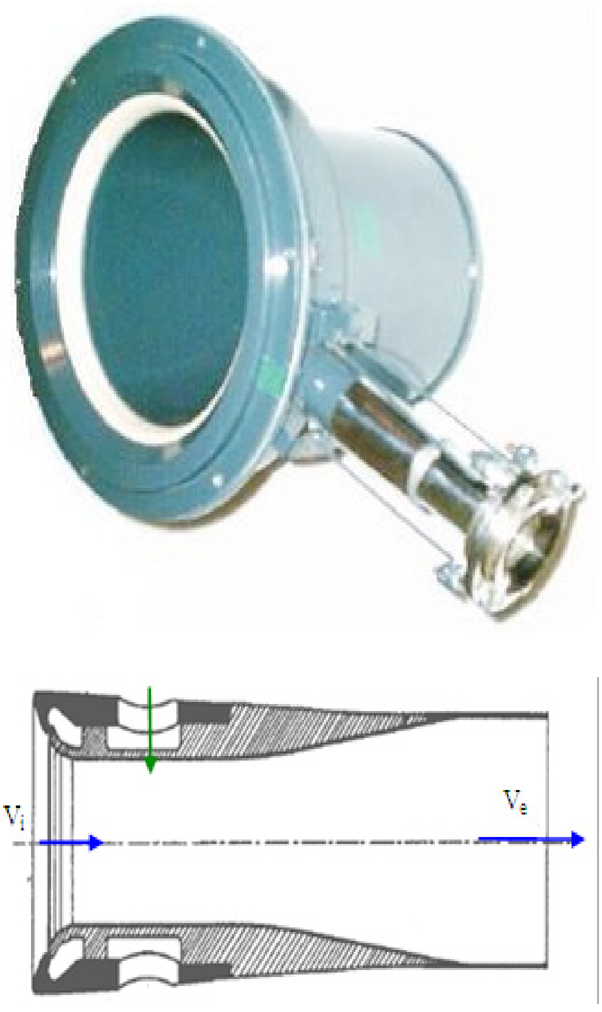


Fig.1 Coandă ejector [14]

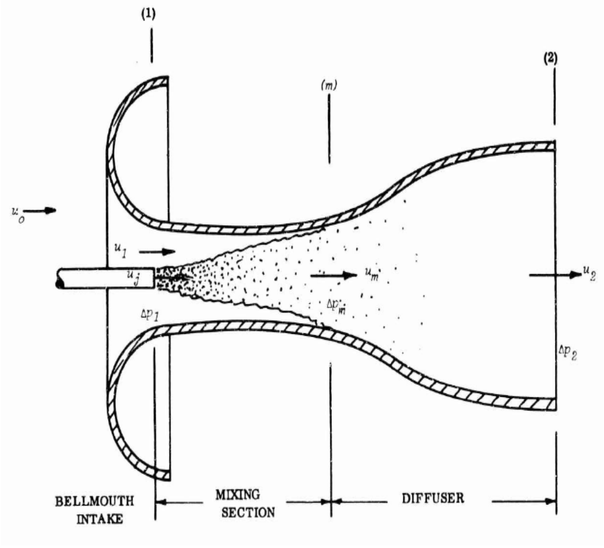


Fig.2Coandă ejector typical geometry [10]

Soon after discovering the phenomenon, the inventor Henri Coandă thought about controlling it and finding its limits through physical and mathematical calculations.

Due to its high complexity, he needed to contact other important theoreticians of the time. Theodore von Karman's model is presented below:

2. THEODORE VON KARMAN MODEL

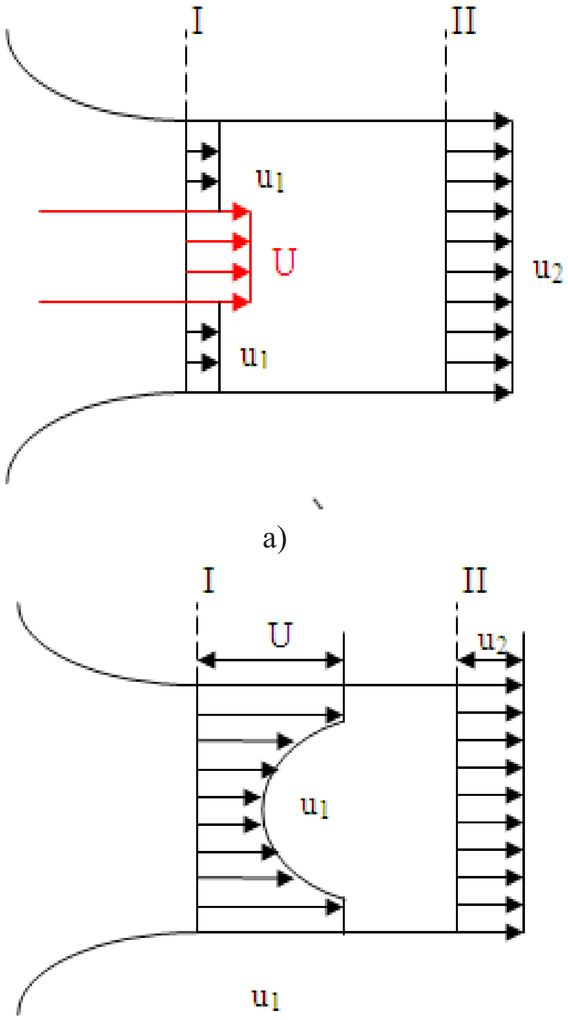
One of the most comprehensive theories belongs to Professor Theodore von Karman who analyzed theories about the Coandă effect and theoretical implications of increased traction.

The interior ejection device was at the basis of this analysis (figure 1 and 2).

Two cases of specific flows of two ejectors were studied:

- Ejector with normal ejection and uniform speeds in the calculation sections;
- Ejector with peripheral ejection and non-uniform speeds at admission point;

The coefficient for the increase of force H is defined as the fraction:



a)

b)

Fig. 3. Speed range in case of:
a) uniform speeds, b) non-uniform speeds (Karman, 1949)

It is defined to increase the force coefficient φ, (fig. 4) :

$$\varphi = \left(\frac{A}{a} + 1\right)\left(-\frac{a}{A} + \sqrt{\frac{a}{A}}\right)^2 ; \qquad (2)$$

and for non-uniform speeds :

$$u_1 = \text{const } R^n \, \lambda = \frac{(n+2)^2}{4(n+1)} \qquad (3)$$

for: a<< A

In both cases, section I is for analyzing the primary flow and the secondary one respectively, while section II is the area for mixing the two flows in section I.

To conclude on his analysis, the author indicates that the maximum value of the coefficient for the generated force (traction) theoretically equals 2, but it is difficult to obtain a value higher than 1.35.

In case of non-uniform speed distribution, where for λ =1, the distribution is uniform (*n*=0).A variation of n implies a variation of the value of λ and they both define the asymmetry of the flow in the admission section [2, 5].

3. ADDITIONS TO THE THEODORE VON KARMAN MODEL

Detailed and completed formulae and conclusions that can be obtained from the Theodore von Karman model are shown below speed range-distribution:

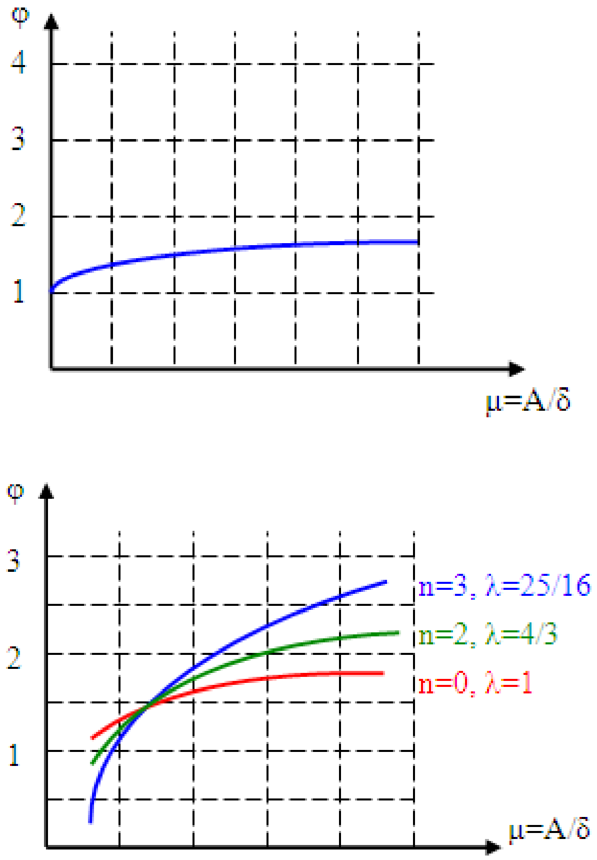


Fig. 4. Increase of force in case of distribution of: a) uniform speeds , b) non-uniform speeds (Karman,1949)

$$\frac{u_1}{U} = C\left(\beta + \eta^n\right) \text{ for } \eta = \frac{r}{h} \le 1;\ |\beta| < 1;$$
$$\frac{u_1}{U} = 1 \text{ for } r \le H \tag{4}$$

$$\left(\overline{\frac{u_1}{U}}\right) = \mathrm{C}\left(\beta + \frac{1}{1+\upsilon}\right);\quad \upsilon = \frac{n}{\varepsilon}\ ; \tag{5}$$
$$\varepsilon = \overline{1,2}$$

$$\left(\overline{\frac{u_1^2}{U^2}}\right) = \mathrm{C}^2$$
$$\left(\beta^2 + \frac{2\beta}{1+\upsilon} + \frac{1}{1+2\upsilon+\upsilon^2}\right) \tag{6}$$

where u= *n*/e,

C being a constant and b, available parameters.

For β = 0, the speed distribution is obtained where ε = 1 and ε = 2 in the axial-symmetrical case.

If we mark by ₭ the combined parameter which refers to both the degree of non-uniformity and the fraction of maximum and average speeds from the secondary flow, we get the quadratic equation in u^2/U.

$$\text{₭} = \lambda - \alpha\left(\frac{u_{1h}}{\overline{(u_1)}}\right)^2;\ \left(\frac{u_2}{U}\right)^2$$
$$\left(2-(1+\alpha)\Omega\right) + 2\alpha\Omega\left(\frac{u_2}{U}\right) - \frac{\alpha(2+\alpha\Omega)}{1+\alpha} = 0 \tag{7}$$

$$\left(\frac{u_2}{U}\right)_{1,2} =$$
$$\frac{\pm\alpha(\alpha+\alpha\Omega)}{(1+\alpha)\left(\sqrt{\Delta'} \pm \alpha\Omega\right)} = \frac{\sqrt{\Delta'} \mp \alpha\Omega}{2-(1+\alpha)\Omega} \tag{8}$$

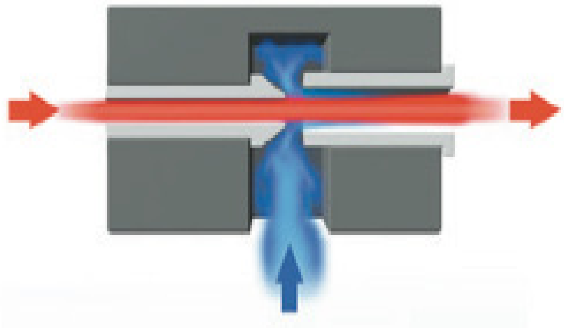
The conclusions of the author are that the jet trajectory is parabolic and the characteristics of the flow and of the forces that challenge the airfoil are influenced by the initial flow parameters as well as by the form of the airfoil [2, 5, and 11].

4. COANDĂ EFFECT APPLICATIONS

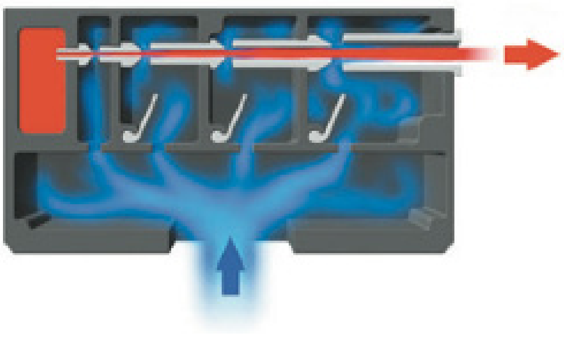
The Coandă effect due to its advantages has a number of applications such as: in aeronautics (blowing boundary layer) [8] and thrust vectoring [10];in transportation/handling, in injection molding and ventilation (vapors, smokes, and gases), silencers, and vacuum systems (loading and unloading), [3], see figure 5 and 6.

Table1. Values for ejector pumps [15]

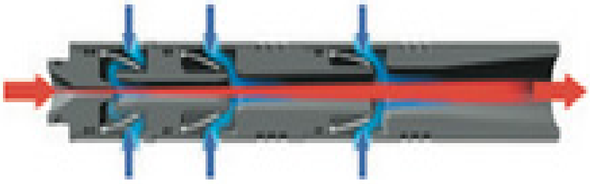
Units		*Vacuum level - Pa*					
		0	10^3	$20x10^3$	$30x10^3$	$40x10^3$	$50x10^3$
Displacement flow	l/s	10	10	10	10	10	10
	m^3/h	36	36	36	36	36	36
Free air	Nl/s	10	9	8	7	6	5
	Nm^3/h	36	32.4	28.8	25.2	21.6	18



Single stage ejector



Multistage ejector



Coaxial technology

Fig. 5 Compressed air-driven ejector pumps [7]

Table2. Features air amplifier [16]

Air supply – 80 PSI (5.5 bar)		
Input flow (Nl/min)	Output flow (Nl/min)	Velocity (m/s)
255	2124	277
142	1189	162
85	623	265

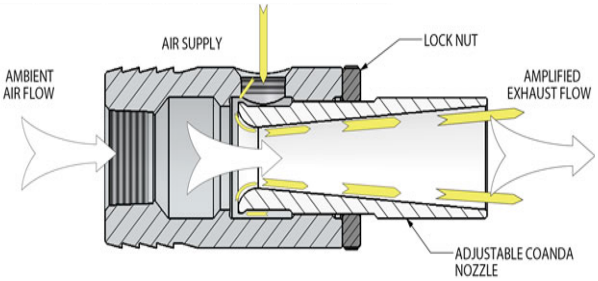
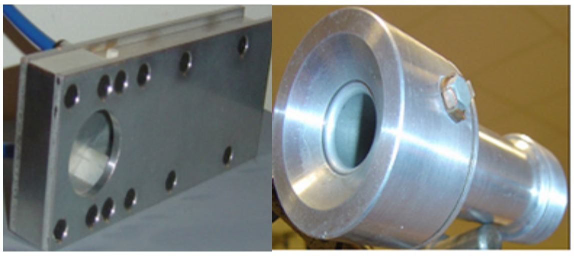


Fig.6 Air amplifier [16]



a) b)

Fig. 7a) ejector plan, b) cylindrical ejector

Such a system has recently been developed by a private Romanian company (AERODIN SRL, 2001) and obtained at 4.7x10^{6}Pa, a flow rate of 2750 m^3 /h at a pressure drop of 882Pa with a coefficient of ejection 60.

The lack of moving mechanical parts allows the movement of various categories of foul air. [6, 10, 13] A number of specialized references prove that the Coandă effect can be used for flow measurement solutions (as an example flow-meters based on oscillation flow principles are simple devices with generally no moving parts.

These flow-meters are limited to 4 inch pipe for a high measurement resolution [8, 12, 14].

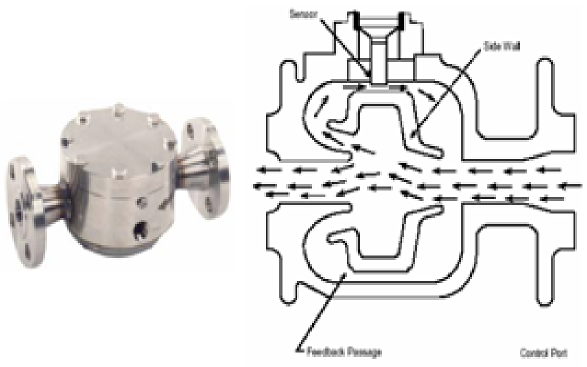


Fig. 8 Flow-meter [8]

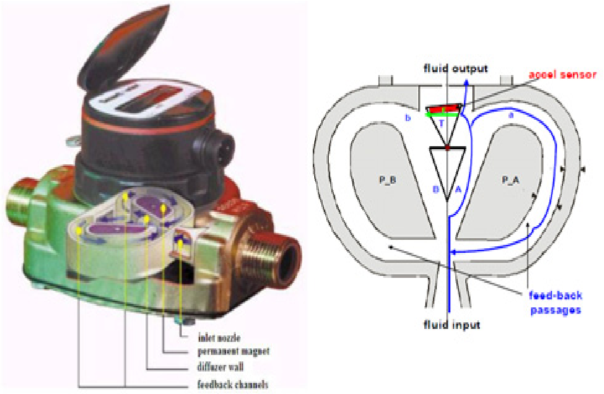


Fig. 9 Smartmeter Flow-meter [12]

CONCLUSIONS

Using the Coandă effect ejectors are able to entrain large amounts of ambient air without any moving mechanical parts.

By applying the Coandă effect, the flow that comes from a primary source (compressor, blower, fan, steam boilers, etc.) adheres to a wall of a shape specially calculated for this, determining the existence of a strong depressure drop.

Coandă nozzles are fed from a blower, compressor or fan of high pressure and low flow and were designed to amplify the primary flow 1,5-5-20-100 times depending on the geometrical configuration adopted.

Coandă nozzles geometries are diverse and vary depending on the application they are used. The diameter can vary from 20 mm to 1-2 m or even 10 m in special cases.

Coandă ejectors can reach lengths from 150mm to 120m 10-20m or in special cases.

The flows circulating in the order of 10-100-1000 m3 / h for the low and even ejectors 1,000,000 m3 / h for special cases.

The Karman model can be improved by introducing the new notation ₭ which allows quick solving of the quadratic equation which facilitates writing the analytical solutions for the power increase in the Coandă ejector.

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