Fluidic Elements based on Coanda Effect

Anniversary Session ***"Celebrating 100 year of the first jet aircraft invented by Henri Coanda"****, organized by INCAS, COMOTI and Henri Coanda Association, 14 December 2010, Bucharest, Romania*

Constantin OLIVOTTO*

*Corresponding author
SIMULTEC S.R.L.
Platforma Magurele, C.P. 24, Bucharest 077125, Romania
c.olivotto@simultec.ro
DOI: 10.13111/2066-8201.2010.2.4.21

Abstract: *This paper contains first some definitions and classifications regarding the fluidic elements. The general current status is presented, nominating the main specific elements based on the Coanda effect developed specially in Romania. In particularly the development of an original bistable element using industrial compressed air at industrial pressure supply is presented. The function of this element is based on the controlled attachment of the main jet at a curved wall through the Coanda effect. The methods used for particular calculation and experiments are nominated. The main application of these elements was to develop a specific execution element: a fluidic step–by-step motor based on the Coanda effect.*

Key Words: fluidic, bistable element on Coanda effect, power air jet wall attachment, step-by-step fluidic motor.

1. INTRODUCTION

On September 1, 1936 Henri Coanda, a Romanian scientist obtained an American patent [1] for "Device for Deflecting a Stream of Elastic Fluid Projected into an Elastic Fluid".

In the following years, many applications were developed using the Coanda Effect, especially concerning: aviation engine devices for thrust reversal, silencers for noise reductions of the reactive jets, ventilation and exhaust devices and many others technical procedures.

An important sentence was defined in this patent with many applications: **"The invention further relates to the application of the said process for the deflection of fluid streams which penetrate with a high velocity into another fluid. In particular, it relates to its application to the change of direction of the direct reactions due to the abrupt discharges of one fluid into another, which reactions are even greatly increases by the fact that on the side which is not checked, the effect of suction is very greatly increased".**

The Coanda Effect is in a simple description the tendency of a fluid to adhere to a curved surface because of the reduced pressure caused by the flow acceleration around the surface. This effect of attachment can be controlled either by injecting a thin jet of fluid tangential to the curved surface, or by acting with a control jet forcing the main jet to attach at the wall.

Between the '50s and '60s many efforts have been made by researchers worldwide in order to control the fluid jets and to obtain the change of directions without acting on them with moving parts or other devices. The solution was the use of Coanda Effect and the results start to be achieved. A new discipline called **Fluidics** and a multitude of **fluidic elements** began to be developed. The main scope of all this new field of automatic control is to develop devices, specially designed with motionless fixed parts, but capable to do all the functions of the electronic devices: oscillators, amplifiers, logic element, action motors and others.

According to an actual definition **"fluidics is a branch of engineering and technology concerned with the development of equivalents of various electronic circuits using movements of fluid rather than movements of electric charge. The basic devices used in fluidics are specially designed valves that, like transistors, can be arranged to act as amplifiers and logic circuits. The principal advantage of fluidic systems is that they can be designed to tolerate conditions under which electronic systems could not possibly operate. For example, a fluidic system could operate in the exhaust of a rocket, using the exhaust as its working fluid. Fluidic systems are also advantageous where the system output is to be a flow of fluid, as in a carburetor".**

This definition gives a general approach and explains the main interest for these solutions.

2. THE GENERAL STATUS REGARDING THE FUIDIC ELEMENTS BASED ON COANDA EFFECT

The main idea was to use fluidic elements to control systems and devices in all technologies involving the use of fluids. The elements were simple in construction, had fixed parts, the manufacture price was attractive and they could be powered by almost any source of the fluid under pressure. An essential advantage was that the fluidic components were capable to work a lot of time under extreme environmental conditions (in the presence of electro-magnetic or nuclear radiations) and having motionless parts the changes in time of the operation were not important.

After a period of intense development in the 60s and 70s, when a lot of scientific papers and elements was developed and yearly congresses are held, a long period of silence succeed and the main achievements in the automatic control field were made using computers and electrical devices.

Now, after many years the fluidics start again to be promoted, this time in specific applications when the electrical devices can be replaced in terms of price and working conditions. This technology is used in applications when the main agent is a liquid or other fluid under pressure and in case when the systems work with air the technology is called some time pneumonic. The main applications of fluidic are in use as specific elements and systems in aircraft systems, missiles and spacecrafts or nuclear field.

Generally, the classification of the fluidic elements is done after the functions performed and based on the function phenomena mainly used.

Based on function the two main categories of fluidic elements are: analog and digital. The digital elements or logical elements operate on digital logic and the state at the output of the elements is „0„ or „1„. In the analog fluidic elements the fluid flowing from the pressure supply can be controlled proportionally in some limits by varying the characteristics of the fluidic input and thus a continuously correlation between the input and the output is obtained.

The classification after the function includes analog devices like:

– fluidic amplifiers in which low-value of input pressures or flows can control higher output pressures or flows.
– fluidic oscillators in which jet pressure or air quantities at different frequencies can be obtained by varying an input.

Fluidic logic or digital elements like:

– fluidic bistable elements
– mono-stable elements.

The classification after the principles of operation divides the fluidic elements in three categories **[2]:**

– elements based on the jet interaction;
– attachment elements based on Coanda effect;
– vortex element based on the commanded transition of jet from a laminar regime to a turbulent regime.

In this paper the analyzed category of fluidic elements is the class of specific logical, general bistable elements based on the Coanda effect.

The general design for a fluidic element from this category is presented in fig.1 reproduced from a basic work in this field **[3].**

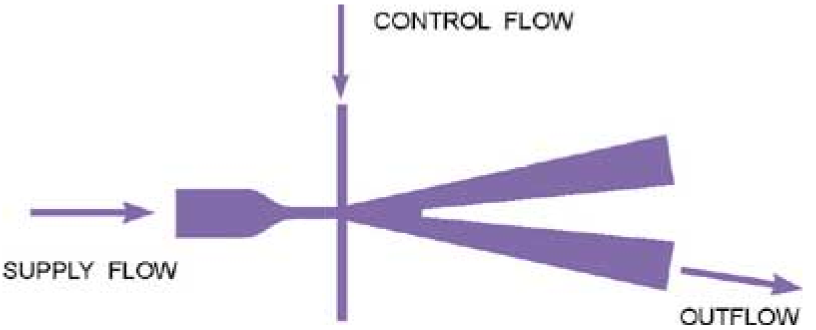

Fig. 1

The function of these elements is based on the Coanda effect who maintains the attachment of the main jet from the supply flow on the wall, producing an output flow at the end of the device. By changing the control flow or pressure it is possible to bascule the main jet of the flow on the other output of the device and to obtain a stable function again.

The process of the jet attachment is not so simple and the methods to switch the main jets are studied in many papers **[4, 5,].**

The construction of the element is simple, in general the element is done on a plate in which the aerodynamic configuration is engraved; a rigid plane plate fixed with screws is mounted on this plate and in its outer side there are some specific elements to assure the connections with the air supply and the fluidic inputs and outputs.

The main jet injected causes a low pressure region called “attachment bubble” near the curved surface of the wall and the jet attaches to the curved surface and stays in a stable state. If an injection of fluid air is applied from the opposite part by a jet or a change in the pressure, the main jet swings from the right wall to the other symmetrical wall and attaches in this new position. After passing the main symmetric center line of the elements the main flow will attach to the opposite and the control jet can be stopped, the new position being stable.

This class of fluidic elements was studied by many Romanian researchers and there are a lot of important works on this matter:

- A category of fluidic logic elements based on the Coanda effect was studied and developed at the “Politehnica” University of Bucharest. In the scientific works made by Dumitrache Ion **[6]** a specific theory for the analyses and syntheses of the logic fluidic systems is developed based on the attached jet, including general models for the logical function. The first fluidic logic element supplied with air at low pressure based on Coanda effect was calculated and realized, and based on some experiments a methodology for the use of these elements was developed.

- The Coanda Effect for air jets on specific walls and the commanded attachment of the different categories of jets was realized between 1970-1973 at the IMFA and INCREST institutes and many technical reports and specific devices using the jet attachment were made during this period. The studies were made by Savulescu Stefan, Zaganescu Florin **[7]** and Dumitrescu Horia and the general project was started and personally conducted for some time by Henry Coanda.

- The research group of Fluid Mechanics of the Technical University of Cluj-Napoca has developed starting from the 80s, an important number of research projects regarding the use of the fluidic elements in the automation of a refrigeration installation produced by Tehnofrig Cluj-Napoca. The main objective was to design and construct a bistable fluidic amplifiers functioning in a biphasic regime: with oil for the supply and air for the command **[8].** The contributions of Tarcea, D., Vaida, L., Mihalcea, D., Popa, M. are original and is of special interest for practical applications,

- The last but not least group of researchers in the use of the Coanda Effect in fluidics is located in Baia Mare. The papers done in the recent years by Cotetiu A., Cotetiu M. and Alexandrescu M. present a new solution concerning the implementation of the fluidic digital devices in the pressing strength control of a pneumatic rotating hammer drill. [**9**] The monostable element, designed and proposed by this team is a special device, with an incompressible fluid as main jet and compressible fluid as command jet.

In this part we point out only a preliminary review in short of the main scientific works made in Romania regarding the fluidics that use the Coanda effect, but the field of works is more developed and can include a large number of papers on this subject.

3. THE BISTABLE FLUIDIC POWER ELEMENT USING THE COANDA EFFECT

The efforts to develop new fluidic elements and new fluidic solutions for process control have led to a large diversity of elements and too many experiments all over the world and special in U.S.A. But the practical result regarding the use of the fluidic solutions was limited. The main cause for this situation was: the fluidics elements cover with specific functions all the general elements used in automatic control: a sensor, transducers, amplifiers, logic elements, switches but for the execution elements (that must act and develop active forces and moments in the process) the systems must be combined with electrical or hydraulic elements.

This situation has a lot of consequences:

– the general viability of the system was affected because the number of the components increases spectacularly,
– it induces in the automatic system a number of elements with moving parts, so the benefit of the fluidics was altered,
– it raises the general price by mixing elements from different technologies.

Between 1973-1979 a project in this field had been started and developed in Romania in order to design a class of fluidic execution elements using the Coanda effect. The scope was to obtain some elements able to be commanded and to act directly in the industrial processes, able to work specifically in contaminated area and nuclear applications where the intense radiations made impossible the use of the electronic computer components and other devices. The Romanian Committee for Nuclear Energy was the end user of this research project.

The start was done by some general measurements on jets and fluidic classical elements. The experiments was made in the IMFCA and INCREST Institutes and a hot-wire anemometrical measuring system was used in the experiments. The main task was in principal to develop a fluidic bistable element capable to respond at some specific conditions, namely:

- to use compressed industrial air at the normal industrial pressure (between 2-4 Bars) and quality,
- to have a simple design in order to be easy obtained with no special technologies,
- to have a specific method and algorithm for performances calculations in order to develop on this basis a class of execution fluidic elements.

Turbulent wall jets attachment at walls have been intensely studied on both theoretically and experimentally aspects, but in those time in the field of fluidic element working at industrial pressure the results were very few.

In this particular area some models and elements are significant:

- Newman (1961) proposed a flow model in order to estimate the reattachment distance, based on surface pressure measurements,
- Olson (1967) developed a theoretical model for attachment of the sonic and supersonic jet,
- F.Bavagnoli (1967) **[10]** developed a model for fluidic amplifier using supersonic and compressible fluids,
- Bourque (1967) and Perry (1967) made studies for modelling the flow in order to predict the jet reattachment distance,
- Sawyer, R.A.(1963) analised the two dimensional jet reattaching flows including the effect of curvature on entrainment.

Starting from theoretical models and based on some tested configuration in order to obtain power jet attachments on walls, the author developed in 1978 **[11]** an original configuration for a fluidic element based on the Coanda Effect.

The general design of this element is presented in fig. 2 where the best metal model is photographically presented.

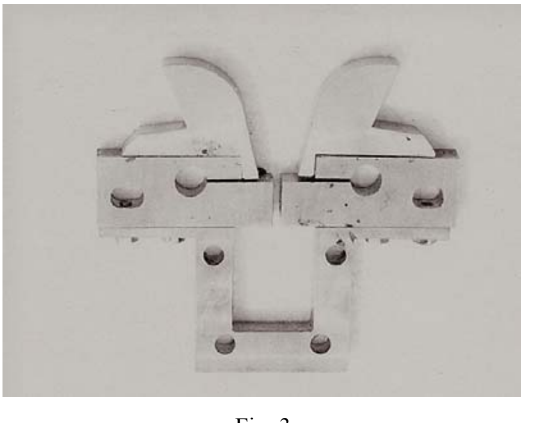

Fig. 3

One strong point of this configuration was the fact that the element has three stable positions. The main stable position was where the main jet was free and not attached to any wall and the others two stable positions were obtained when the main jet was controlled and forced to attach on the right or left wall.

The theoretical models used in order to obtain a good attachment and to design an optimal configuration for the curvature of the walls was:

– the Prandtl - Schlichting models for free air jets expansion from a rectangular nozzle in subsonic regime and the characteristics method when the jet passed the sonic conditions.

The use of two models was mandatory because the imposed regime of air supply pressure was between 2 Bar to 6 Bar.

– the Olson model of wall attachment for the Coanda Effect applied at sonic and supersonic jets.
– the model of the separation bubble near the main jet and the control of the attachment.
– All those models were integrated in an original computing programme that can be run on a PC Computer.

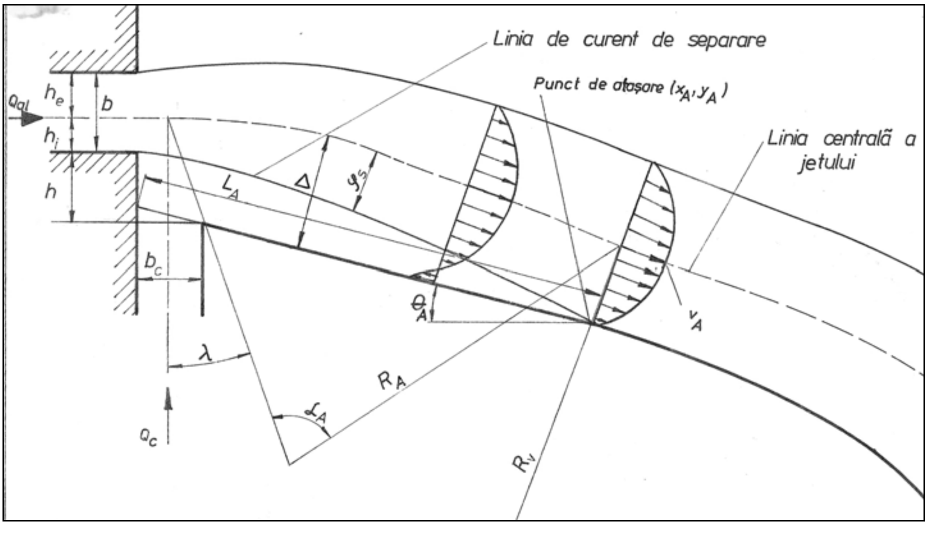

Fig.4

The input parameters where the values of the main parameters for the use of the new fluidic element geometrically presented in fig.4.

– the jet main air supply pressure,
– the ratio between two quantities: the mass of the control flow and the mass of main jet flow,
– the dimensions for main jet channel (nozzle) and the dimensions for the control channel,
– the radius of the wall curvature
– the angle of the wall.

The output results of the calculation for a determinate configuration were the value of the control air pressure, the pressure in the attachment bubble (this value is necessary for experiments because it is easy to measure) and the position of the attachment point.

The theoretical results of this computing program were confirmed with good approximation with the Olson results and with the results obtained by more recent studies made by Katz (1992) **[12]** and other researchers.

Based on the programme that was tested for 100 variants, around 20 configurations were selected.

For those 20 configurations it was decided to made experimental models and measurements on them and to test the proper functioning of the fluidic elements. In order to select the best configurations the method of factorial experimental is used (called the Box-Wilson method for programming experiments).

The tests were made on a structure of metal models as in fig .3 and the geometrical parameters selected to be changed are presented in fig.5.

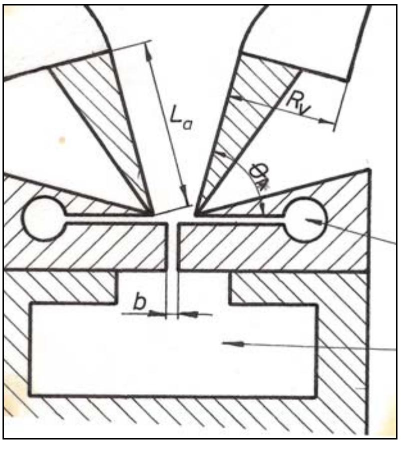

Fig.5.

The field of variation for those parameters was defined as:

- the supply air pressure for the main jet between 2 Bar to 6 Bar,
- the dimension of the main jet nozzle between 1 to 3 mm,
- the radius of the curved wall between 10 to 30 mm,
- the wall angle between 10 to 30 degrees.

The general results were cheeked with the theoretical results obtained by applying the Olson model and some good results of stable attachment were obtained for the 2 mm in dimension of the main jet nozzle and a radius of the curved wall between 30 and 40 mm. The depth of the channels was 10 mm.

In this experiment the speed profile in the attachment jet was investigated with hot-wire anemometer for the first time in Romania and the process of determination are difficult to make due to the little dimensions of the element and the high pressure of the jets.

Experiments in this field were made by Lai & Lu (1996) for a wall angle between 15°and 45° and a nozzle exit Reynolds number of 10,000, using constant temperature hot-wire anemometry. Another study of a flow on an inclined wall jet was conducted by the same authors Lai & Lu in 2000 by a new measure technology using a two - component laser Doppler anemometer (LDA) **[13].**

After those theoretical and experimental studies the optimised variant of fluidic element with three stable output positions for jet was ready to be used in some applications with switching time measured between 2 to 8 msec.

4. THE FLUIDIC STEP-BY-STEP MOTOR

The second step after the studies made theoretically and experimentally confirmed was to design an execution device capable/able to use the fluidic element based on the Coanda Effect. The original solution was to utilise the force developed by the jet attachment at a curved wall. The first application on this effect was made by Teodorescu Constantin who designed and made experiments with a radial turbine based on the Coanda Effect [**14**]. Unlike others turbines the rotor was equipped with a structure of radial curved pallets. The air jet attached to this array of pallets through Coanda effect and the force developed on each pallet produce the rotation of the turbine.

Based on this force developed on the Coanda curved profile and with the fluidic element as main element **an original step by step fluidic motor** was developed. The motor was specially made to act in a corrosive medium and in a nuclear environment and its main advantage is that in its design there are not moving parts. The control to operate the motor step by step in both senses is done only by the air pressure acting in the command channels. Another advantage and original solution is that the whole rotor of the motor is sustained on air bearings and by this method the friction at the beginning of the motion is very low.

In fig 6. the general design of the step by step motor is presented.

The main components are according to the numbers:

- the central axe of the motor (1).
- the stator body (2)
- the control channels systems (3)
- the central body with Coanda pallets and the conduct for main air supply (4)
- the plate with four fluidic elements and the distribution of the air control and command (5)
- the end plate covering the fluidics elements (6)

The main advantages of this solution compared with electrical or hydraulic step by step motors are:

- when the fluidic motor is overcharged there is no damage of the device,
- by varying the air supply we can obtain a big variation of the rotor speed
- the step by step motor can be used as servo-motor with two sense of rotation with no change in construction,
- the total weight is less compared with some hydraulic or electrical devices.

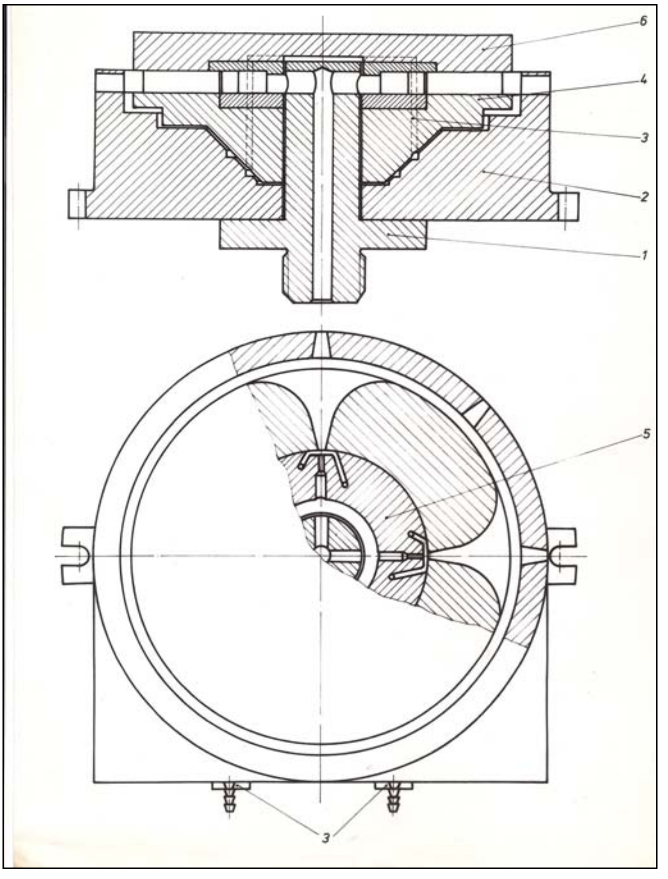

Fig. 6

Two variants of this device were executed according to the project, both with four fluidic elements. One was designed to work at low air pressure between 2 to 3 Bar and the other was designed to work in supersonic regime with air pressure over 3 Bar to 6 Bar; the results for the command and execution function are approximately the same as in the theoretical model. The only disadvantage of the solution was the high level of the noise generated in during operation due to the jet expansion.

5. CONCLUSIONS

1. The solution of fluidic elements using the Coanda Effect even for execution elements is possible and presents superior advantages over the existing solutions by his safety in operation in hostile environments.

2. The theoretical models and the calculation algorithm were verified and agree well with the experiments and for general condition the model predictions cover demands for the design of the fluidic elements. The general design for fluidic elements consists in using rectangular flow channels. The theoretical approach of the study meets the requirements of the technical design.

3. The direction to develop the fluidic element using Coanda Effect is not abandoned, some recent papers **[15], [16]** are the proof of a growing interest in this field.

REFERENCES

[1] *** US Patent # 2,052,869 , *Device for Deflecting a Stream of Elastic Fluid Projected into an Elastic Fluid,* Henri Coanda Sept. 1, 1936.

[2] G. Besterling, *Fluidic System Design*, John Wiley and Son, New York, 1974.

[3] R. P. Roger and S. C. Chan, *Numerical study of fluidic Bistable Amplifier*, 33rd AIAA Fluid Dynamics Conference, Orlando FL.USA, June 2003.

[4] C. Bourque, *Reattachment of a two dimensional jet to an adjacent flat plate*, Advances in Fluidics, ed. by F. T. Brown, ASME, New York, 1967.

[5] K. Ayukawa and T. Shakouchi, *Analysis of a jet attaching to an offset parallel plate (1st Report, Oscillation of a jet*), Bulletin of the JSME, 19(130), 1976.

[6] I. Dumitrache, *Proiectarea asistata de calculator a elementelor si circuitelor fluidice numerice*, E.E.- Automatica si Electronica, 20, nr.4.1976.

[7] F. Zaganescu, *Unele particularitati aerodinamice ale elementelor pneumonice cu jet*, Revista Transporturilor, No.10, 1966.

[8] D.Tarcea, L.Vaida, D. Mihalcea, M. Popa, M., *Studiul experimental al unui element fluidic bistabil, funcţionând ca amplificator de putere, cu jet de alimentare lichid şijet de comandă gaz*. A X a sesiune de comunicări şi referate, a I. M. Aiud, iunie, 1987.

[9] A. Coteţiu, *Studii şi cercetări asupra elementelor fluidice utilizabile în instalaţiile miniere*, Teză de doctorat, 1998.

[10] F. Bavagnoli, *Sul punto di riattacco di una strato-limite supersonico turbulenta a valle di uno scalino*, Aerotecnica, Fasc.4, 1967.

[11] C. Olivotto, *Contributii la studiul si aplicativitatea elementelor fluidice bazate pe efect Coanda*, Teza de doctorat, 1978

[12] Y. Katz , E. Horev, and I. Wygnanski, *The forced turbulent wall jet*, J. Fluid Mech., 242, 1992

[13] J.C.S. Lai, and D. Lu, *Effect of wall inclination on the mean flow and turbulence characteristics in a two-dimensional wall jet,* Int. J. Heat & Fluid Flow 17(4), 1996

[14] C. Teodorescu, *Asupra unu nou principiu functional in teoria turbinelor cu gaze bazat pe efectul Coanda: turbine cu palete depressive,* Studii si cercetari de mecanica aplcata, Tomul 24, 1967.

[15] D. Feikema and D.Culley, *Computational Fluid Dynamic Modeling of a Fluidic Actuator for Flow Contr*ol, AIAA–2008–557, 46th AIAA Aerospace Sciences Meeting and Exhibit, January 7–10,2008, Reno, NV.

[16] V.Tesar, C.H. Hung, and W.B. Zimmerman, *No-moving-part hybrid-synthetic jet actuator*, Sensors and Actuators A, Vol. 125, 2006.