AUTOMATIC CONTROL OF FLAPS IN A TRANSONIC WIND TUNNEL INSTALLATION

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Abstract. *The Pilot Transonic Wind Tunnel (PTT) from the Institute of Aeronautics and Space (IAE) is a conventional closed-loop wind tunnel, continuously driven by a main compressor at a Mach number range from 0.2 to 1.3, and it has automatic controls of stagnation pressure from 0.5 bar to 1.2 bar, temperature and humidity. The test section with 0.25 m x 0.30 m and length of 0.82 m has adjustable sidewalls in divergent angles up to 0.5 degrees. All the test section walls have longitudinal slots with geometries specifically planned for a uniform Mach number distribution in it. The flaps panels are installed in opposite walls just after the test section with a height of 0.25 m and length of 0.40 m. The original flaps angle opening is manually adjustable by means of wheels that command a worm screw. A transonic tunnel distinction is the presence of the openings at the test section walls, which allows the transonic flow regime establishment, avoiding the aerodynamic choking, as well as reducing the wall interferences and the shock wave reflections at the transonic test range (Mach number from 0.8 up to 1.2). The pressure is equalized in the surroundings of the test section walls by the plenum chamber pressure control, resulting in a well behave mass flow exiting through the slots. The flow returns to the main stream after test section through the flaps, by "Venturi" effect. Changing the re-entry flaps opening, the quantity of extracted mass through the slots varies. This way, it is possible the use of the first throat with sonic geometry to obtain supersonic flow. In some cases it is necessary a forced mass extraction of the Plenum Chamber by a dedicated compressor to this condition in combined use with the opening flaps angle. At the PTT case, the forced extraction up to 2% of the main flow permits flows with Mach number about 1.2 at the test section. Further, the PTT use this idea to enable tests of models with large blockage ratio. In the original installation it is necessary to stop the test process to, manually, act at the flaps. In transonic tunnels, it is important to operate them remotely to investigate optimum test conditions for each configuration. For example, varying the angle of attack during the test, it can be necessary the flaps adjustment. This work shows the main characteristics of the components and the main steps used during the development of a project to the installation of a remote control system for the re-entry flaps, to improve reliability and productivity in the PTT tests. The step motor fixed on the tunnel structure will operate the flaps during the test, saving inestimable time and increasing the tunnel productivity. Some demonstrative tests are conducted to establish optimum operational conditions related to the flaps positioning to obtain good parameters distribution in the test section, being shown by the use of a pressure probe.*

Keywords*: Transonic Wind Tunnel, Flaps, Remote Control*

1. INTRODUCTION

A transonic wind tunnel facility is a complex installation constituting for a long time one of the critical issues of aerodynamic science. As stated by Von Kármán (Goethert, 1961), one can justify the difficulty to assess the transonic regime tests by a theoretical reasoning: purely subsonic and purely supersonic flows can be described by approximate solutions derived from linear differential equations, by scaling rules and fundamental flow properties analysis. However, in a transonic regime the measurements become highly dependent on the ratio between dimensions of the wind tunnel and the dimensions of the model, and the location of the interface between subsonic and supersonic regions, and that is why even today a comprehensive study of the problem of transonic testing has a great value. After 1950, a large number of transonic wind tunnels have been constructed in the world and many relevant works have been published (Davis *et al.*, 1986). Transonic wind tunnels have semi-open walls to allow mass flow extraction through them, basically in order to establish a continuous Mach number adjustment in transonic range (from 0.8 to 1.2), to prevent choking phenomenon, diminish the intensity of shock wave reflection and to control wall interference effects. Timely stable and spatially uniform Mach number distribution in test section is pursued to better reproduce flight conditions. These semi-open walls define either the slotted or the perforated type test sections. As a general rule, the slotted type is preferred whenever the main emphasis is placed on the subsonic speed range to slightly above Mach number one and the perforated type is preferred when the emphasis is placed on the supersonic range.

Good uniformity of the Mach number distribution along the test section in transonic range can effectively be achieved by using venting walls combined with pressure control in the surrounding plenum chamber, resulting in a well behave mass flow exiting through the openings, as schematically represented in Fig. 1 (Goethert, 1961). Basically there are two different ways to extract mass from test section: by means of an auxiliary compressor and by means of re-entry flaps. In the first case the control of the air removed from the plenum chamber can be easily accomplished with an auxiliary compressor by means of throttling valve which is independent of the main compressor power. In the second case the air can be spontaneously removed from the test section and readmitted to the main circuit by *Venturi* effect – flap aperture angle and plenum chamber pressure control the mass flow through walls. The method should not affect the Mach number distribution in the test section as long as the total mass removed from the test section remains the same. Only minor local differences can occur in the immediate vicinity of the suction device utilized. This way it is also possible to reach supersonic flow in the test section with sonic first throat. TTP incorporates these two ways of controlling the mass flow removal, as can be seen in Fig. 1. During the tests the use of re-entry flaps may be sufficient in most cases, however for models with higher blockage area ratio and at high Mach number the forced plenum chamber extraction (by using the auxiliary compressor) may be helpful, as long as care is taken no to exceed a certain limit beyond which it can occur non-uniformity in test section.

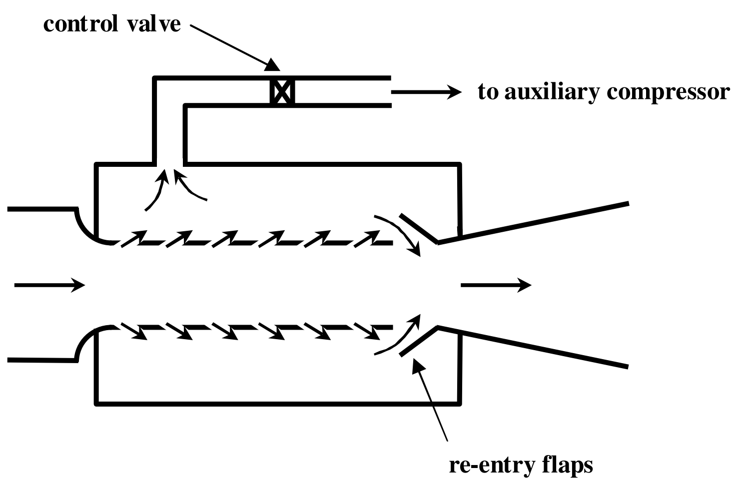


Figure 1. Different schemes for mass flow removal from the test section

There are other possible ways to modify Mach number distribution in the test section, as the diverged/converged wall settings, wall open area ratio, and variable porosity in the walls, which may be used simultaneously with the re-entry flaps positioning and plenum chamber pressure control to obtain an optimal condition. Although indispensable, a perfect match of all setting parameters of these devices is not easily achieved and it depends on the particular test article and its attitude. For example, the boundary layer thinning through the entire test section length, which is required for decreasing shock-wave reflection, is not attained only with pressure plenum control without proper walls convergence. Then, in order to contribute with the flow establishment in test section a remotely controlled flap system is highly desirable. The concern of flap operation in a transonic wind tunnel can be seen by a relevant numerical study of Fico Jr. and Ortega (1991), a team member of TTP (Pilot Transonic Wind Tunnel) at the time.

The Pilot Transonic Wind Tunnel (TTP), installed in the Aerodynamic Division (ALA) of Institute of Aeronautics and Space (IAE), is a modern conventional closed-loop transonic facility, continuously driven by a main compressor at a Mach number range from 0.2 to 1.3, and it has automatic controls of stagnation pressure from 0.5 bar to 1.2 bar, temperature and humidity. The test section with 0.25 m x 0.30 m and length of 0.82 m has adjustable sidewalls in angles up to 0.5 degrees. The tunnel has also an injection system which operates in intermittent mode combined with the main compressor action to enlarge the operational envelope without increasing the installed compressor power. Figure 2 shows a diagram of the Plenum chamber with devices idealized to perfectly establish the flow into a transonic test section: the first throat which accelerates the flow to the test section condition, the slotted test section in which the test article is mounted, the re-entry flaps section, the second throat to adjust conditions whenever supersonic tests are performed, and the injector section. There are ten injector beaks which operate in a choking condition at Mach number 1.9, to transfer momentum to the main stream. The Pilot tunnel is a scaled down 1:8 from an industrial facility intended for Brazilian Air Ministry to support the aeronautical research and development almost decades ago (Falcão Filho *et al.*, 2009). Because budget restriction, only the pilot facility could be built, which basically incorporates all the features of the industrial facility. Some constructive simplifications were also adopted, since it was not wanted a high productivity, like a manually adjusted re-entry flaps design. However, with the current use of the tunnel in support of various sectors of the IAE and universities it becomes necessary to increase the tunnel productivity. More details about TTP characteristics may be found in Falcão Filho and Mello (2002).

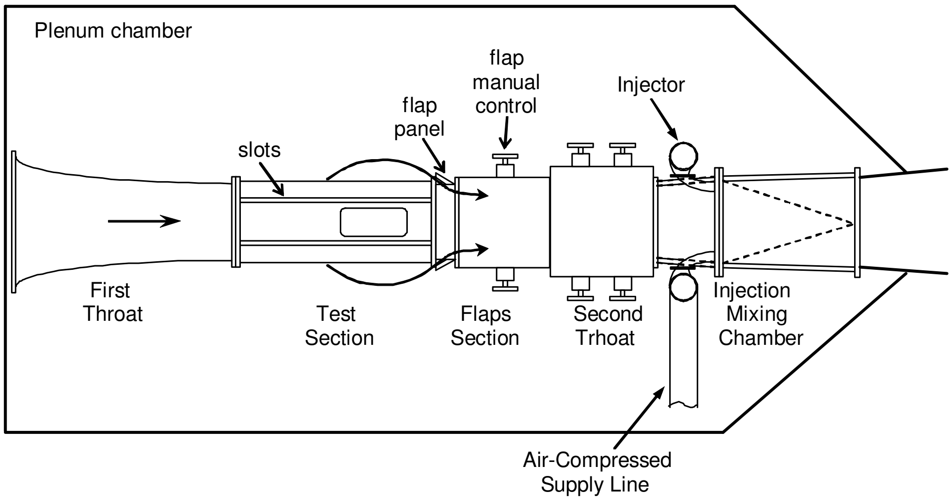


Figure 2. Detail of the Plenum Chamber inner parts

All the test section walls have longitudinal slots with geometries specifically designed for a uniform Mach number distribution in it. The flaps panels are installed in opposite walls just after the test section with a height of 0.25 m and length of 0.40 m.

The original flaps angle opening is manually adjustable by means of wheels that command a worm screw, as can be seen in Fig. 3 with the flaps closed (a), fully open (b), and the panel front (c) showing two shafts, one with a rotary lever to manually actuate the flap and another to align the panel when it travels in its hinges. In the test section there is a NACA 0012 profile installed in a vertical direction and note that the lateral wall of the test section was removed. In this installation it is necessary to stop the test process to, manually, act at the flaps manual command (Fig. 3(c)). Since the tunnel circuit is pressurized, this procedure is very tedious and time consuming. In transonic tunnels, it is important to operate them remotely to investigate optimum test conditions for each configuration. For example, at high angle of attack, it can be necessary flaps adjustment during the test.

(a) (b) (c)

Figure 3. Original installation: (a) flap closed; (b) flap open; (c) manual opening control.

The best available solution for this problem was to substitute the rotary levers (see Fig. 3(c)) by stepper motors to remotely actuate the opening angle of the flap panels. The present work describes the mechanic and electronic details of the control system and presents the first results obtained in tests.

It is important to note the flap panel completely open (20 degrees) with the so called finger flaps in its end if Figs 3(a) and (b). There are channels dug in the panel surface at the exact location of the slots which causes mass flow, even with the flaps completely closed: the mass flow is extracted through the test section slotted walls returning spontaneously to the flaps section main stream through these finger flaps. Thus, in the TTP operation, the flaps act at any run condition.

2. FLOW ESTABLISHEMENT IN TRANSONIC WIND TUNNELS

To understand the role of the re-entry flap in the uniformity of flow in the test section a general view of what is at play is important. The re-entry flaps, diverging capability of the walls, amount of forced mass flow extraction from the plenum chamber, pressure at the surrounding of the plenum chamber, and first and second throats geometry, must work together to establish the best possible uniform flow conditions in partially open transonic test sections. Goethert (1961) discusses some interesting typical experiments at tunnels of NACA (National Advisory Committee for Aeronautics) to clarify this subject. For example, for supersonic Mach number range with sonic first throat, significant non-uniformities of the Mach number distributions occurs and grows in intensity as the Mach number in the test section is increased. It was observed a local Mach number at the centerline fluctuated between 1.15 and 1.27 at an average Mach number 1.2. A summary of this discussion is that: (1) the mass flow removal through the walls will result in uniform boundary layer thinning through the entire test section length, only when the correct wall convergence angle is simultaneously applied; (2) merely extracting air through the walls without properly converging the walls will not produce uniform thinning of the boundary layer, as is required for shock wave reflection consideration (3) at subsonic speeds, concentrated local disturbances in the downstream portion of the test section are established. Figure 4 shows the influence of plenum chamber suction with flaps closed on Mach number distribution at centerline of slotted test section for Mach number 0.9. It is evident that at 0% of extraction, the flow in the downstream portion of the test section is disturbed, being increased. A proper amount of suction, approximately 2.8%, resulted in uniform Mach number distribution through practically the entire test section. For a higher amount of suction (5.0%) the disturbance reappears with lower Mach number values. Goethert shows that in slotted test sections plenum chamber suction affects only the flow in the downstream end of the test section. This fact proves the great importance of controlling the flaps allowing them to modify the mass flow through the walls in order to obtain the best condition for each particular test and article installed in the test section.

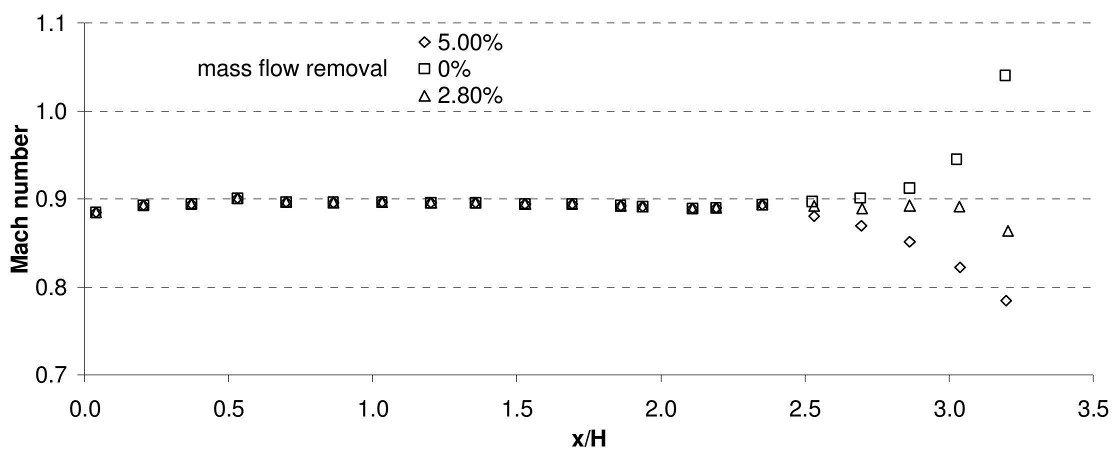
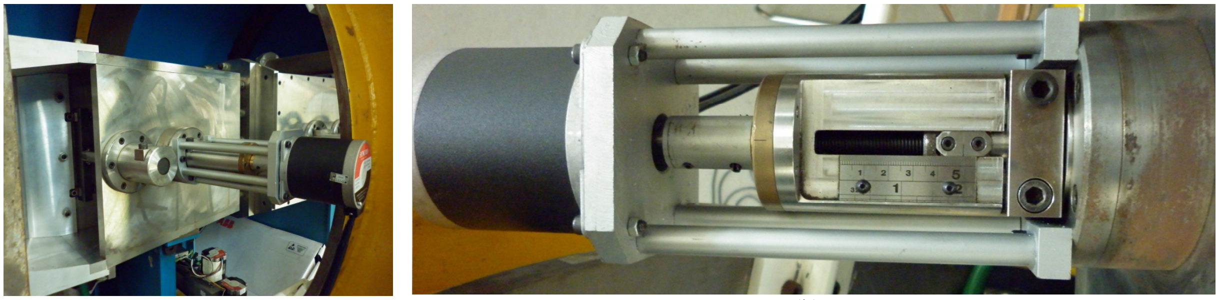


Figure 4. Influence of plenum chamber suction on Mach number distribution at centerline of slotted test section (solid diffuser walls, sixteen slots with 11 % open-area, parallel walls) (Goethert, 1961).

3. FLAP CONTROL SYSTEM DESCRIPTION

Each flap is made of thick aluminum plate, which opens from 0 degree to 20 degree in 29.2 turns of the rotary lever. Initially it was determined the required torque to drive the lever and two stepper motors were selected with starting toque of 70 Nm and cruiser torque of 1.8 Nm. A mounting structure device shaped cage was designed in steel to connect the stepper motor to the original flap command shaft. Figure 5 shows a lateral view of the stepper motor mounted on the camshaft flap (a) and a top view with the positioning ruler and the cursor on the camshaft (b).



(a) (b)

Figure 5. Automatic control: (a) motor installation in the tunnel; (b) top view showing the positioning ruler and the cursor on the shaft.

The flow chart in Fig. 6 shows the electronic components involved in the project to operate the stepper motors. In the central microcomputer located in the TTP control room (1), used to manager and monitor all subsystems actions in the tunnel, it was created a particular command to set the flap angle. The signal is sent to the stepper motors (5) through auxiliary circuits (2), programmable microcontrollers (3), and power drivers (4) – the programmable microcontrollers and the power drivers are supplied by a stable voltage source (6).

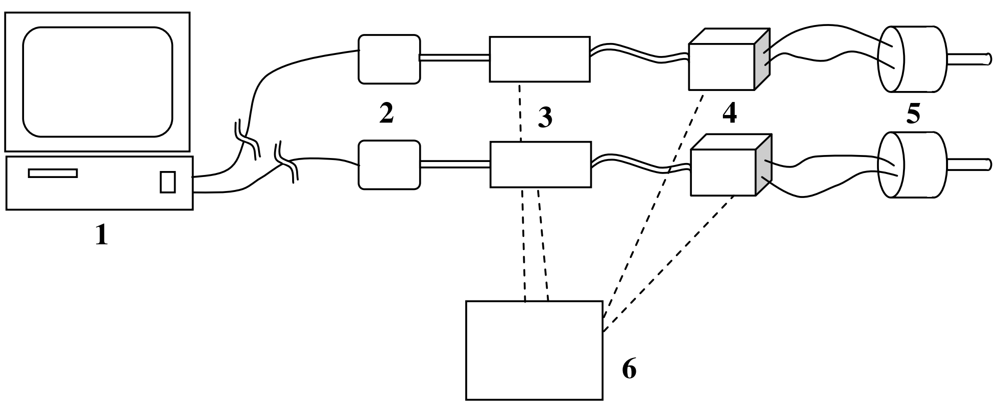


Figure 6. Electronic logical data transference for stepper motor control using PIC.

Two hybrid stepper motors were selected from SYNCRO (2011), model 821.550-2, with 1.8 degrees per pass with two phases. The motor can be connected in three different modes: unipolar, bi-polar in series, and bi-polar in parallel. The bi-polar in series mode was chosen since it is more appropriate to the driver utilized, with only two poles and with a lower raged current per phase. The power drivers chosen were from SYNCRO, model MDB 5042 DC with high performance. They receive signals from a programmable microcontroller (clock, direction and enabling) conditioning these signals to the correct stepper motors operation.

The choice of a programmable microcontroller was based on the feasibility of having it very close to the drivers and motors. These programmable microcontrollers are very popular due to their low cost, wide availability, large user base and programming and re-programming capability. It was chosen a programmable microcontroller type PIC (Peripheral Interface Controller) from the Microchip™ (Microchip, 2003), model PIC16F877A. It works as a microcomputer extension, allowing a logical unit distant from the microcomputer, receiving data from it and freeing it to perform other tasks. The PIC was programmable by a code developed in MPASM™ assembler language, recorded by an original recorder from Microchip, in order to follow the commands to the drivers. The code contains information to control the stepper motors, as the amount of pulses to move, the direction and an emergency signal. As this logic unit is close to the motors, the communication frequency may be higher without electronic noise, allowing a faster motor move, and also, the motor the microcomputer does not need to control every step of the operation.

A switched mode power source, which supplies the programmable microcontrollers (5VDC) and the power drivers (38VDC), is of SYNCRO, model SYN-PC 38/24/5. An auxiliary electronic circuit between the microcomputer and the PIC was introduced to voltage level adjustment and optical isolation aiming operational safety.

The PIC receives instructions from the central microcomputer through a program developed in LabView®. This program reports the current opening angle of flap, and when the user changes this value a warning sign on yellow background displays the value of the flap until the operation is completed and the original background display white color is restored.

Embedded in this operation is the conversion between the desired angle and the amount of pulses and motor rotation direction, and a protocol for communication with the PIC. It was necessary to establish a relation between the angle position (θ) and the positioning ruler (x) in the shaft (Fig. 5(b)); the nominal relation is given by Eq. (1).

$$\theta = -4.6x + 22.9 \,. \tag{1}$$

The opening flap angle can be monitored and changed during a tunnel test procedure. Its average speed is 0.7 degrees per second, which is adequate for all tests devised in the tunnel.

4. RESULTS

A first concern was to demonstrate that the flap control speed is fast enough. Figure 7 shows the stagnation pressure variation during tests at Mach number 0.9 and flap opening of 0°, 1°, 2°, 3°, 4° and 6°, in this sequence. The figure shows five data acquisition periods of about 60 seconds and between them there happens transient due to flap angle changing. The shadow region limits the controlled pressure region. The pressure control system took 13s, 9s, 8s, 9s, 7s to return the stagnation pressure value to its set point for each flap movement, from 0° to 1°, from 1° to 2°, from 2° to 3°, from 3° to 4° and from 4° to 6°, respectively. It interesting to observe the first flap opening provoked the longest transient. As the flap opens lower impacts occurs.

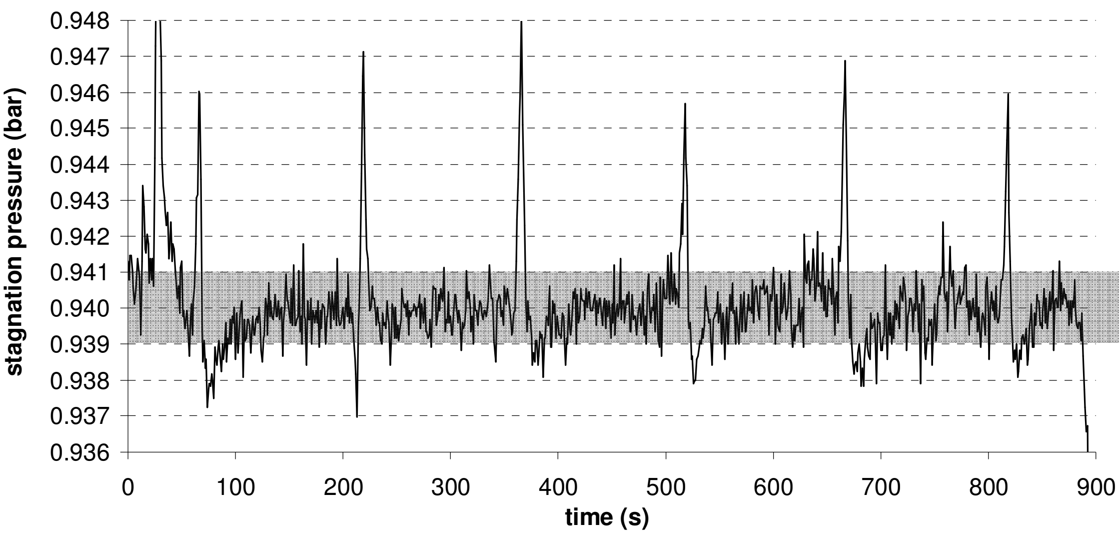


Figure 7. Stagnation pressure variation during flap movement (0°, 1°, 2°, 3°, 4° and 6°) between five data acquisition periods.

Figure 8 shows the Mach number variation for the same time period. A temporal Mach number variation of about ± 0.002 could be observed. The time periods taken to reestablish the Mach number set value for each flap movement were 36s, 10s, 18s, 23s and 23s, respectively. The reason the Mach number reestablishment if longer than for the case of the stagnation pressure, is because during a flap variation there occur also temperature change, and the Mach number itself whose fine tune is made manually by acting in tunnel central control program.

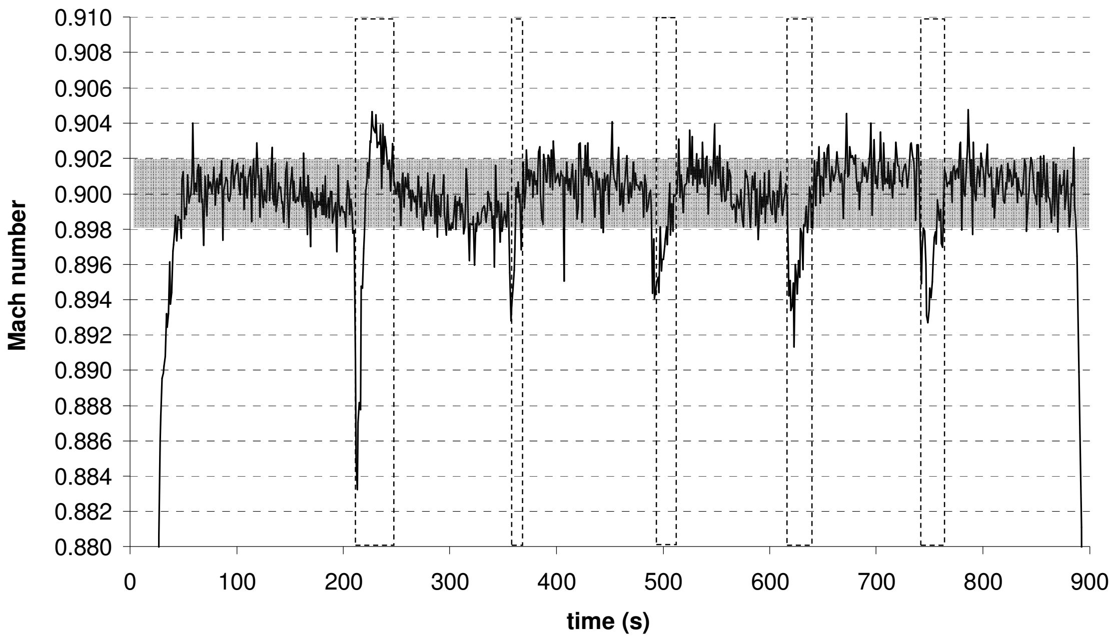


Figure 8. Mach number variation during flap movement between five data acquisition periods (0°, 1°, 2°, 3°, 4° and 6°).

Figure 9 shows the Mach number variation in centerline of the test section at Mach number 0.9, varying the flap opening angles of 0°, 1°, 2°, 3°, 4° and 6°. In the figure the shadowed region marks the nominal test section – the region where the test article is installed – and the dashed vertical line marks the test section end limit. Two measuring points are out of test section: they are into the flap section. Observe that the Mach number decay into the flap section due to the area increase in the flap section.

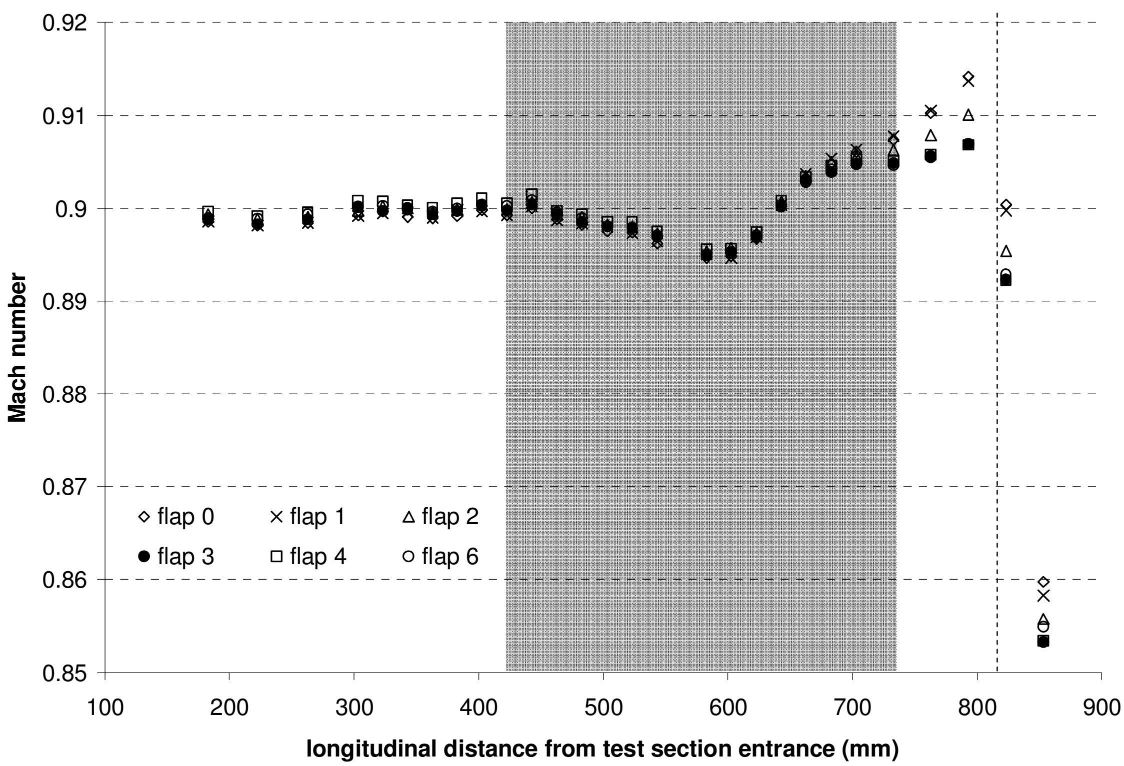


Figure 9. Mach number variation during flap movement between five data acquisition periods (0°, 1°, 2°, 3°, 4° and 6°).

It is interesting to observe the effect of flap opening in Fig. 9. With the flaps completely closed (0°), as stated in item 2, there is strong non-uniformity in the downstream portion of the test section at high Mach number. As the flap opens up to 3° there is a tendency to decrease the Mach number at the test section end. Beyond this value no further Mach number decrease is observed. Besides all, it is clear in figure that for any flap opening angle it is possible to observe non-uniformity near the test section central region. The reason for that seems to be related to other adjustments than the flaps. Leading candidate is the test section wall convergence angle, which will be verified in future tests in TTP.

Figure 10 shows the results for Mach number 1.0 for flap positions of 0°, 1°, 2°, 3°, 4°, 6°, 8° and 10°. The Mach number was much more uniform than for Mach number 0.9. The same tendency of Mach number distribution distortion in the final part of the test section was observed. As the flaps open, this tendency is clear minimized. However, for this Mach number condition the flap was of minor effect. A full investigation varying the flap opening for each Mach number is extremely desirable and the remote activation of the flap will be very helpful.

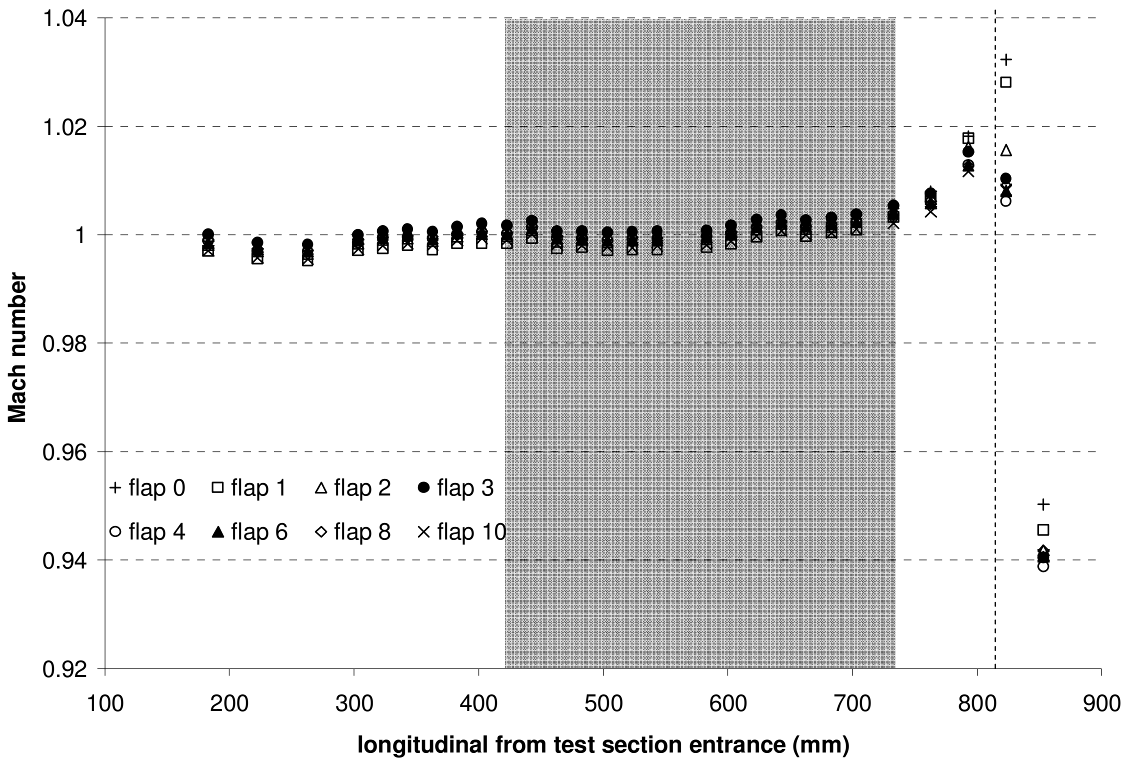


Figure 10. Mach number variation during flap movement between five data acquisition periods (0°, 1°, 2°, 3°, 4°, 6°, 8° and 10°).

5. CONCLUSIONS

It was described the flap design and how its main operational functions are used in a transonic wind tunnel to establish good flow conditions in the test section. This is made with the help of the plenum chamber pressure control and the mass extraction through the test section walls. Flow establishment in test section with the help of the flaps is discussed, as well as the reason to remotely control the flap opening.

The flap control system design based on stepper motors with programmable microcontrollers and power drivers was described. Some operational characteristics are confirmed by functional tests, and time response was determined to be faster in comparison with pressure, temperature e Mach number control systems.

The capability of using the flap control in managing the Mach number uniformity in the test section was assessed by two study cases for Mach number 0.9 and 1.0.

The flap control system performance was confirmed by its speed and its inherent precision due to stepper motors use, successfully installed in the flap command shaft. Many tests are envisioned with the use of flaps to obtain a better uniformity in the test section.

6. ACKNOWLEDGEMENTS

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