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# CONTROL SYSTEM OF THE CTS - CAPTIVE TRAJECTORY SYSTEM

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***Abstract.*** *The TTP (Pilot Transonic Wind Tunnel of IAE – Aeronautics and Space Institute) is a modern tunnel capable of aerodynamic tests in Mach number range from 0.2 to 1.3 with automatic controls of pressure (from 0.5 bar to 1.2 bar), temperature and humidity. In a transonic wind tunnel design the test section walls are semi-open to allow mass flow extraction, which is important to prevent aerodynamic chocking phenomenon, minimize shock/expansion wave reflections from walls, and also to help on wall effects correction. To set the mass flow ratio through the walls, the test section is enveloped by a plenum chamber, in which the pressure is controlled by means of a dedicated compressor. What determines how much of the flow will pass through the walls are mainly the plenum chamber pressure and the reentry flaps positioning, located at the end of the test section. On high speed tunnels, simple aerodynamic models are connected through a device named sting wich supports the model by its back, in order to reduce as much as possible the interference effects with the clamping devices. However, there are more complex models composed of more than one body, such as aerospace vehicles with boosters coupled to a central body or artifacts suspended in aircraft wings, wich cannot be correctly positioned in the test section without an auxiliary positioning device. A positioner system of three degrees of freedom called CTS (Captive Trajectory System) was designed in order to simulate a missile being jettisoned from a generic fuselage, expanding the ability of tests to be developed in the TTP. This positioner controls the position in the X and Y axis of the projectile and its angle of attack α through the linear displacement of three independent movers, controlled by step motors. The controller will guide the device from TTP's control room using a software created in LabView 2009 platform. This software will calculate the necessary moves on the device to place the aerodynamic model in the desired position. These informations will be sent to the microcontroler, wich is responsible for correctly driving the step motors. The microcontroler will then send signs to the drivers that control each step motor. This work describes details of the main software used to guide the CTS from the control room of the TTP, and the first calibration realized on the device.*

***Keywords***: *Captive Trajectory System, Control System, Positioning, Attitude, Calibration*

## 1. INTRODUCTION

The Pilot Transonic Wind Tunnel (TTP) is one of the three wind tunnels that belongs to the Aerodynamics Division (ALA) of the Aeronautics and Space Institute (IAE), located in the Department of Aerospace Science and Technology (DCTA) in Sao Jose dos Campos - SP. Created in 1988 by a Brazilian team in conjunction with the American company Sverdrup Technology Inc., the TTP has already conducted several experiments to verify the reliability of its results in subsonic and transonic regimes (Sverdrup, 1989). Tests were conducted to examine the uniformity of the flow in the test section of the tunnel, initially with open circuit and intermittently driven by the injection system (Escosteguy, 1998 Zanin *et al*., 2008), then with closed circuit and directed by the injection system (Silva *et al*., 2009), and finally with closed circuit and driven by a two-stage axial compressor with 830 kW (Falcão *et al*., 2011).

TTP's test section has a cross section of 0.25 m x 0.30 m and 0.85 m in length. Aerodynamic models are fixed in the tunnel by its back through a device called sting (Fig. 1), aiming to reduce the effects of the clamping devices on the results of the experiments. This clamping device has a single degree of freedom, being able to control the angle of

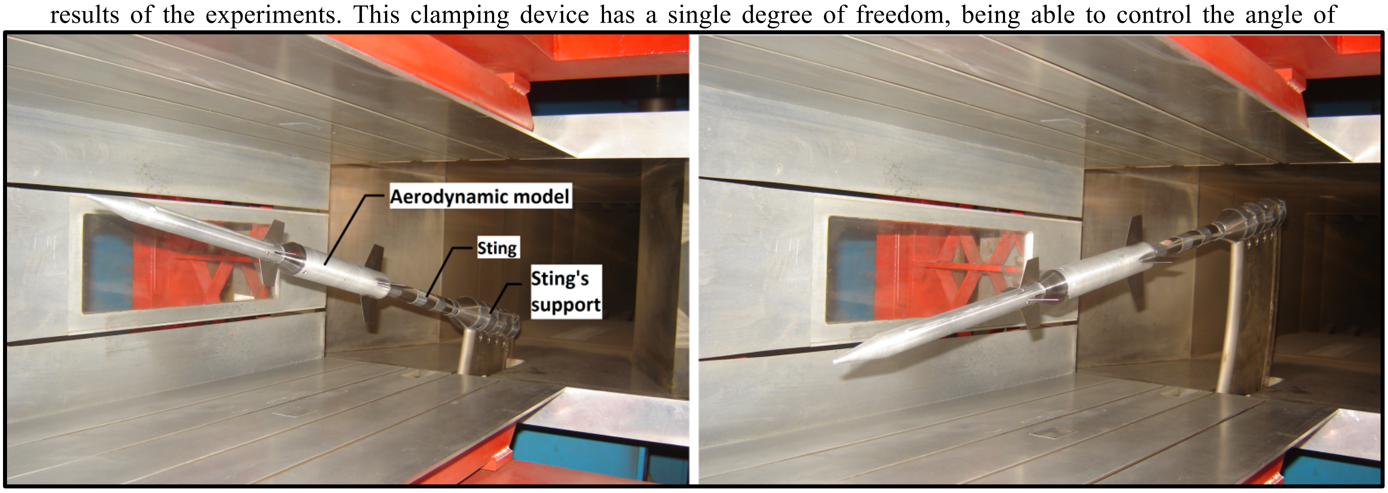


Figure 1. Aerodynamic models clamping device

attack of a simple model in the range of -15 ° to +15 °, while maintaining fixed the vertical and horizontal position of the center of rotation of the model. To continue the improvements, the TTP is expanding its application through the creation of a three degrees of freedom positioner, called Captive Trajectory System (CTS). Through this, the TTP is able to precisely determine the position in the X and Y axis, and angle of attack α of any aerodynamic model fixed to the device, and perform tests on complex models composed of more than one body, such as aerospace vehicles with boosters attached to a central body or artifacts attached to the fuselage of an aircraft.

Captive Trajectory System is the name given to the device used in high-speed tunnels for positioning bodies adjacent to the main aerodynamic model, in order to perform tests to check the interference caused by the presence of this body. Some modern devices have up to six degrees of freedom, and are able to traverse a predefined path in the middle of an experiment. They also rely on various safety sensors to prevent collisions and accurate position sensors that optimize the application of CTS and improve the quality of the results.

There are two ways of operating a Captive Trajectory System: open-loop control and closed-loop control. In the open-loop control, the CTS is operated step-by-step by the controller, who defines the desired position for the aerodynamic model, initiates the experiment, analyses the results, and then defines the second position for the model. These steps are repeated until the final position for the model is achieved. In the closed-loop control, the aerodynamic model attached to the device is instrumented with an inner balance that sends aerodynamic informations to the computer. The software uses these informations to calculate the next step for the model, and automatically sends it to that position without the controller's intervention. The loop is then reinitiated and the proceedings steps are calculated in the same way. Closed-loop control is faster and more efficient than open-loop control, but has the disadvantage of needing an inner balance installed on the aerodynamic model. On wind tunnels with large test sections this is not a problem since it is possible to create big aerodynamic models capable of supporting the inner balance. On small wind tunnels, such as the TTP, the aerodynamic models are relatively small, and inserting the inner balance into them is not always possible. For this reason, TTP's CTS is being created to support only the open-loop control.

A specific design of CTS should be created in each wind tunnel so that it can be adapted to their size and needs. The positioner designed for TTP (Fig. 2), which is fixed to the plenum chamber structure, was designed according to the various constraints encountered during its development (Ubertini *et al.*, 2012), and has a peculiar architecture, mainly due to the reduced space for access to the test section, shown in Fig. 2 by the orifice inlet.

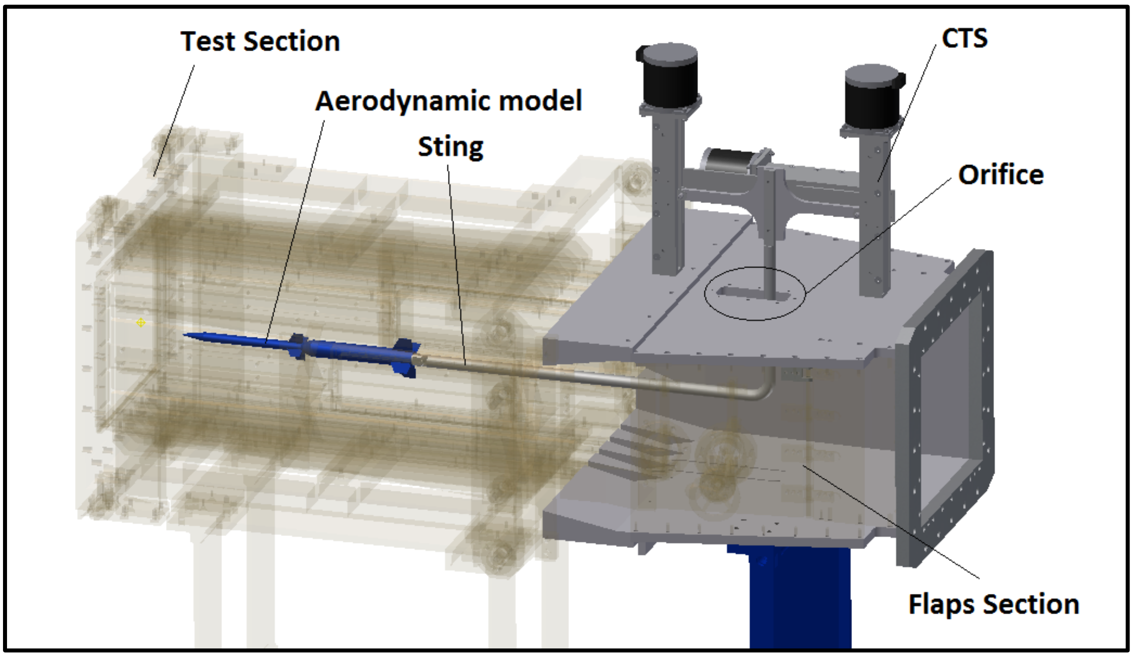

Figure 2. Virtual model of the TTP's CTS with aerodynamic model

The position and attitude of the model fixed to the device are controlled by three linear movers, which are driven by step motors. These motors are operated remotely by the controller, using a software developed in LabView 2009 platform. Inserting in the software the desired position and attitude of the model, the computer calculates the required position on each mover, and the steps needed in each step motor so that the model is positioned at the desired location. The results are then sent to a microcontroller which, in turn, sends the data to the drivers that control the step motors. Potentiometers are used as position sensors of the movers, and continuously send information to the controller in order to monitor in real time the displacement of the device and the model fixed to it. Presence sensors prevent the impact of the sting with the walls of the hole used to access the test section (Fig. 2), but possible impacts of the model with the walls of the section are calculated only through software, given the impossibility of fixing sensors in aerodynamic models or in the tunnel walls.

The project is currently in the programming phase, when the software is being tested to adequately calculate the necessary movements in the CTS's movers, in accordance to the desired position for the aerodynamic model attached to the device. This article will describe the main software created in LabView 2009 platform, the steps needed to correctly insert informations of the experiment on the software, the impact prevention system and the first calibration realized in the device.

## 2. TTP'S CTS DESCRIPTION

Three independent movers (fixed Y mover, mobile Y mover and X mover) are connected by a sliding platform, as shown in Fig. 3 below:

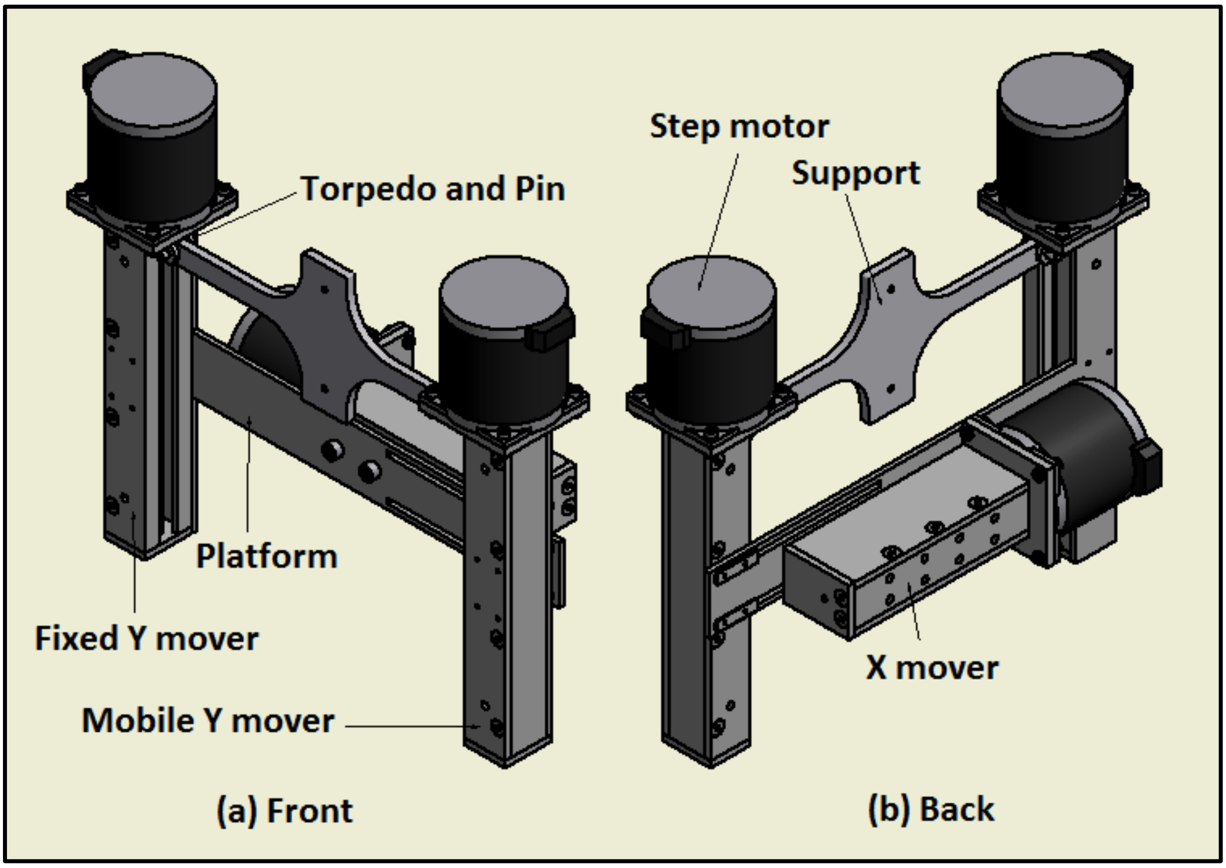


Figure 3. Virtual model of TTP's CTS

The aerodynamic model attached to the sting is fixed to the support, which in turn is fixed to the torpedo of the mobile and fixed Y movers by two pins. The X mover is responsible for the correct positioning of the aerodynamic model in the X axis, while the Y movers control the position in the Y axis and the angle of attack α of the model.

The difference between the positions of the torpedoes of the fixed and mobile Y movers determines the angle of attack α of the aerodynamic model. When this difference is zero (the torpedoes are in the same position), the axis of symmetry of the support is parallel to the X axis and no angle is created between them. When there is any difference between the positions of the fixed Y torpedo and mobile Y torpedo, there is an angle $\beta$ between the axis of symmetry of the support and the X axis, and this angle reflects on the angle of attack α of the aerodynamic model fixed to the device.

When an angle is created between the axis of symmetry of the support and the X axis (Fig. 4), the total length of the support ($\boldsymbol{L}$) is no longer the distance between the Y movers and becomes the hypotenuse of the triangle formed. When this happens, the distance between the fixed Y mover and mobile Y mover is reduced in accordance with the Theorem of Pythagoras (Eq. 1). This reduction is accomplished by sliding the mobile Y mover on a rail existing on the platform.

$$L^2 = C_X{}^2 + C_Y{}^2 \tag{1}$$

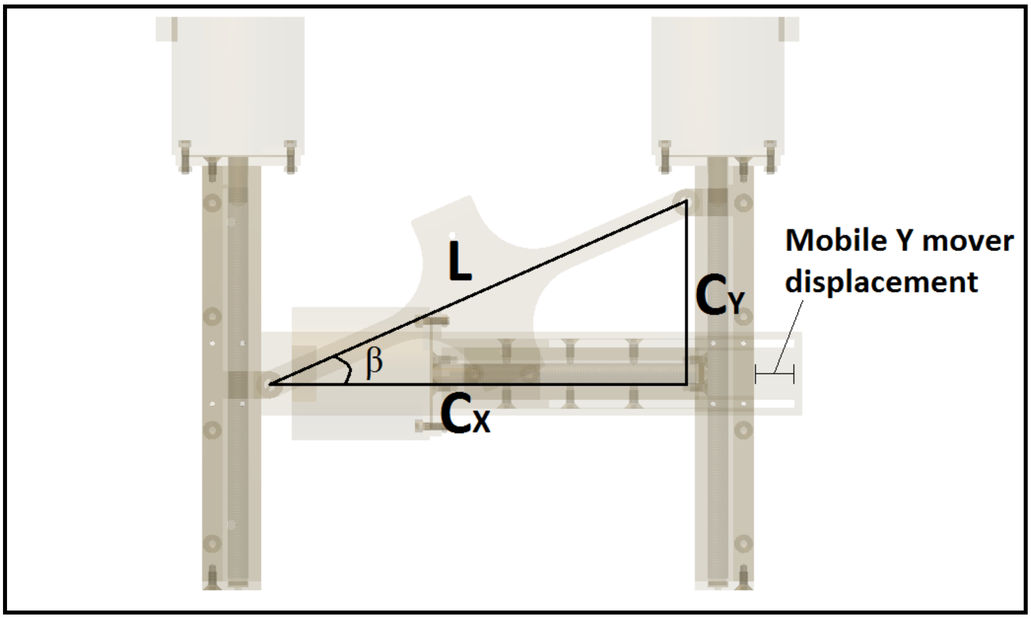


Figure 4. Representation of the mobile Y mover displacement and the angle β created between the axis of symmetry of the support and the X axis.

Correctly positioning the torpedoes of the fixed Y mover, mobile Y mover and X mover, it is possible to position the aerodynamic model attached to the device in the desired position and attitude within the test section of the TTP.

## 3. CONTROL SYSTEM

During any experiment that makes use of the TTP's CTS, the device remains installed inside the plenum chamber of the TTP, inaccessible by anyone outside. Since during the experiment it is necessary to reposition the aerodynamic model attached to the CTS, it would be impracticable to stop the experiment and open the plenum chamber in order to reposition the model. This is why the control system is responsible for digitally positioning the model attached to the device through the TTP's control room.

The control system is formed by three steps:

- Main software
- Microcontroller
- Step motor's drivers

The first step is the main software, which is the interface between the controller and the CTS. It is used to insert, visualize and control everything about the CTS before and during the experiment. Its layout is simple and intuitive, but its applicability is complex and requires knowledge about the experiment and about the CTS itself, before it can be used to its full capacity.

Figure 5 shows the initial view of the CTS main software, the drawing view. This is the starting point of the experiment, the stage when the controller is inserting geometric informations about the aerodynamic model attached to the device, and any other model or object placed in the test or flaps sections of the TTP. It is extremely important to represent as precise as possible the geometry and position of any object inside the TTP, since these informations will be used to calculate and prevent impacts that might occur. A bad representation of the position or geometry of the objects generates wrong calculations of impact prevention, and might allow movements that result in impact, that would normally be detected if the informations about the experiment were correctly inserted.

In the Attitude view, the user is able to insert any number of desired positions for the aerodynamic model attached to the device, by defining the X and Y positions, as well as the angle of attach $\alpha$. The steps recorded will be executed in the same sequence they were inserted, requiring planning of the experiment before the steps are recorded in the software. At this stage, the software starts the calculations of possible impacts with the orifice inlet used by the sting to reach the test section of the TTP, with the test sections walls, and with any other object inside the test or flaps sections of the TTP. The geometric and position informations of the objects inserted in the drawing view are now treated as boundaries. TTP's test section walls and objects inside the test and flaps sections are fixed boundaries, and the aerodynamic model attached to the CTS, as well as the sting itself, are treated as mobile boundaries. Each time a step is recorded, the software simulates the displacement of the model from the last step to the recording step, and if any fixed boundary is intersected by a mobile boundary during this displacement, an impact will occur, and the software blocks the recording of this step exposing to the user a pop up warning.

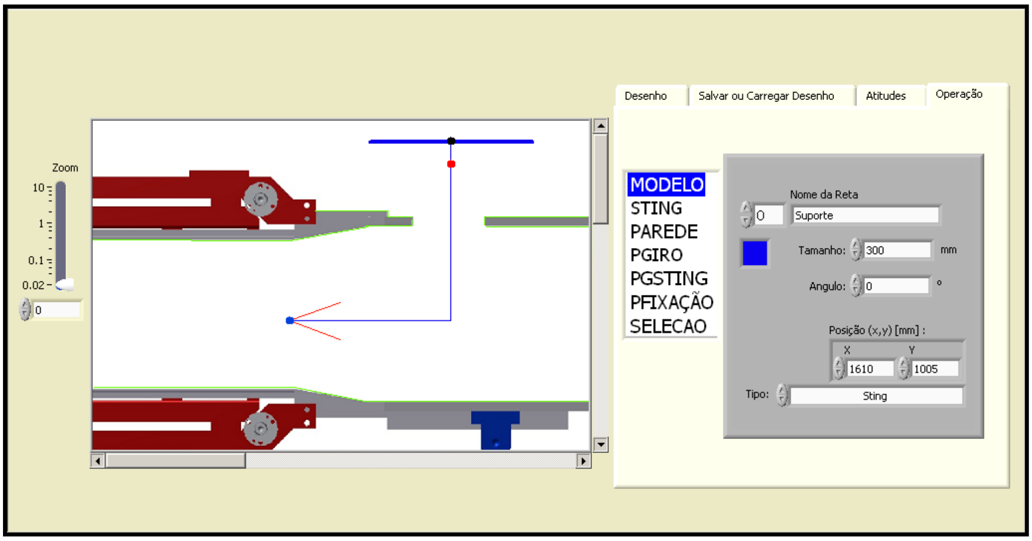


Figure 5. CTS main software drawing view.

Changing to Operation view, the geometric and position informations about the objects inside the test and flaps section of the TTP are exposed, as well as the position and attitude of the aerodynamic model attached to the device in each of the recorded steps. At this view, the user is able to see the actual position of the CTS's torpedoes, as well as the needed displacement in each mover, for the next step to be reached. When the start button is pushed, the main software sends the informations about the needed displacement in each mover to the microcontroller, and waits for the microcontroller's feedback. When this feedback is received, the software calculates the needed displacement in the movers for the next step to be reached, and waits for the user to push the start button. This process is repeated until the last recorded step is reached.

The second step of the control system is the microcontroller. This step is needed in order to leave the computer able to execute other functions besides controlling the CTS while the torpedoes are moving. The microcontroller receives the informations from the main software about the needed displacements in each mover, and redirects it to the corresponding step motor's driver. While the torpedoes are moving, the microcontroller compares the actual position of the torpedoes, detected by the position sensors of each mover, with the final position of the torpedoes, sent by the main software, and keeps sending pulses to the drivers until the final position is reached. When this happens, the microcontroller stops sending pulses to the drivers, and sends a feedback to the main software, informing that the desired position has been reached, and waits for more information.

The third and last step of the control system is the step motor's driver, its aim is to simplify the control of each step motor, by receiving informations about direction of the movement and the pulses needed to rotate the axis of the step motor. With these informations, the driver efficiently controls the charge in each coil, in order to rotate the step motor in the right direction, at the right time, and with the right torque. This is realized by controlling the current of each coil, and, subsequently, its potency.

When all of these three steps of the control system are working correctly, the user of the CTS can accurately position any aerodynamic model attached to the device in the desired position and attitude, with the security of the impact prevention system, and the precision of the step motors combined with the position sensors of each mover.

## 4. CALIBRATION

The calibration of the TTP's CTS was realized to verify the precision of the control system, and the capacity of the device to position its torpedoes in the desired position. Correctly positioning all of the three torpedoes is extremely important to achieve precise results in any future experiment, and to guarantee the functionality of the equipment. In order to realize this calibration, the CTS was installed in the control room and directly connected to the computer (Fig. 6).

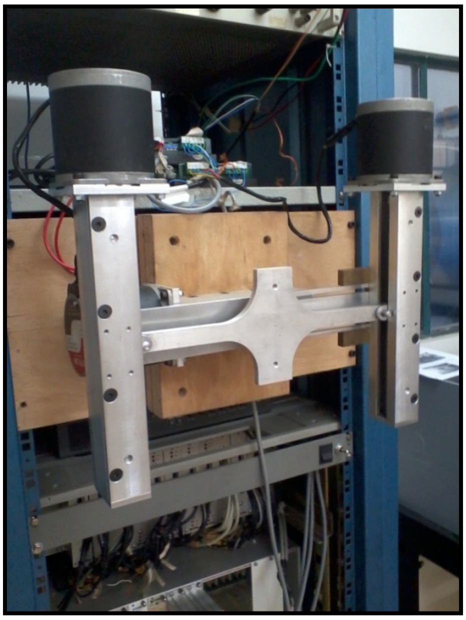

Figure 6. CTS installed in the control room and prepared for calibration.

Through the main software created in LabView 2009 platform, informations about the desired position of the torpedoes were sent directly to the step motors drivers, without passing through the microcontroller, which is still being programmed. Since the microcontroller is used only to leave the computer able to realize other functions while the CTS is moving, the removal of it in the calibration process does not interfere in the results of the same, but the incapacity of the main software of receiving informations from the mover's position sensors is sure to have some bad influence in the results.

The step motors drivers receive the informations from the main software and convert these informations into the necessary steps in each step motor. After the displacement of the torpedo, the position of it was measured using a caliper rule, and the real position of the torpedo was compared to the ideal position inserted in the main software.

Each mover was calibrated at a time, in order to include the sliding of the mobile Y mover in the uncertainties of the experiment. The movers that were not being calibrated were placed in the middle of its total curse, while the mover being calibrated was placed in the lower limit of its curse. The initial position of the mover was measured with the caliper rule and compared to the ideal position inserted in the software. The torpedo was then sent to the second position, measured and compared again. This process was repeated until the higher limit of the mover's curse was reached. At this time, the reverse process began, moving the torpedo from the it's higher limit to its lower limit, step by step, in order to include the hysteresis uncertainty in the calibration.

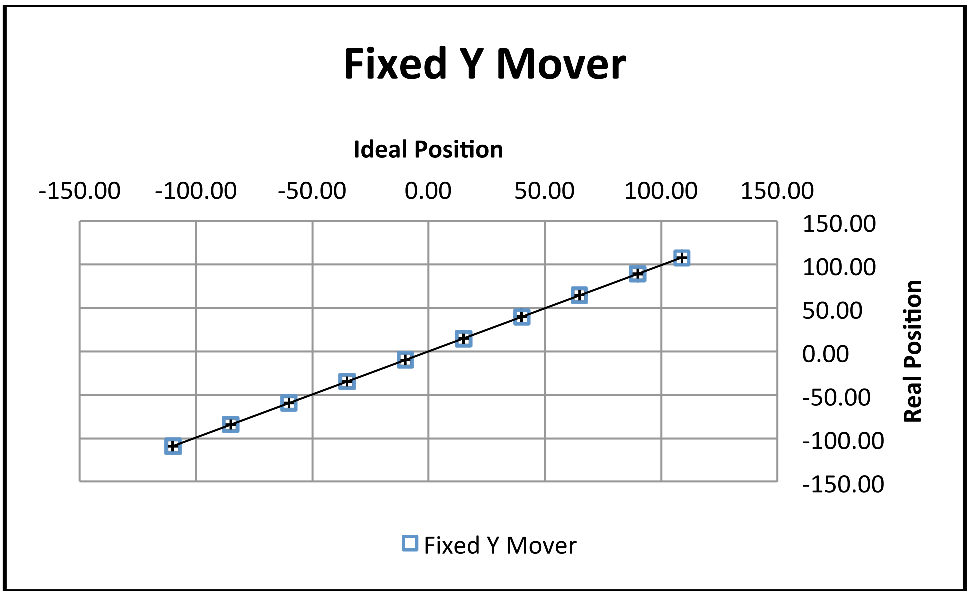


Figure 7. Calibration of the Fixed Y Mover.

Being the ideal position of zero millimeters of displacement located exactly in the middle of each movers curse, the Y movers were calibrated from the ideal position of -110 to +110 millimeters of displacement (a total of 220 millimeters of displacement). Each step of the calibration of the Y movers had a displacement of 25 millimeters, with a total of 19 steps from the lower limit to the higher limit and back to the lower limit. The X mover was calibrated in the range of -40 to +40 millimeters of displacement, with 20 steps of 8 millimeters of displacement each. The results of the calibration of the Fixed Y mover, Mobile Y mover and X mover can be seen in Fig. 7, Fig. 8 and Fig. 9, respectively.

The comparison of the ideal position with the real position of the Fixed Y Mover was satisfactory, with a standard deviation of ± 0.4 mm (95%). This result is sufficient to place the torpedo in the desired position with good precision, even though it represents a standard deviation eighty times greater than the expected ideally (± 0.005 mm). The source of this huge difference is the sum of several mechanical complications which were not taken into account during the idealization of the precision of the equipment.

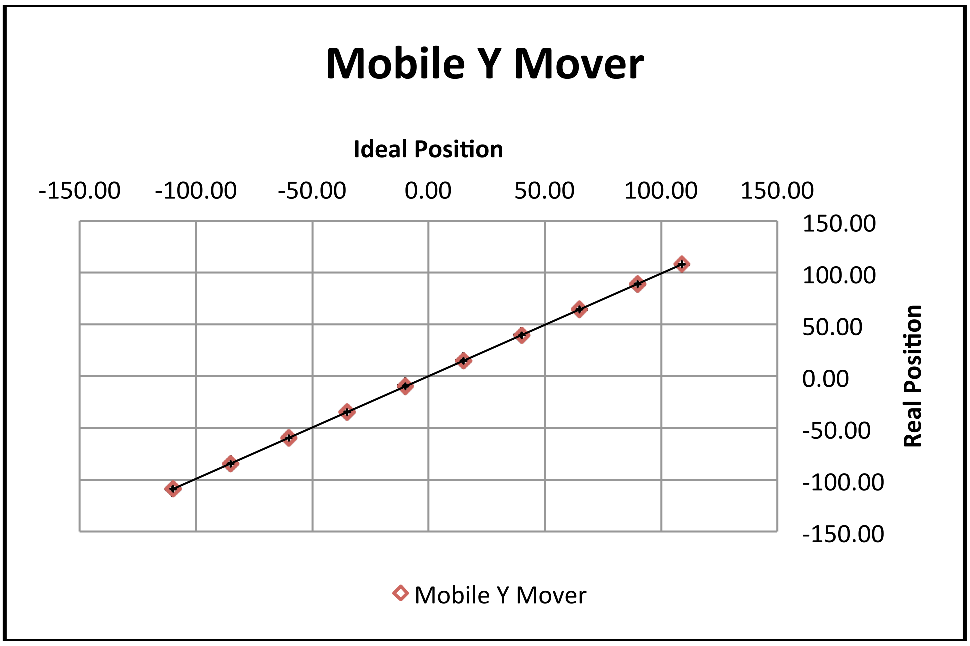


Figure 8. Calibration of the Mobile Y Mover.

The calibration of the Mobile Y Mover showed similar results to the calibration of the Fixed Y Mover. The resulting error was ± 0.5 mm (95%), also satisfactory and representing a good precision of the device.

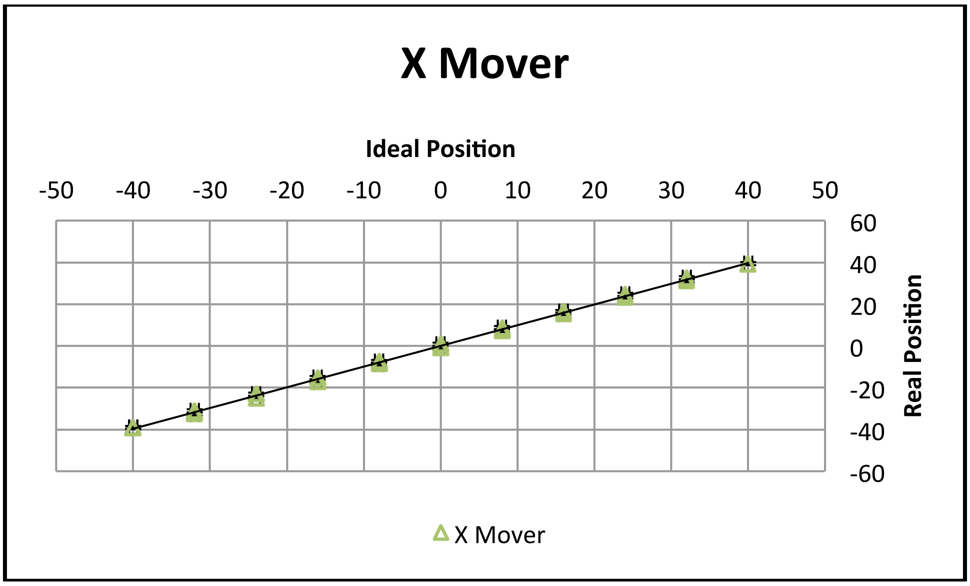


Figure 9. Calibration of the X Mover.

Unlike the precedent results, the calibration of the X Mover resulted in a standard deviation even greater, of ± 1.5 mm (95%). This precision is not sufficiently accurate and can interfere in the results of any experience that uses the device to position aerodynamic models in TTP's test section, and can even be the reason of any impact that might occur with the TTP's test section walls or adjacent models. The reason of this imprecision is being evaluated, and a solution must be found before the CTS can be properly used.

## 5. CONCLUSIONS

The description of the control system of the Pilot Transonic Wind Tunnel's Captive Trajectory System showed that the device can be correctly driven from TTP's control room with good precision. The desired positions for the aerodynamic models are recorded in the main software, and the impact prevention system guarantees there is no solid object between the initial and final position of the model. Besides the calculated standard deviation of the X mover, the results of the first calibration were satisfactory, and the precision may still be improved with the fixation of the mover's position sensors.

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