Identification and control of a subsonic aerodynamic tunnel

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Abstract. *This work develops and implements a dual closed loop wind velocity control system for a subsonic wind tunnel. The feedback signal is obtained by a differential pressure piezoelectric sensor connected to a Pitot static Prandtl type pressure probe, allowing the measurement of the main airflow dynamic pressure. The main goals are to improve significantly the repetition feature and reduce the execution time of the tests. The plant model was obtained via identification and the PI controller parameters were designed via optimization. Simulation and experimental results are presented and discussed.*

Keywords *Control system, identification, optimization.*

1. INTRODUCTION

The implementation of an automatic control for dynamic pressure of the aerodynamic tunnel nº 3 at I.A.E. Institute of Aeronautics and Space showed considerable improvement in the quality of the results in terms of repeatability of the test. This reduced the execution time and decrease the amount of specialized personnel used. There is, therefore, a clear need for implementation of automatic control also to the aerodynamic tunnel nº 2 at the laboratory for aerodynamic testing.

The equipment available to implement the control is: a data acquisition system PXI-1045, manufactured by National Instruments with LabVIEW 7.1 software for use with dedicated data acquisition systems and with control systems. Virtual instruments were developed at I.A.E. for the generation and acquisition of signals.

The literature shows that it is customary to use the proportional-integral-derivative control for the aerodynamic wind tunnel. As example can be mentioned the tunnel at the University of Texas at El Paso accordingly Henessey *et.al.* (2000) and Pefia *et.al.* (2001) of the Higher Polytechnic School, University of Coruña and also the tunnel nº 3 of I A E Institute of Aeronautics and Space, which is used for calibration of anemometer and other experiments.

The aerodynamic control of the tunnel nº 2 is dependent on two factors. First, by controlling the engine speed and second by the position of the propeller blades. This article aims at implementing the PI controller to regulate the dynamic pressure in the test section of a tunnel of wind through the engine speed.

The main contributions are:

a) identification of a nominal model for controller design, since the system consists of motor, rheostats and air mass and position of the propeller blades, and there are no models available in the literature for complete system;

b) PI control design aiming at meeting the requirements of regulation and physical constraints of actuators, and

c) experimental work in order to evaluate the performance of the control system in typical situations of practical interest.

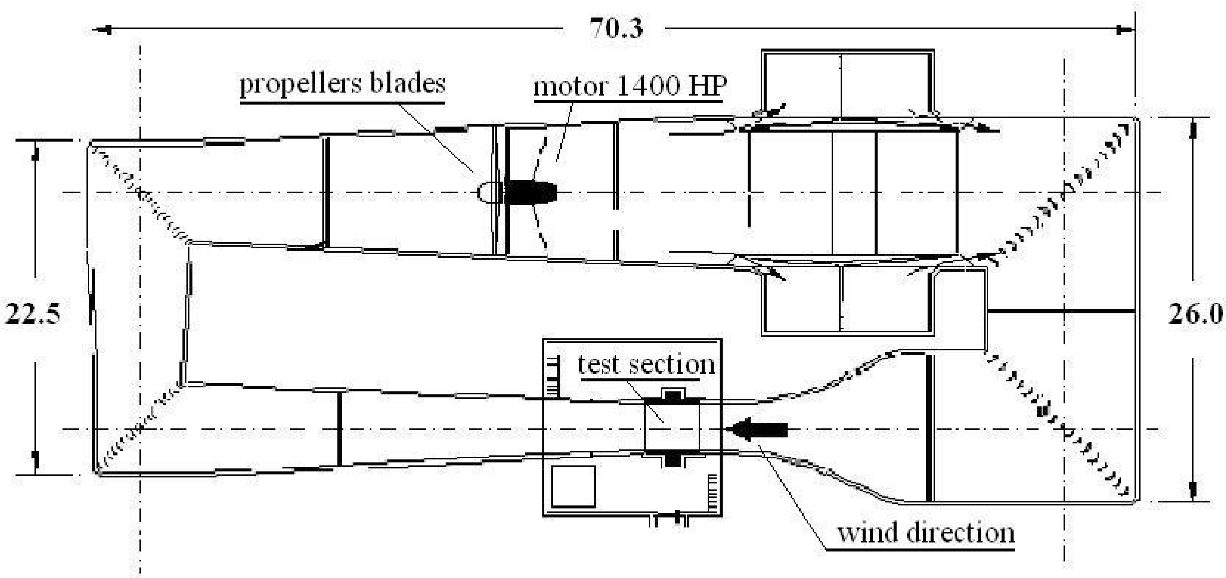
This article is structured as follows: in section 2, the description of the aerodynamic tunnel where the drivers will be implemented is presented, its physical dimensions, speed range and applications. Section 3 concerns the system identification. In section 4 is described the basic structure of the controller and the parameters. In Section 5 the experimental results are discussed, showing improvement in terms of regulation of the dynamic pressure in the tunnel test section. The conclusions follow in section 6.

2. AERODYNAMIC WIND TUNNEL

An aerodynamic wind tunnel is mainly used to investigate the action of wind on a particular model, such as aircraft, ships, buildings, bridges. In aeronautics, there is particular interest in the aircraft drag coefficient.

The aerodynamic wind tunnel used for the development of this control system has a closed test section. It shows a maximum speed in the test section without blocking of approximately 500 km / h and maximum turbulence intensity of 0.2 %. It is powered by a three-phase motor controlled by current supplied through a chilled water rheostat. The maximum engine power is 1400 HP and maximum rotation of 360 rpm.

The dimensions of the test section and the positioning of all motor-propeller in the tunnel nº 2 are shown in Fig. 1.



all dimensions in meters

Figure 1. Aerodynamic wind tunnel nº 2

The main feature of this tunnel is the dual control of the dynamic pressure of flow through the position of the propeller blades and through the positioning of the rheostat.

The position of the rheostat is controlled by a servo motor and a controller model SLVD-7, manufactured by Parker Hannifin, which provides digital reading of the position, given in mm. The total range of rheostat position is from 0 to 1530 mm. The speed of rheostat is preset in three bands of operation, as shown in table 1 below.

Table 1. Rheostats settings and ranges of operation.

Range of operation	Initial position [mm]	Final position [mm]	Speed [mm/s]
1	0	1300	11.4
2	1300	1400	2.3
3	1400	1530	1.2

The angle of the propeller is given in degrees and the motor control is done via serial communication by a radio link. The range of control of the propeller angle is preset between 8 and 28 degrees.

3. IDENTIFICATION OF THE AERODYNAMIC TUNNEL MODEL

The design of the optimized PI controller requires system transfer function: rheostat, engine, the propeller blades, the air mass. There is no information about this complex system in the literature. The transfer function was obtained from the measurement and analysis of the input and output signals. Then, three identification experiments were carried out.

In the identification tests nº 1 and nº 2 was used a constant input signal corresponding to the position of the blades, and a signal continuously varying the position of the rheostat, as shown in Fig. 2.

The identification test nº 1 was made with the input signal related with the position of the blades at 20 degrees, and the input signal related with the position of the rheostat varying at the time.

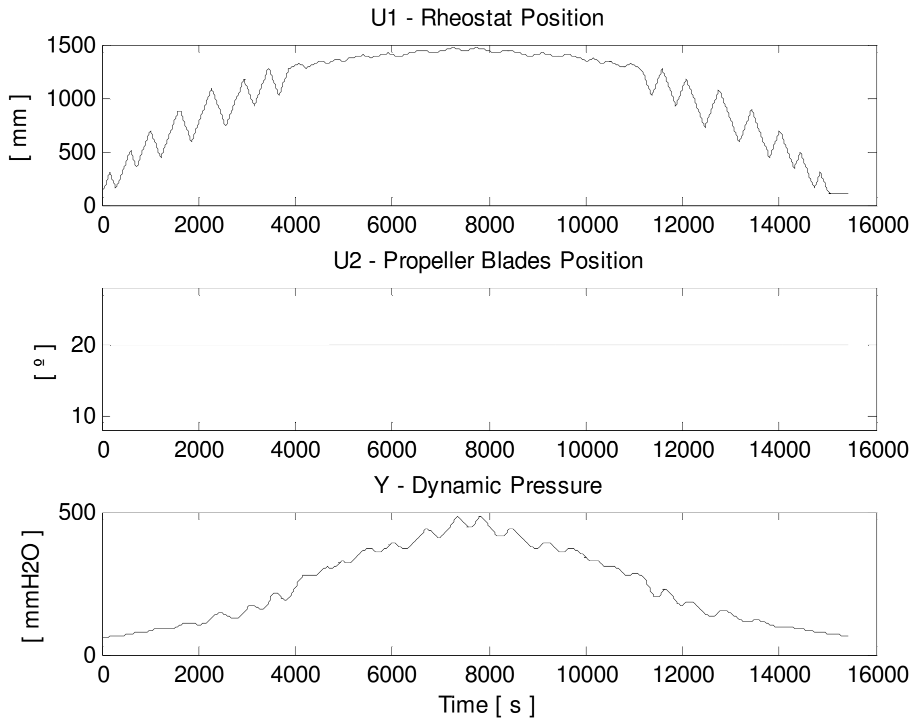


Figure 2. Input and output signals for identification nº 1.

The identification test nº 2 is similar to the identification test nº 1 unless the position of the blades at 24 degrees.

The identification test nº 3 was made with one signal continuously varying the position of the rheostat and the position of the blades. The values were fixed between 18 and 26 degrees, as is observed in Fig. 3.

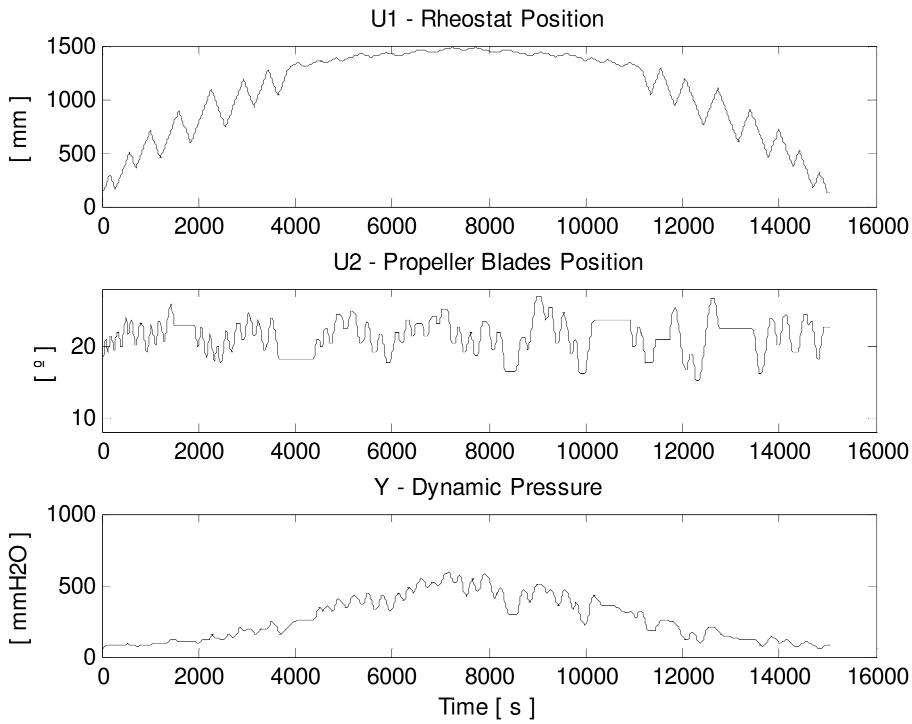


Figure 3. Input and output signals for identificationº 3.

With the use of the Matlab identification toolbox and taking the data obtained from the experiment nº 3, two models were obtained for the aerodynamic tunnel nº 2. The validation data were obtained from the experiment nº 1. Figure 4 shows the screen of the tool ident.

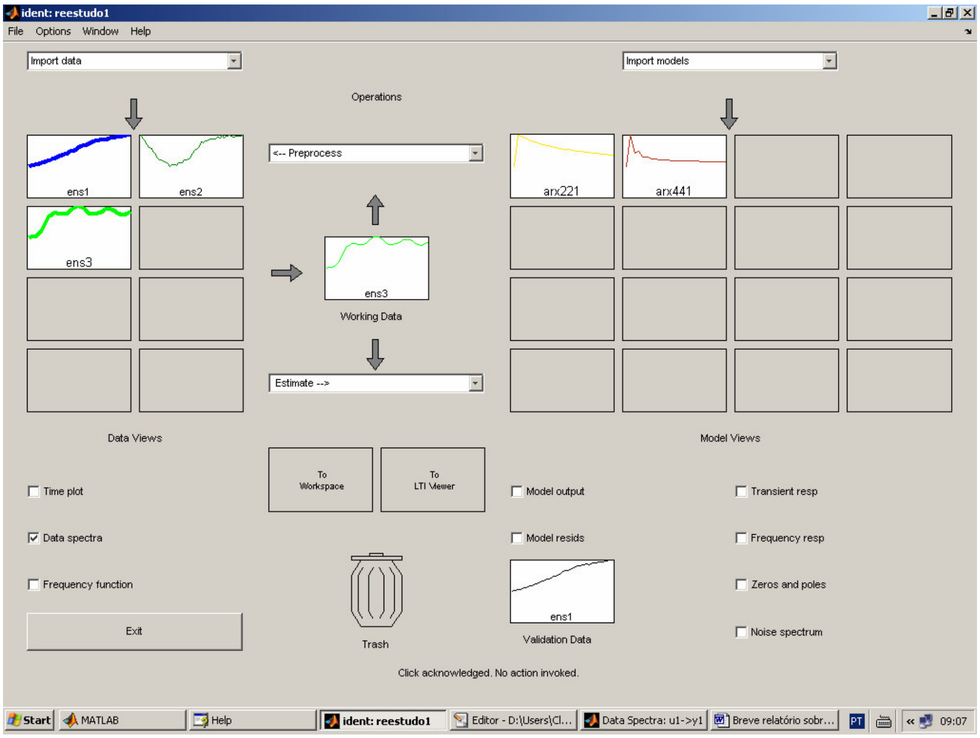


Figure 4. identification toolbox in Matlab with two wind tunnel models.

The models obtained are the type ARX in discretized time.

Model nº 1 :

$$A(q)y(t) = B(q)u(t) + e(t)$$

$$A(q) = 1 - 1.835\,(\pm 0.01067)\,q^{-1} + 0.8388\,(\pm 0.01071)\,q^{-2}$$

$$B1(q) = 0.01404\,(\pm 0.006052)\,q^{-1} - 0.01267\,(\pm 0.006057)\,q^{-2}$$

$$B2(q) = 2.747\,(\pm 0.1812)\,q^{-1} - 2.77\,(\pm 0.1809)\,q^{-2}$$

Model nº 2 :

$$A(q)y(t) = B(q)u(t) + e(t)$$

$$A(q) = 1 - 1.726\,(\pm 0.02741)\,q^{-1} + 0.4331\,(\pm 0.05554)\,q^{-2} + 0.5146\,(\pm 0.05499)\,q^{-3} - 0.2182\,(\pm 0.02569)\,q^{-4}$$

$$B1(q) = 0.03075\,(\pm 0.01549)\,q^{-1} - 0.0401\,(\pm 0.03401)\,q^{-2} + 0.004967\,(\pm 0.03402)\,q^{-3} + 0.00571\,(\pm 0.01549)\,q^{-4}$$

$$B2(q) = 1.909\,(\pm 0.2922)\,q^{-1} - 1.531\,(\pm 0.5901)\,q^{-2} + 0.3972\,(\pm 0.5866)\,q^{-3} - 0.7991\,(\pm 0.295)\,q^{-4}$$

So far, the parameters B2 were not included in the PI design, because there are other technical problems related to the control system of blades which are not in the scope of this work.

The predicted outputs for both models were compared and it turned out that they are quite similar. Hence, for simplicity, the model 1 was selected for designing the PI controller.

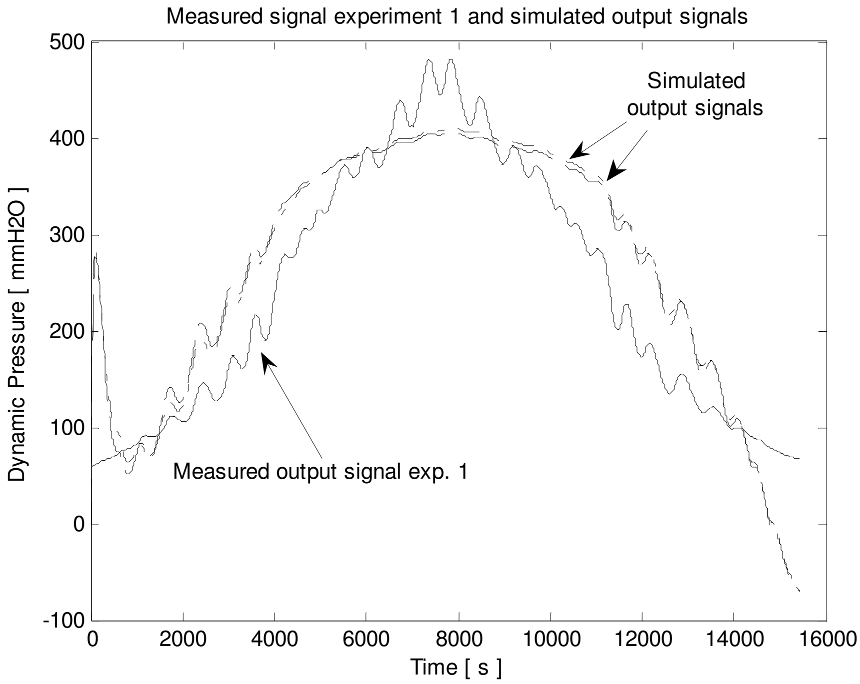


Figure 5. Measured and predicted outputs for the input used in experiment nº 1.

4. THE CONTROLLER

The basic structure of a PI controller is

$$u(t) = K_p \cdot e(t) + K_i \cdot \int_0^T e(t)dt \tag{1}$$

where *e(t)* is the tracking error.

The parameters *Kp* and *Ki*, were determined by using the model 1 with sampling period T = 0.1 s and an optimization technique .

The criterion for optimization was selected as

$$I'_{ISE} = J(Kp, Ki) = \sum_{k=1}^{n} e^2(k) \tag{2}$$

The parameters obtained for the controller using the Matlab "fminsearch" function taking as a starting point $K_p = 0.1$ e $K_i = 2$ were

$K_p = 0.1270$ and $K_i = 3.8469$

5. EXPERIMENTAL RESULTS

The PI controller was implemented in a data acquisition system model PXI and the National Instruments LabView 7.1 platform.

The experimental and simulation results were obtained adopting the optimal values for K_p and K_i.

Figure 6 shows the comparison between the measured output signal and the simulated output signal by application of reference signal at 400 mmH_2O.

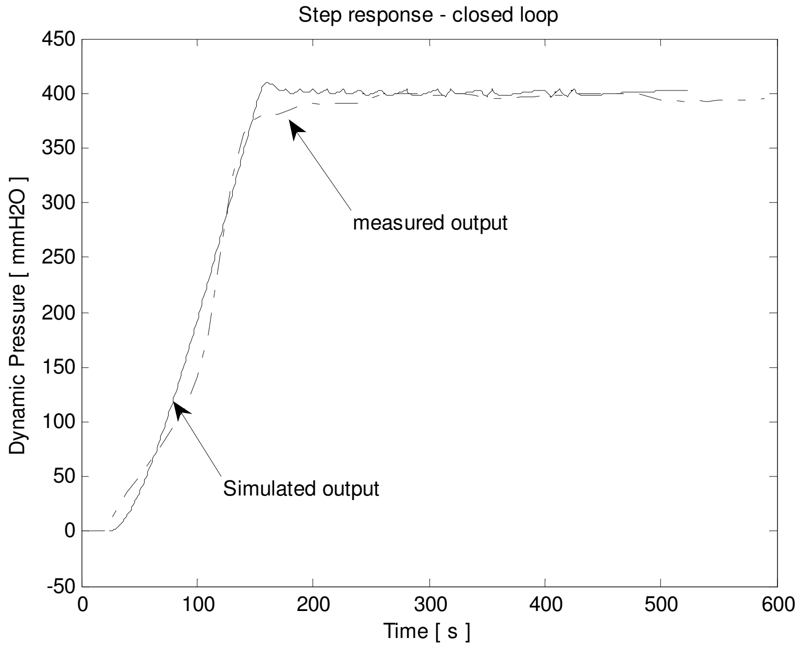


Figure 6. Step response : measured and simulated.

The rise times of both outputs are similar and they are faster than that obtained by the operator adjustment. So, the model was considered good enough for use up to range 400 mmH20.

6. CONCLUSIONS

The results obtained so far indicate that the implementation of the controller in the control system of the tunnel worked to reduce the time to perform the test.

Using the controller to adjust the desired dynamic pressure at test chamber has showing a better quality of test results when compare to the operator using a manual procedure to control the speed of the tunnel, who acts on the control acceleration or deacceleration, by means of visual inspection of the pressure gauge.”.

As future work, it will be designed a controller for the position of the blades, that operates together with the current system in regulating the speed of the flow in the section test.

7. ACKNOWLEDGEMENTS

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10. RESPONSIBILITY NOTICE