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FLUCTUATING PRESSURE MEASUREMENTS IN A INLET-ISOLATOR MODEL IN MACH 2 FLOW

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ABSTRACT

Fluctuating pressure measurements are performed as a preliminary effort to investigate the shock wave boundary layer interaction in a supersonic inlet model at Mach 2. Experiments are carried out in the 15x15 cm Trisonic Wind Tunnel located at the Istanbul Technical University. A supersonic inlet model with a sharp-edged shock generator (a 12-degree compression ramp) is designed and manufactured to be installed in the test section floor. The wind tunnel floor is modified to accommodate a plug specially designed to install a series of Kulite miniature pressure transducers flush with the surface. A considerable effort is made to design and manufacture the plug instrumented with Kulite transducers and the holders for the transducers in order to mount them in different points and combinations along the inlet floor. These implementations have led to gain a capability to perform unsteady and fluctuating pressure measurements in the Trisonic Wind Tunnel for complex flow problems such as the shock wave boundary layer interaction in a supersonic inlet model.

INTRODUCTION

The developing technologies for the future generation of hypersonic atmospheric and space vehicles are scramjet and ramjet propulsion. The dual-mode engine concept proposed by Curran and Stull allows the engine to act in ramjet mode at lower supersonic flight Mach numbers and then transition to scramjet mode at higher supersonic to hypersonic flight Mach numbers [Curran and Stull 1964]. Since the dual-mode proposal, much work has gone into understanding the complex flow fields involved, improving the performance of such engines, and developing methods of practical implementation.

In the dual-mode engine, the pre-combustion compression components are the inlet and the isolator [Curran, Heiser and Pratt, 1966]. The isolator is a duct connecting the inlet to the combustor. In addition to providing compression, the isolator also serves to reduce the sensitivity of the inlet to combustor pressure perturbations. The performance of a given isolator, as characterized by static pressure rise, total pressure recovery, shock system stability and exit flow uniformity, is dependent on isolator entrance flow conditions. In general, uniform isolator entrance flow profiles yield the most desirable isolator exit (and therefore combustor entrance) conditions [Emami et al., 1995; Bachchan and Hillier, 2004; Wang et al., 2005]

In this paper first, schlieren imaging was used to determinate the shock wave pattern and structure in and around the inlet-isolator model. Using the information gained from these observations locations of the pressure transducers was determined to obtain the pressure distribution and study the shock boundary layer interaction along the floor of the inlet-isolator model. These studies constitute the milestones for more comprehensive and advanced studies of inlet unstart which might result from shock wave boundary layer interactions and boundary layer separations.

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METHOD

Experimental Setup

Facility and Test Model:

Experiments were carried out in the trisonic blowdown wind tunnel at the Istanbul Technical University. The wind tunnel air is supplied by tanks with a volume of 80 m^3 at a pressure of about 2.7 MPa. Tests were conducted at temperature of T_0 = 293.15 K and freestream pressure of p_∞ = 0.36 atm. The nominal values of the freestream Mach number and velocity were 2.0 and 510 m/s, respectively. The test section was 15 cm wide by 15 cm tall and had a length of about 50 cm. Windows with a diameter of 24 cm at the wind tunnel sidewalls provided optical access to the test section. A schematic of the measurement system is shown in Fig. 1.

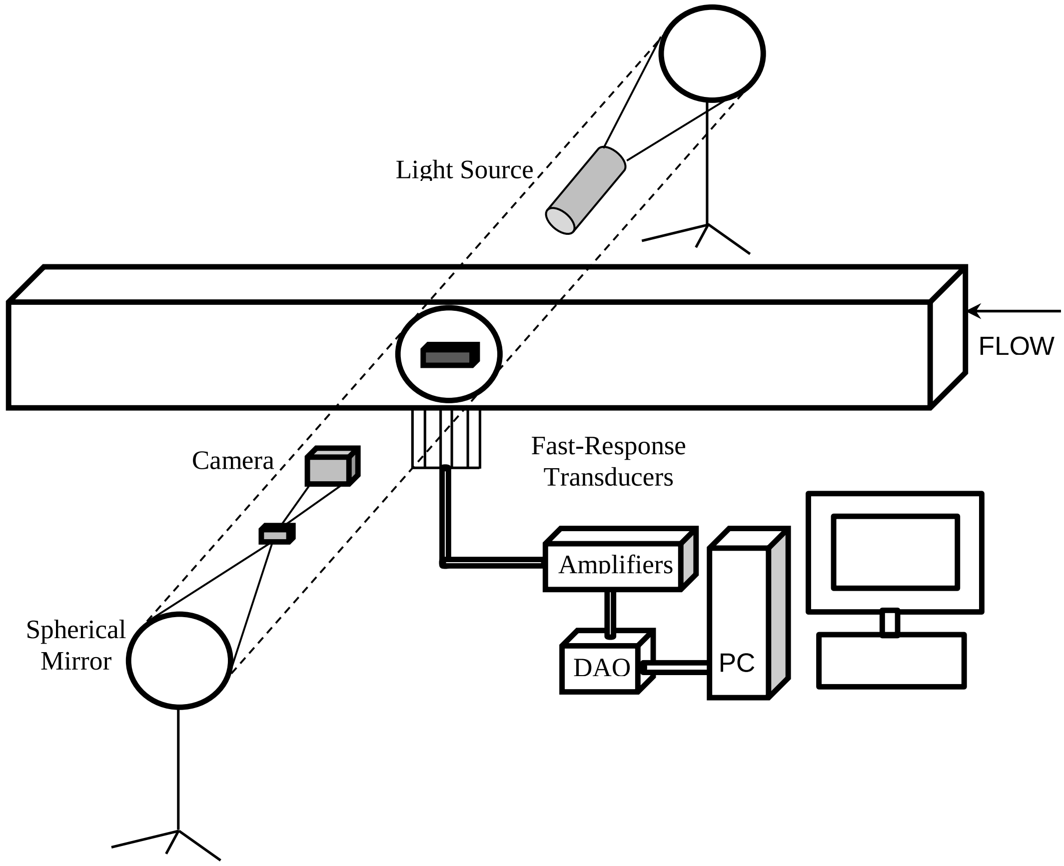

Figure 1: *Schematics of the model in the wind tunnel with schlieren imaging and fluctuating pressure measurements setup*

To perform unsteady pressure measurements test sections floor is re-designed and manufactured to fit the pressure transducers. Thus, we are able to make measurements at minimum 5 mm intervals in 35 different locations.

The inlet/isolator model was mounted on the floor of the test section as shown in Fig. 2. Figure 2 shows schematics of the model. The inlet portion of the model consisted of a 12-deg compression ramp. The inlet entrance height H_0 and the throat height at the entrance of the isolator h were 58 mm and 50 mm, respectively. The isolator and inlet were 137.4 mm and 37.6 mm long, respectively. The inner width of the model was 44 mm giving an inlet entrance aspect ratio of 0.76 and an isolator aspect ratio of 0.88. The model was a bolted assembly of four pieces. The upstream piece, made out of aluminum, contained the ramp and the isolator throat. The rest of the isolator was formed from an aluminum ceiling and two acrylic sidewalls to allow optical access. This resulted in a streamwise length of 143.1 mm where the flow within the isolator could be visualized. The thickness of the all three isolator pieces was 8 mm.

As shown in Fig. 2 the tunnel floor had a brass plug with 35 holes for mounting the transducers flush with the surface in minimum 5 mm intervals. 6 transducers would be mounted using any six of these 35 ports at a time. A row of six fast-response pressure transducers were flush mounted in a row at the centerline of the inlet-isolator model. The transducers had an effective frequency response of 50 kHz. Two types of transducers (Kulite XCEL-072-25A and Kulite XCLE-072-50A) with ranges of 0–170 kPa and of 0–350 kPa were used both to obtain the pressure distribution along the inlet-isolator and also to measure the fluctuating pressures for the investigation of the unsteadiness caused by the shock wave boundary layer interaction within the inlet-isolator. A flat-type fast-response Kulite transducer (LQ-125-15A) with a range of 0–100 kPa was mounted in the most upstream location of the pressure plug to obtain the freestream static pressure since this location would always be upstream of any shocks caused by the inlet. This transducer is identified as T0 in subsequent sections.

Since Kulite transducers used in the study do not come with any sort of mounting means such as a screw thread or a similar mechanism, special holder-sleeves with outer threads have been designed and manufactured both to protect the transducers from mechanical damage and to enable them to be re-installed in a given pressure port on the pressure plug. Transducers were placed and fixed in these sleeves so that they could be mounted in a given port and then moved to another port if needed. Ports without transducers were filled with blank plugs specially manufactured from standard screws to fit in these holes for sealing the flow within the inlet from conditions under the bottom of the tunnel floor.

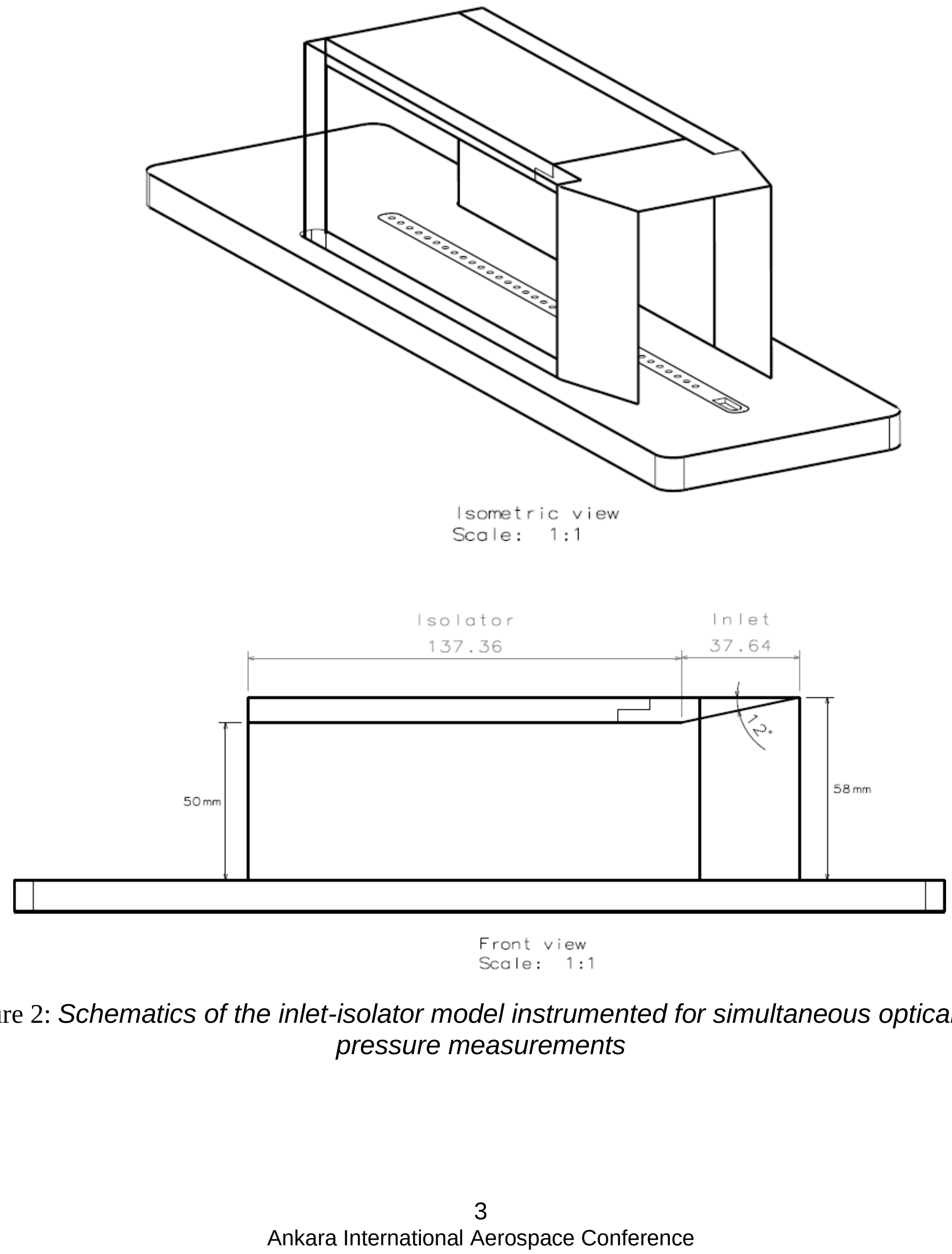

Figure 2: *Schematics of the inlet-isolator model instrumented for simultaneous optical and pressure measurements*

Calibration of Pressure Transducers:

Transducers were calibrated for their output voltage in order to obtain the maximum signal resolution for data acquisition using the signal conditioning units that came with them. For the calibration process, a vacuum/pressure box with provisions to supply a range of pressures was manufactured. As shown in Fig. 3, a vacuum pump (Value 1-Stage), an analog absolute pressure gauge (Wallace&Tiernan 1500 Series), a differential DC amplifier (Tesar-Elektronik AW980-A4S), and a digital pneumatic calibrator (Wallace&Tiernan DPE750) were connected to the vacuum/pressure box. Using this setup, absolute pressures from 0.000725 psi to 50.000 psi can be applied to pressure transducers placed in the box. The signals from differential DC amplifier output sent to A/D card (National Instruments DAQ PCI-6110E). To perform the calibration and measurements an in-house LabView code is prepared and used.

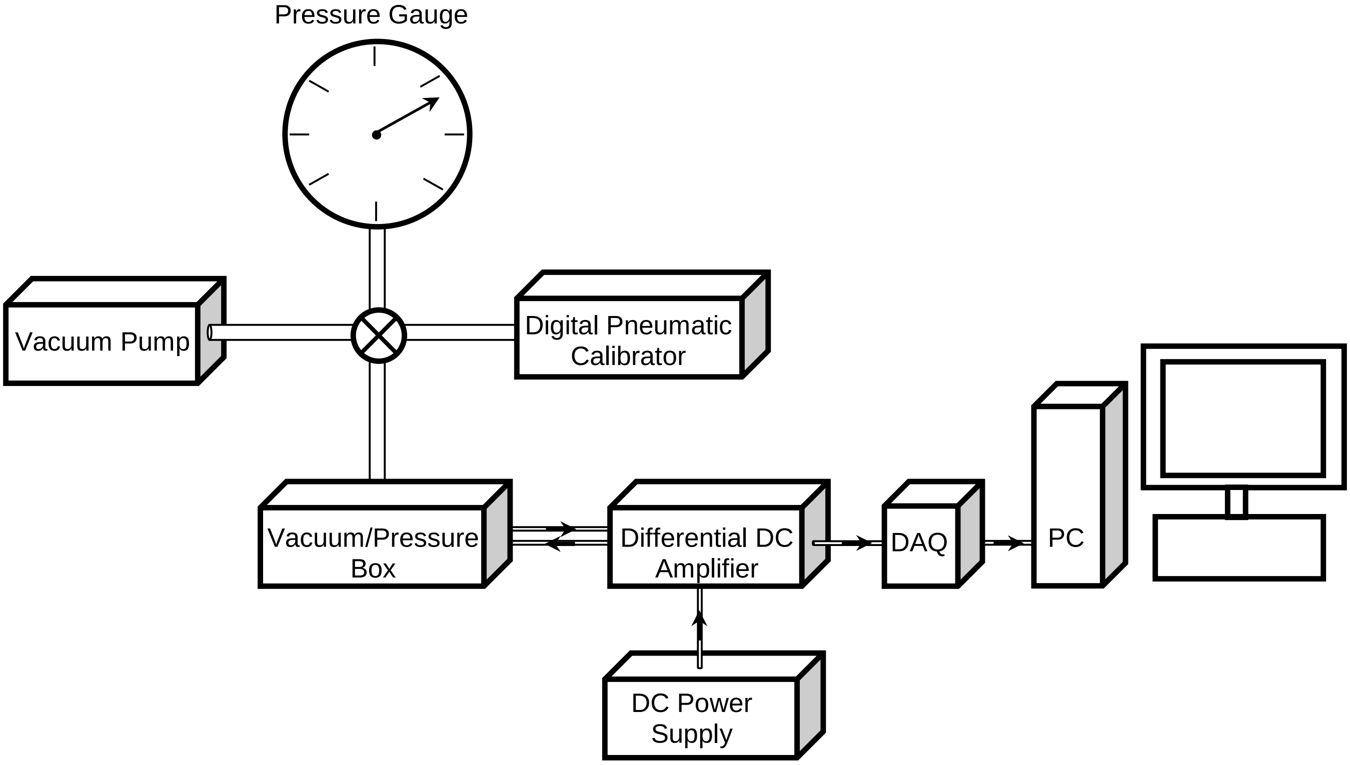

Figure 3: *Schematic of the setup for calibration of pressure transducers*

Fast-Response Pressure Measurements:

For the measurement of fluctuating pressures a row of 7 fast response pressure transducers (Kulite; XCLE-072-50A (3 pieces), XCEL-072-25A (3 pieces) and LQ-125-15A (1 piece) were flush mounted with different combinations in the spanwise centerline of the inlet-isolator model. The transducer signals were each sent through a differential DC amplifier and then the signals were digitized at a rate of 200 kHz with two A/D cards installed in a personal computer. The A/D cards were controlled by a Labview code.

RESULTS

Figure 4 shows a schlieren image taken during the run for a freestream Mach number of approximately 2. White lines mark the floor, 12-deg ramp, and the isolator ceiling. The inlet section is seen in shadow because they are made of aluminum. The initial oblique shock from the inlet ramp is seen as dark line (arrow 1). The first reflected shock impinges on the isolator ceiling (arrow 2). The subsequent reflected shock is seen as a dark line (arrow 3), which then reflects again from the isolator floor (arrow 4). Regions of shock wave / boundary layer interactions are seen on the isolator throat floor (arrow *A*) and around the area where the second reflection from the isolator floor takes place (arrow *B*).

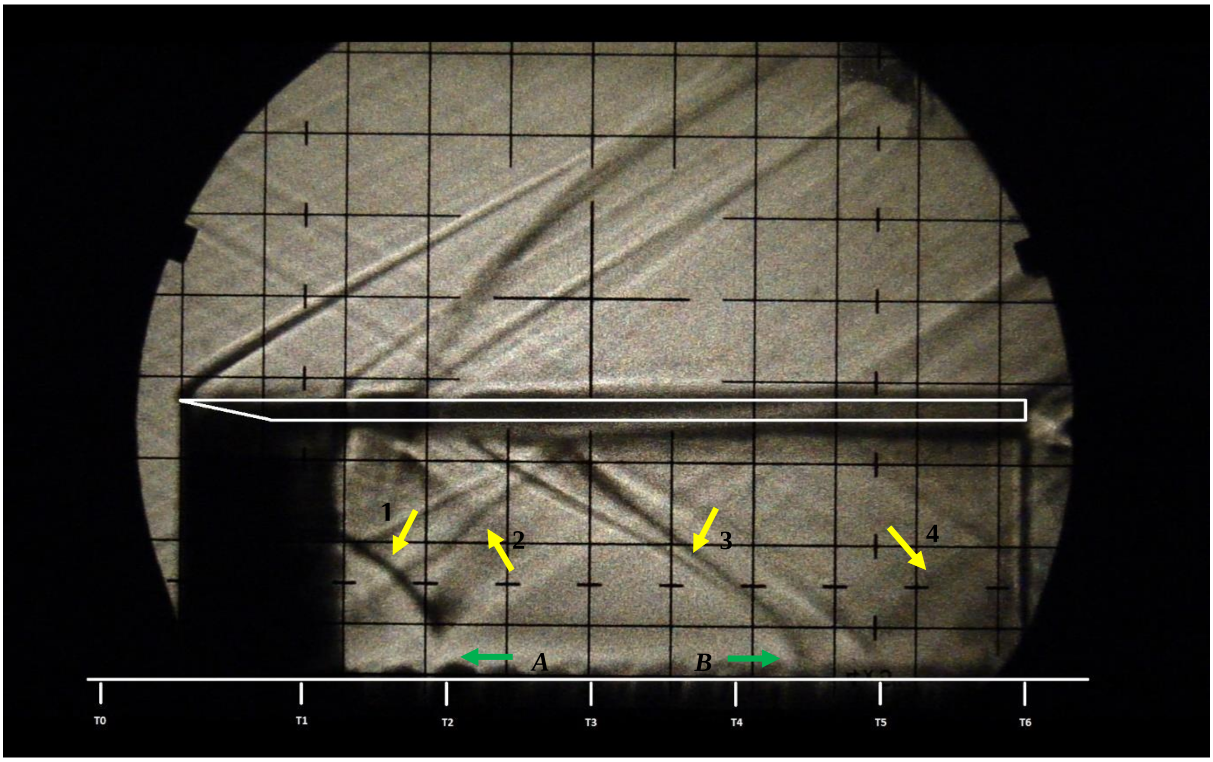

Figure 4: *A sample schlieren image of flow in the inlet-isolator model at Mach 2.*

Locations of the pressure transducers on the surface of the isolator floor were determined from the schlieren images and pressure measurements were made along the surface. Thus, transducers were installed at every 6 holes giving a 30 mm distance between them to obtain an overall pressure distribution along the floor of the inlet-isolator model. From these measurements both the mean and rms of surface pressures were obtained. The mean P_m and rms σ pressure distributions are shown in Figure 5. All pressures reported herein are normalized by that measured at transducer T0 because the same values measured at empty test section and when the model was mounted to test section. More clearly the pressure at T0 was measured to be 37.1 kPa (5.381 psi) that is equal to the free stream pressure P_∞. A representative schlieren image during the period at which the pressure data are taken is shown in Figure 5a. Inlet ramp / isolator ceiling and the corresponding locations of the transducers on the floor are shown schematically in Figure 5a. Figure 5b shows that the shock wave/boundary layer interaction has a major effect on the pressure along the wall from T0 ($x/h = \mathbf{0.33}$) upstream of the inlet to T1 ($x/h = \mathbf{0.503}$) within the inlet portion of the model. An additional pressure increase is seen at T2 ($x/h = \mathbf{1.103}$) and T3 ($x/h = \mathbf{1.703}$). At T3, the flow has been processed by the 12-deg ramp shock as well as the first reflected oblique shock. Using inviscid oblique shock theory, the pressure ratio of the free stream to that processed by two oblique shocks with flow deflection angles of 12-deg is computed to be 1.86. The pressure ratio P3/P1 is measured to be 1.866, which is in good agreement. As the flow passes through reflections of the inlet shoulder expansion fan, the pressure decreases across T4 ($x/h = \mathbf{2.303}$). Moving downstream, at T5 ($x/h = \mathbf{2.903}$) the pressure increases again for the same reason as T2. Finally the pressure decreases at the isolator exit where T6 ($x/h = \mathbf{3.503}$) was mounted.

The rms pressure distribution shows that T1 has the highest pressure fluctuations. Location of T1 corresponds to the upstream of ramp-shock impingement where the shock-boundary layer interaction takes place and therefore the resulting separated flow causes relatively large amplitude fluctuations. The amplitude of the pressure fluctuations generally decreases as the streamwise distance increases along the inlet/isolator.

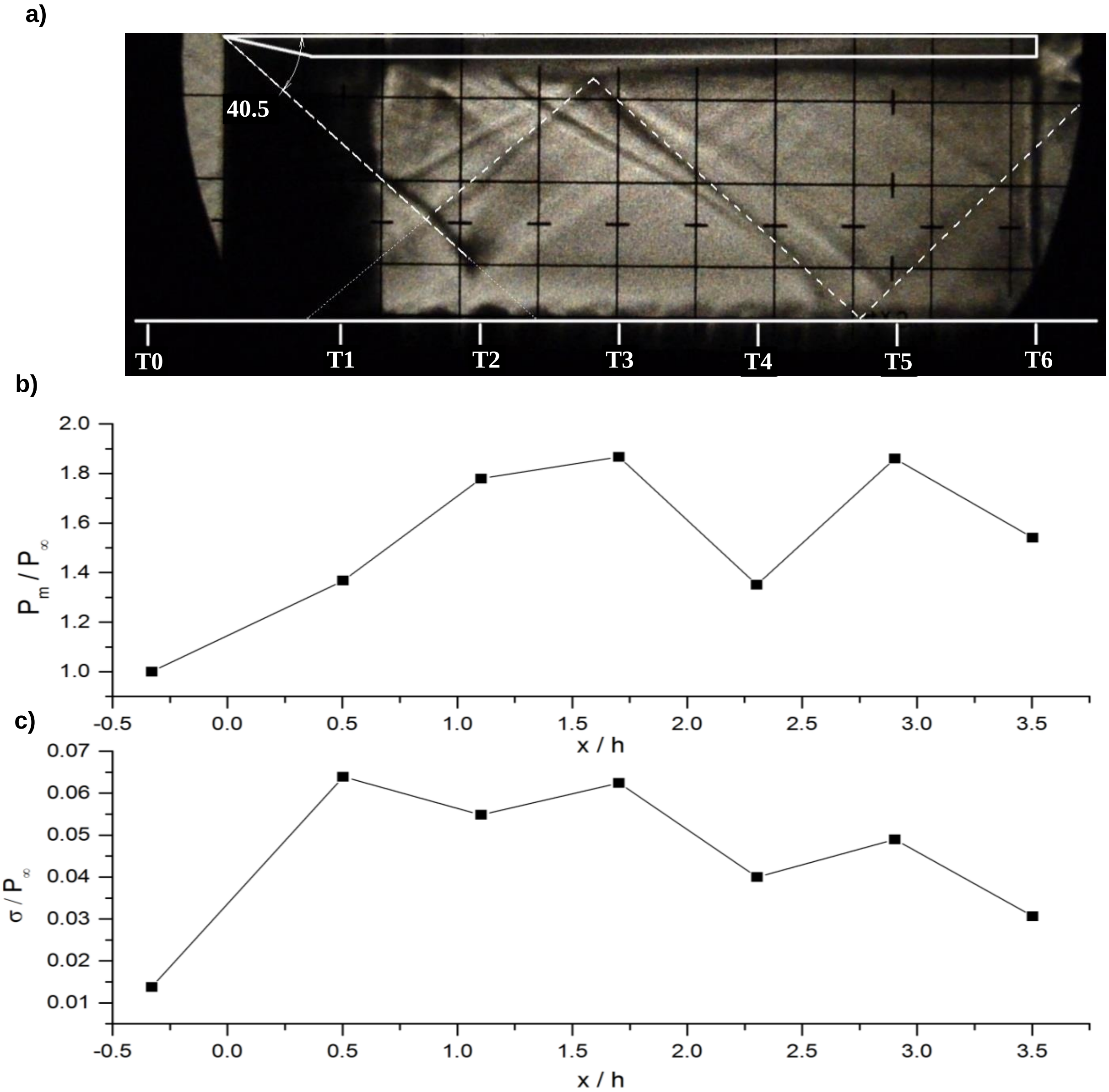

Figure 5*: a) A schlieren image b) Mean pressure distribution along the inlet/isolator model c) Standart deviation of mean pressure*

CONCLUSIONS

Schlieren imaging and fluctuating pressure measurements were performed in a supersonic inlet model at Mach 2. The model has an inlet with a 12-deg compression ramp and a rectangular isolator. An oblique shock from the inlet ramp and reflected shock waves were observed by schlieren imaging method. Schlieren images also helped to have an idea of where to install the pressure transducer on the surface of the model floor. Pressure data were obtained at rate of 200 kHz and normalized with the free stream pressure which was measured by a transducer (T0) located slightly upstream of the inlet. The influence of the shock wave/boundary layer interaction occurring on the floor caused by the impingment of the ramp oblique shock on the pressure along the wall was detected by the first upstream transducer (T1) within the inlet, which had higher pressure fluctuations than those of other transducers downstream. In the next phase of the study frequency content of the pressure fluctuations will be obtained by performing power spectral analysis of the pressure signal with proper digital filtering techniques to determine whether separation region upstream of the impingment shock has the low frequency expansion and contraction behavior observed in previous studies caused by the interaction. In addition, locations of the transducers will be changed to obtain a better-resolved measurement within the interaction area.

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