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Plenum Response to Simulated Disturbances of the Model and Fan Inlet Guide Vanes in a Transonic Tunnel

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Plenum Response to Simulated Disturbances of the Model and Fan Inlet Guide Vanes in a Transonic Tunnel

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National Aeronautics
and Space Administration

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Information Branch

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SUMMARY

To design the National Transonic Facility (NTF) control system a knowledge of the tunnel response to disturbances is required. To aid in the design of the NTF control system, test section/plenum response studies were carried out in a 0.186-scale model of the NTF high-speed duct. Simulated in this study were two types of disturbances, those induced by the model and those induced by the compressor inlet guide vanes. Some observations with regard to the test section/plenum response tests are summarized as follows. A resonance frequency for the test section/plenum area of the tunnel of approximately 50 Hz was observed for Mach numbers from 0.40 to 0.90. However, since the plenum is 3.1 times (based on volume) too large for the scaled size of the test section, care must be taken in extrapolating these data to NTF conditions. The plenum pressure data indicate the existence of pressure gradients in the plenum. The test results indicate that the difference between test section static pressure and plenum pressure is dependent on test section flow conditions. Plenum response to inlet guide vane type disturbances appears to be slower than plenum response to test section disturbances.

INTRODUCTION

The National Transonic Facility (NTF), a fan-driven transonic, pressurized, cryogenic wind tunnel, will bridge the gap between the Reynolds numbers attained in conventional wind tunnels and flight Reynolds numbers. This facility will operate at Mach numbers from 0.10 to 1.20, stagnation pressures from 1.00 to 8.96 bars, and stagnation temperatures from 80 to 353 K. The design Reynolds number capability of this wind tunnel is 120×10^6 based on a reference length of 0.25 m (the NTF has a square, 2.5 m by 2.5 m, test section with filleted corners) at a Mach number of 1.00. The test media in the NTF is gaseous nitrogen or air. In the cryogenic mode, the tunnel and test media, gaseous nitrogen, are cooled to cryogenic temperatures with liquid nitrogen injected into the tunnel stream, and in the ambient temperature mode the tunnel and air are held at a constant temperature by the use of a water-cooled heat exchanger installed in the settling chamber. For further details concerning the NTF see references 1 to 5.

The flow processes for the NTF will be automatically controlled with the aid of onsite computers; this control system is briefly described in reference 5. To design the NTF control system a knowledge of the tunnel response to disturbances is required. The most difficult area of the tunnel to estimate tunnel response to disturbances is the test section/plenum region. Thus, the test section/plenum response to tunnel disturbances produced by simulated model attitude change and compressor inlet guide vane change was obtained in a scale model of the NTF high-speed duct. This paper will describe those results of this plenum response study which should be useful in the NTF control system design.

SYMBOLS

The physical quantities used in this paper are given in the International System of Units. Note all pressures are given in bars or millibars; 1 bar = 100 kPa.

M	reference free stream Mach number
p_p	plenum pressure, millibars
Δp_p	$= p_p - (p_p)_{t=0}$, millibars
p_s	wall static pressure, millibars
Δp	$= (p_s - p_p) - (p_s - p_p)_{t=0}$, measured 83.34 centimeters from the tunnel throat (see fig. 6), millibars
p_t	stagnation pressure as measured in the settling chamber, bars
T_t	stagnation temperature in the settling chamber, kelvins
x	longitudinal distance measured from tunnel throat, centimeters

Subscript:

t	time, seconds

MODEL DESCRIPTION

The plenum response tests were performed in a 0.186-scale model of the high-speed duct of the NTF (hereinafter referred to as the diffuser flow apparatus, DFA). The other portions of the circuit are not representative of the NTF. A schematic of the complete circuit is shown in figure 1, and it will be noted that the return portion is very tortuous and does not represent the return legs of the NTF. The implication of this will be discussed later. Also, as illustrated in figure 1, the DFA is vented to atmospheric pressure. In addition, the DFA plenum was made 3.1 times (based on volume) larger than the correct scaled size to allow convenient access to the test section area.

To simulate a test section disturbance produced by a model change of attitude, and a disturbance produced by compressor inlet guide vane change, two different models were installed, at different times, in the DFA at the locations indicated in figure 2. The test section disturber, which consists of two small vanes attached to 1.27-cm-diameter rods, is shown in figures 3 and 4. The rods are geared together so that the vanes rotate in opposite directions producing a symmetric disturbance in the test section. The vanes may be driven by either a piston type activation device, which rotates the vanes 90° simulating a step change in model attitude, or an electric motor, which provides continuous rotation of up to 3000 rpm simulating a dynamic disturbance in the test section.

The inlet guide vane type disturbance was simulated by the model shown in figure 5 and located in the DFA as shown in figure 2. The diameter of the duct at the disturber location is approximately 101 cm. Since there are extensive flow treatment devices between the disturber and the test section (fig. 1), the turbulence produced by this disturber was not an element of consideration in this test.

INSTRUMENTATION

Figure 2 shows the locations and identifies the instrumentation in the settling chamber. Figure 6 shows the locations and identifies the instrumentation in the test section/plenum region. All of the pressure gages used for measuring tunnel response were capable of measuring pressure oscillations of over 100 Hz. The thermocouple located in the settling chamber was constructed of 0.508-mm-diameter wire. Since the thermocouple in the plenum was constructed of 0.0508-mm-diameter wire, it was much more responsive than the settling chamber thermocouple.

The position time history of the different disturbers was obtained using variable resistance potentiometers and a tachometer.

In addition, wall static-pressure orifices were located along the sidewall center line (fig. 6). The wall static-pressure orifices were used to obtain the steady state sidewall static-pressure distribution through the test section. The absence of a pressure trace on a data figure will indicate that for that particular case the amplifier sensitivity was improperly set and the data for that trace was not recoverable.

RESULTS AND DISCUSSION

Simulated Model Disturbance

The disturbance produced by the movement of the test section vanes (figs. 3 and 4) located in the DFA simulates a disturbance in the NTF test section produced by a model change of attitude. The rods holding these vanes produce 5.52 percent solid blockage in the test section while the vanes present an additional 2.00 percent blockage when normal to the free stream. With this hardware in the test section the maximum attainable Mach number in the test section was approximately 0.9. As noted earlier there are two modes of operation for this disturber, continuous rotation and step change.

Continuous mode.- No physical data for these tests are presented since all conclusions were reached from observations made during the tests. The rotational speed of the vanes was gradually increased while monitoring the output from the pressure instrumentation in the plenum and test section. A resonance frequency of approximaely 50 Hz was observed for Mach numbers from 0.40 to 0.90. Before extrapolating this resonance frequency for the NTF, consideration must be given to scale effects as well as the fact that the plenum was not properly scaled, as noted earlier.

Step mode.- For this mode of operation the vanes were rapidly rotated 90° producing a change in the vane position which closely approximates a step change. For all the results presented, the vanes are initially positioned so that the longitudinal axes are parallel to the free stream direction to produce minimum blockage and then rotated such that the longitudinal axes are perpendicular to the flow to produce maximum blockage. After the tunnel flow is again at steady state conditions, the vanes are rotated back to the original position. Figure 7 presents the plenum response data for this type of disturbance at Mach numbers of 0.60, 0.70, 0.80, and 0.90. Since the Mach numbers used to identify the different run conditions were obtained from steady state plenum pressure and steady state stagnation pressure measured just prior to the disturber movement, these Mach numbers should be taken as reference conditions and do not imply that the test section Mach number remains constant throughout a test. The Δp versus time traces for Mach numbers 0.60, 0.70, and 0.80 (fig. 7) indicate that the plenum response is quite fast with the plenum lagging the test section by less than 0.05 sec. However, at a Mach number of 0.90 the plenum appears to lag the test section by approximately 0.5 sec (fig. 7). The steady state sidewall static-pressure gradients produced by the model hardware in the test section are shown in figure 8. At the free stream Mach number of approximately 0.90, the data in figure 8 indicate that the tunnel is either choked or very nearly choked at the downstream edge of the test section (since the total pressure is not accurately known at the downstream edge of the test section, the local Mach number cannot be exactly determined). This choking condition at a test section Mach number of 0.90 most likely accounts for the delay in plenum response noted above for a Mach number of 0.90. It should be noted here that the sidewall static-pressure distributions for test section Mach numbers less than 0.90 do not indicate this choking condition at the downstream edge of the test section. It should not be assumed from this discussion that the NTF will choke at the downstream edge of the test section, since the geometry of the NTF is variable in this vicinity and increasing the reentry gap height would eliminate the choking. Figure 9 shows a sketch of the reentry region of the NTF. The magnitude of the pressure difference between the plenum and test section appears to be determined by the flow conditions in the test section for a given test section Mach number (fig. 7).

For all the different Mach number test cases shown in figure 7, the plenum pressure Δp_p versus time traces indicate a response time of the order of 7 sec; likewise, since the Δp gage indicates a rather fast response, the static pressure in the test section would also indicate this rather long response time. The long time constant is due to the complete circuit requiring some time to reach an equilibrium condition; this should not be surprising since the DFA circuit is rather tortuous (fig. 1). As can be seen in figure 7, there is a measurable pressure gradient in the plenum as indicated by the different pressure levels in the plenum. Note the difference between the pressure levels of both gages 1 and 3 from that of gage 2. Figure 6 shows that gage 2 is directly above the six slots in the test section ceiling and thus is probably in an area where there is some circulation of air in the plenum; while gages 1 and 3 are located in areas of the plenum where the air movement is probably much less than at the location of gage 2.

Simulated Guide Vane Disturbance

The simulated guide vane disturber (fig. 5) was located in the DFA as shown in figure 2. For all the results presented, the flaps are initially deployed in the high loss configuration and then folded back in such a manner that the airstream aided the desired movement. These tests were run in this fashion since for the higher Mach numbers the drive was not powerful enough to open the flaps up against the flow quickly enough. The plenum response data for the simulated guide vane disturbance is shown in figure 10. As noted earlier, the Mach numbers used to identify the different cases are reference Mach numbers and should not be taken to mean that the Mach number remains constant throughout a run.

In general, when the disturber was actuated there is an immediate increase in settling chamber stagnation pressure followed by a very gradual stagnation pressure rise associated with the DFA circuit adjusting to the disturbance. As would be expected, there is a plenum temperature change associated with the flow disturbance.

In analyzing the data, recall from figure 2 that the disturber is located just downstream of an atmospheric vent; thus, the steady state static pressure at this location remains constant and steady state stagnation pressure just downstream of the disturber will increase after the disturber flaps are folded back. It is therefore understandable that the steady state plenum pressure need not decrease after the disturber is activated and the flaps fold back, and in fact the data in figure 10 show that the steady state plenum pressure increases when the disturber flaps have folded back. For this type of disturber, distinguishing between plenum response and tunnel circuit response becomes very difficult. When the flaps are folded back, there is an almost immediate increase in mass flow accompanied by a reduction in plenum pressure; however, since the tunnel circuit cannot sustain these flow conditions, the plenum pressure starts to increase. The duration and magnitude of these unsteady flow conditions are a function of the geometry of the tunnel circuit and since the DFA circuit does not model the NTF, these plenum response data (fig. 10) should be carefully studied before making any quantitative conclusions. Although nothing quantitative will be said about the plenum response, the Δp traces in figure 10 seem to allow the qualitative statement that plenum response to this type of disturbance is slower than for that of a test section disturbance.

CONCLUDING REMARKS

To aid in the design of the National Transonic Facility (NTF) control system, test section/plenum response studies were carried out in a 0.186-scale model of the NTF high-speed duct. Simulated in this study were two types of disturbances, those induced by the model and those induced by the compressor inlet guide vanes. Some observations with regard to the model tunnel tests are summarized below.

1. A resonance frequency for the test section/plenum area of the tunnel of approximately 50 Hz was observed for Mach numbers from 0.40 to 0.90. However, since the plenum is 3.1 times (based on volume) too large for the scaled size of the test section, care must be taken in extrapolating these data to NTF conditions.

2. The plenum pressure data indicate the existence of pressure gradients in the plenum.

3. The test results indicate that the difference between test section static pressure and plenum pressure is dependent on flow conditions in the test section for a given test section Mach number.

4. Plenum response to inlet guide vane type disturbances appears to be slower than plenum response to test section disturbances.

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September 5, 1980

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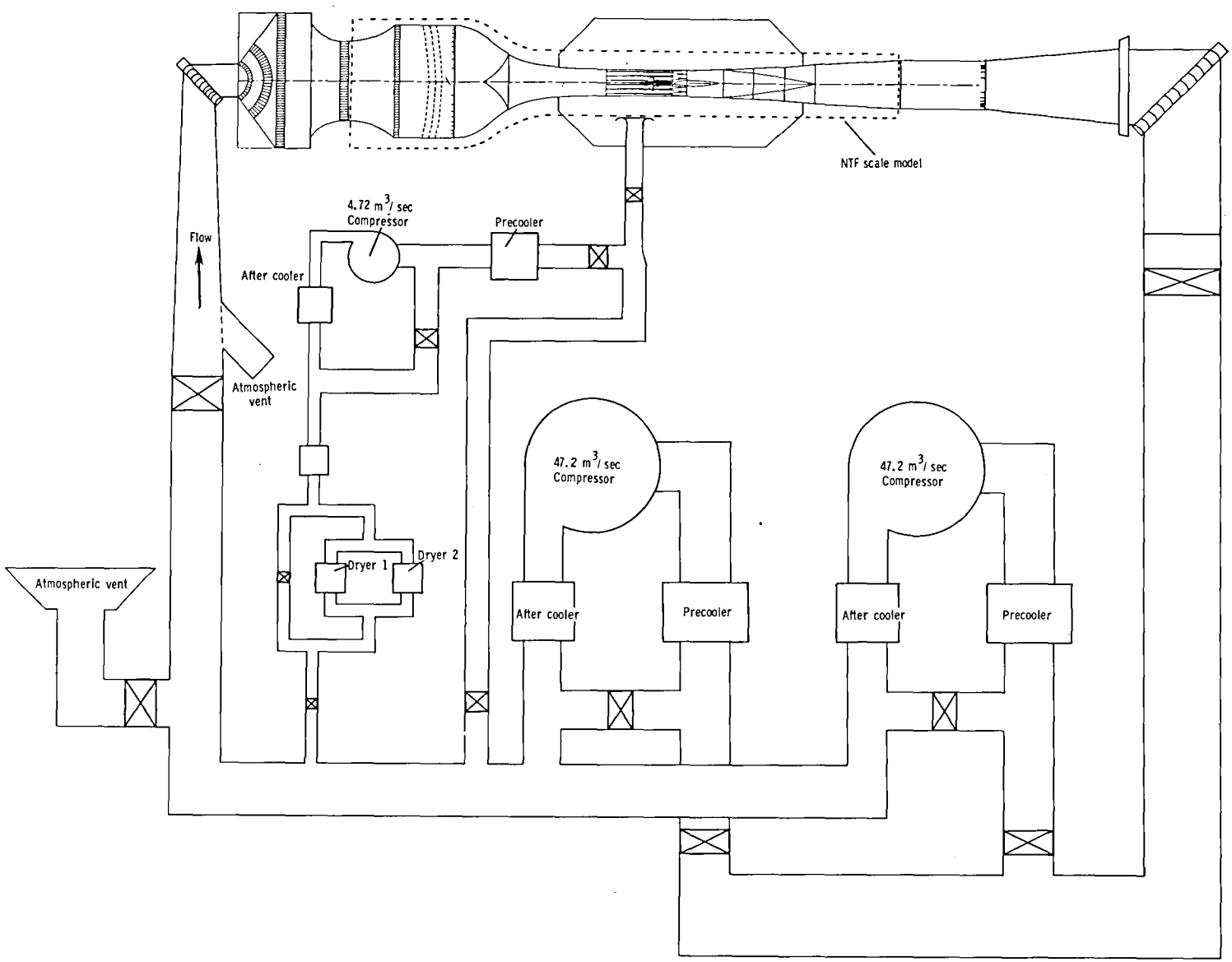

Figure 1.- Schematic of the diffuser flow apparatus.

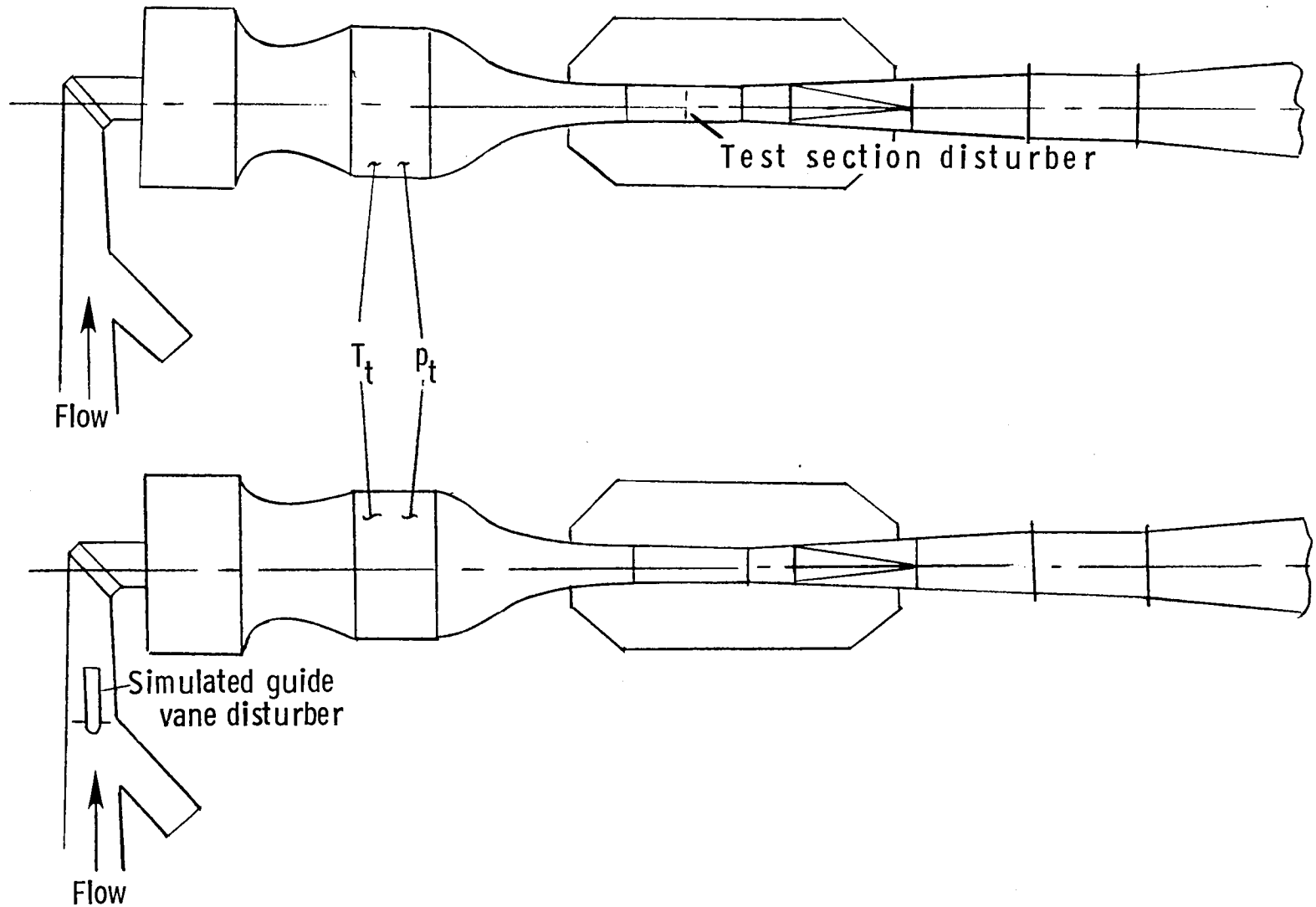

Figure 2.- Sketch of disturber locations.

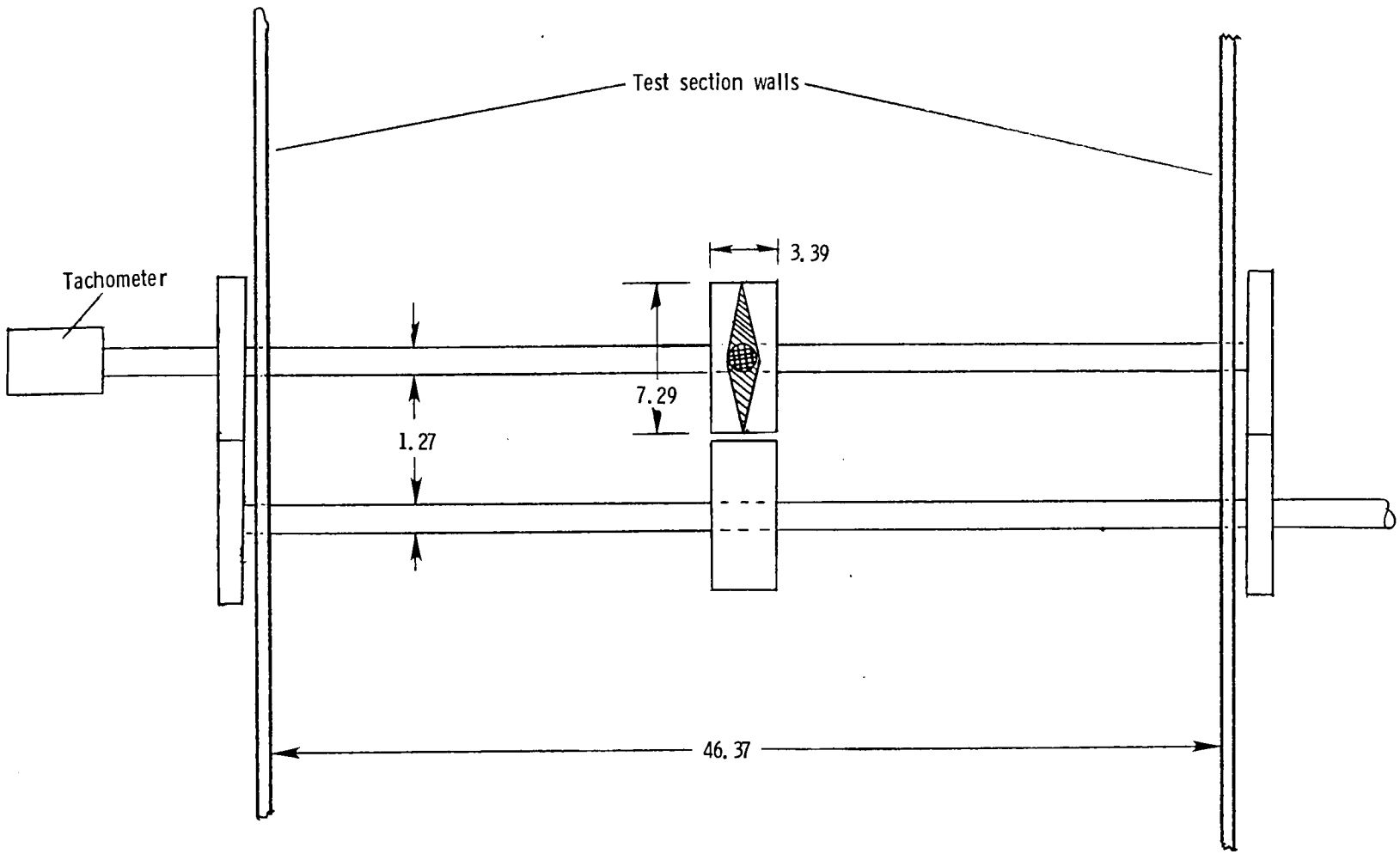

Figure 3.- Tunnel cross-section view of the test section disturber. All dimensions are in centimeters.

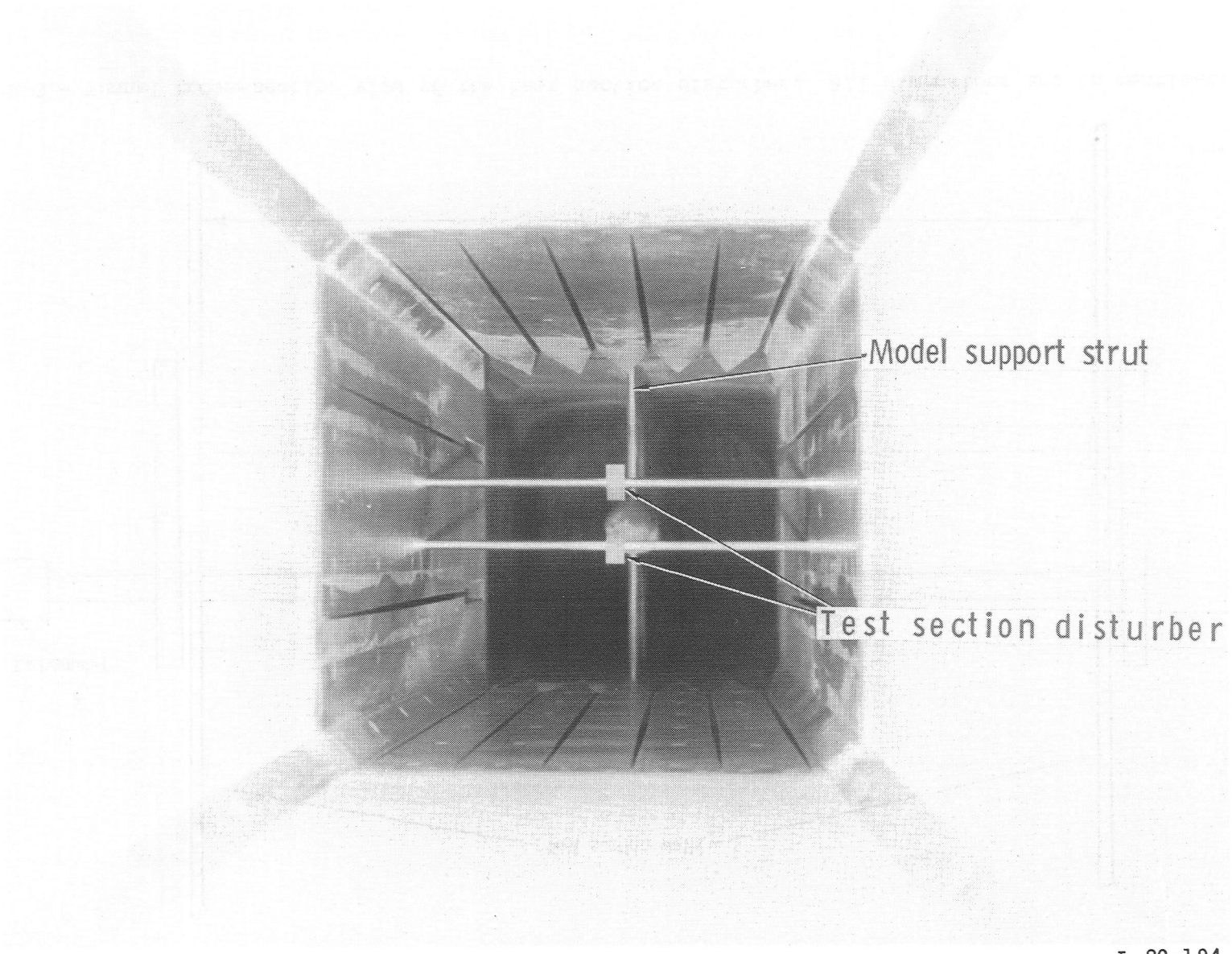

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Figure 4.- Photograph of the test section disturber.

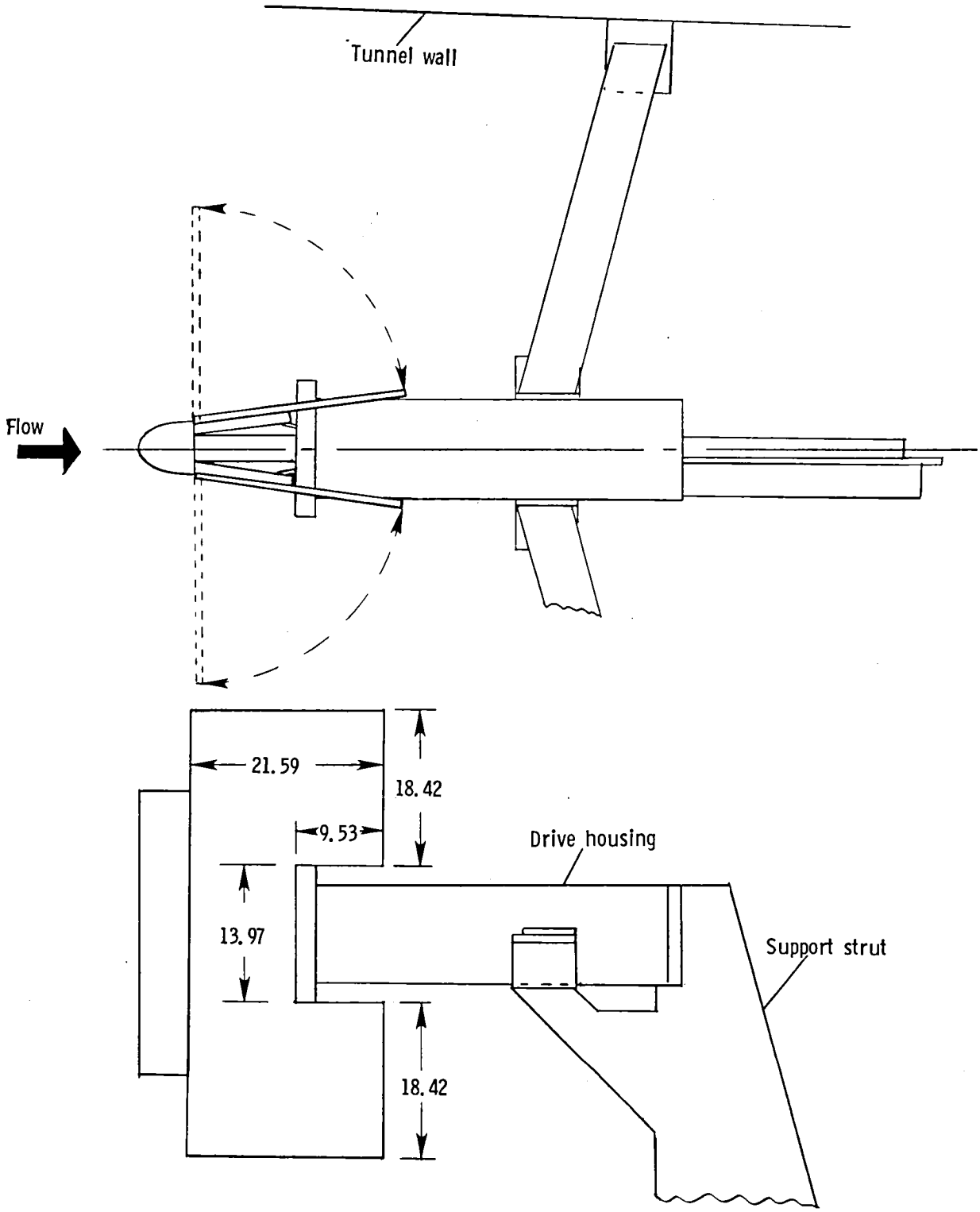


Figure 5.- Sketch of the inlet guide vane type disturber. All dimensions are in centimeters.

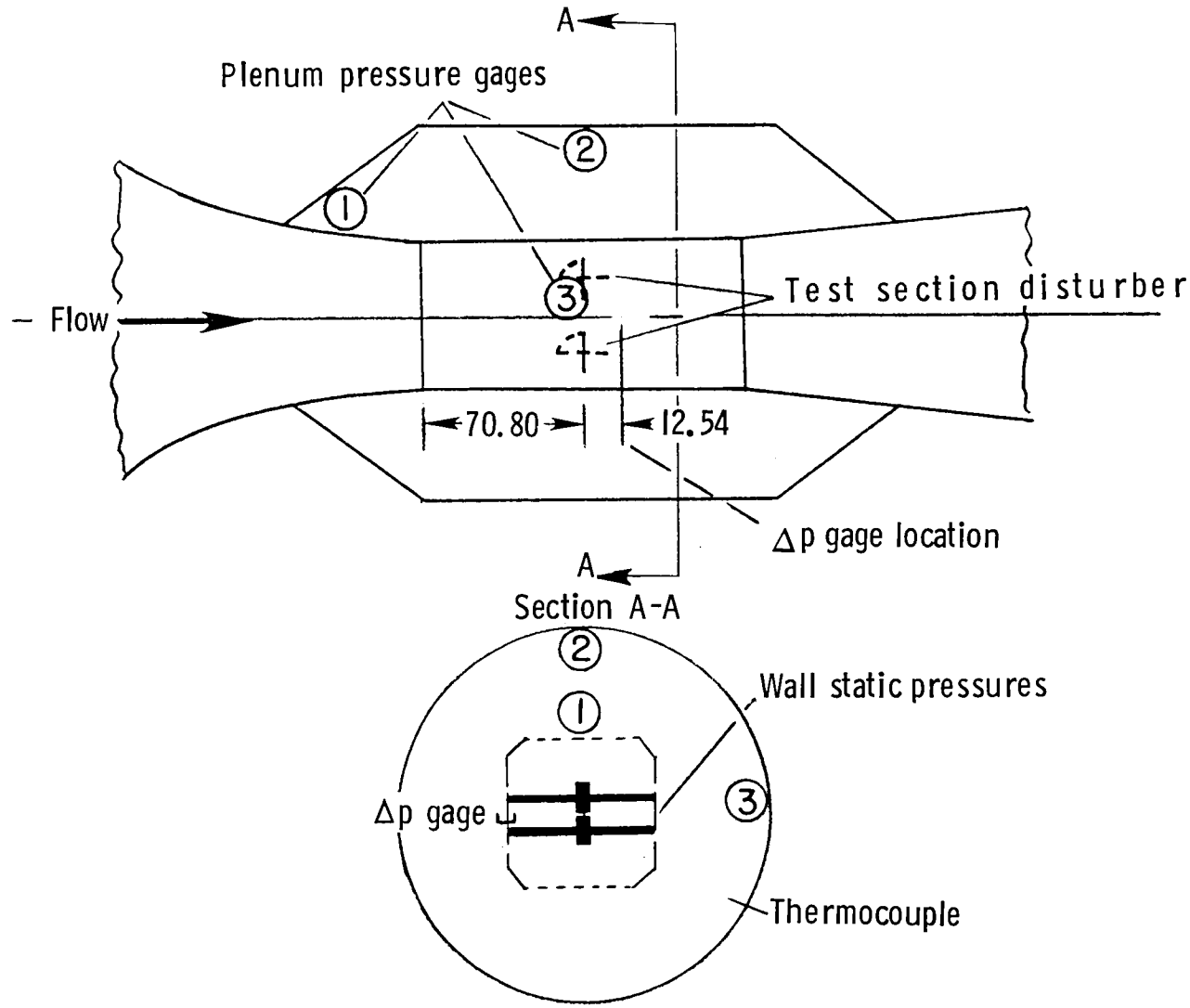
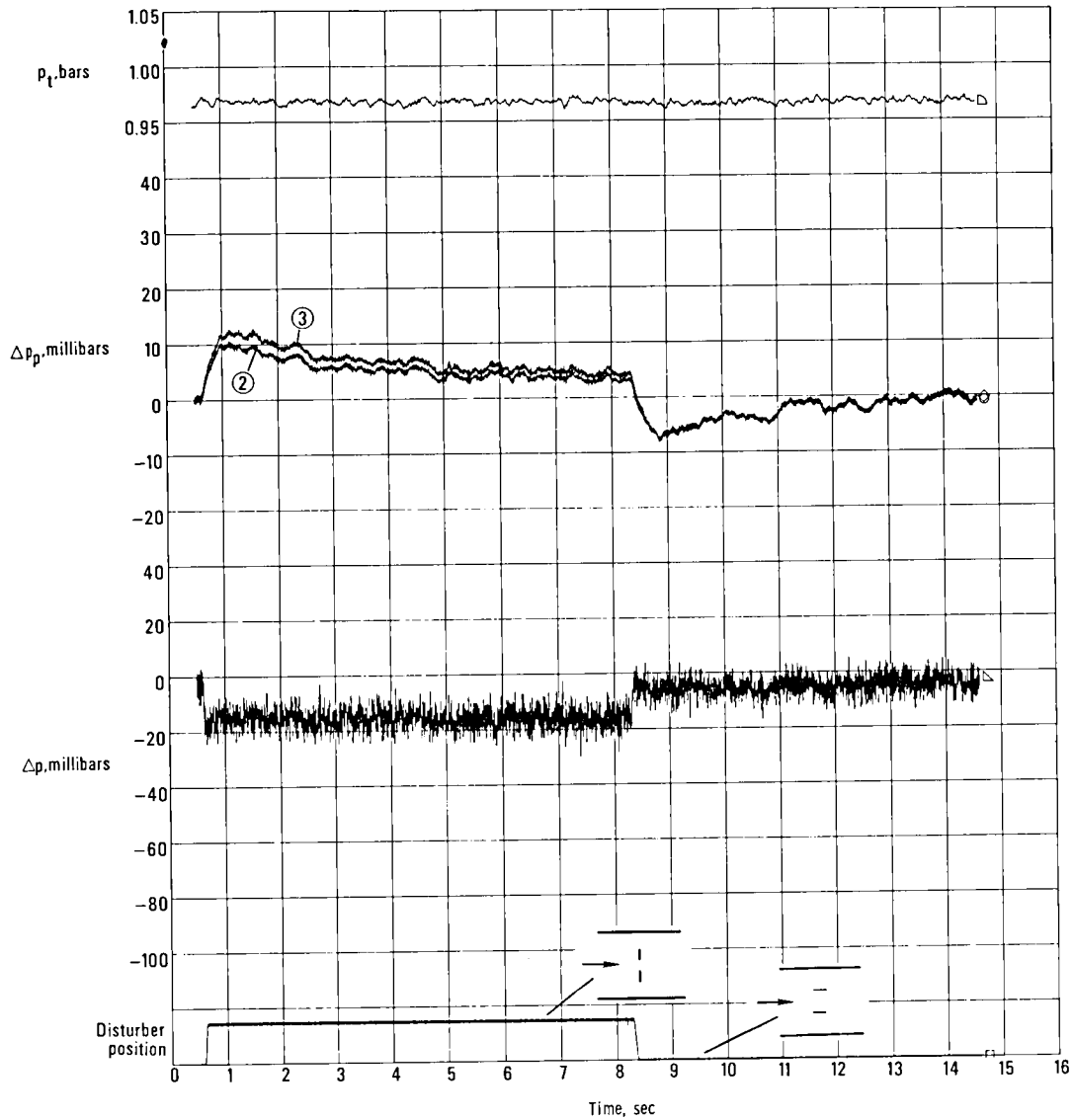
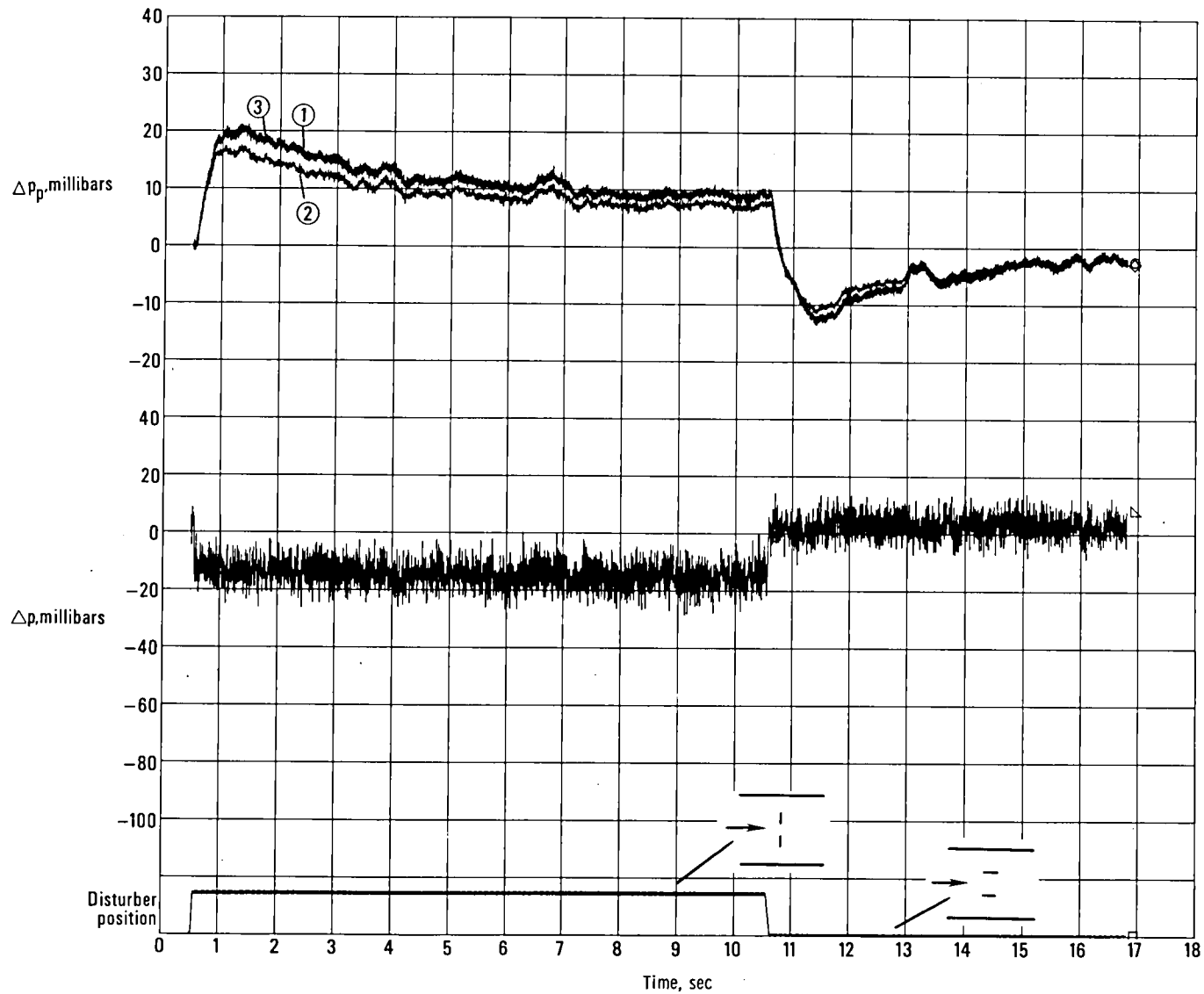


Figure 6.- Location of test-section/plenum instrumentation. All dimensions are in centimeters.



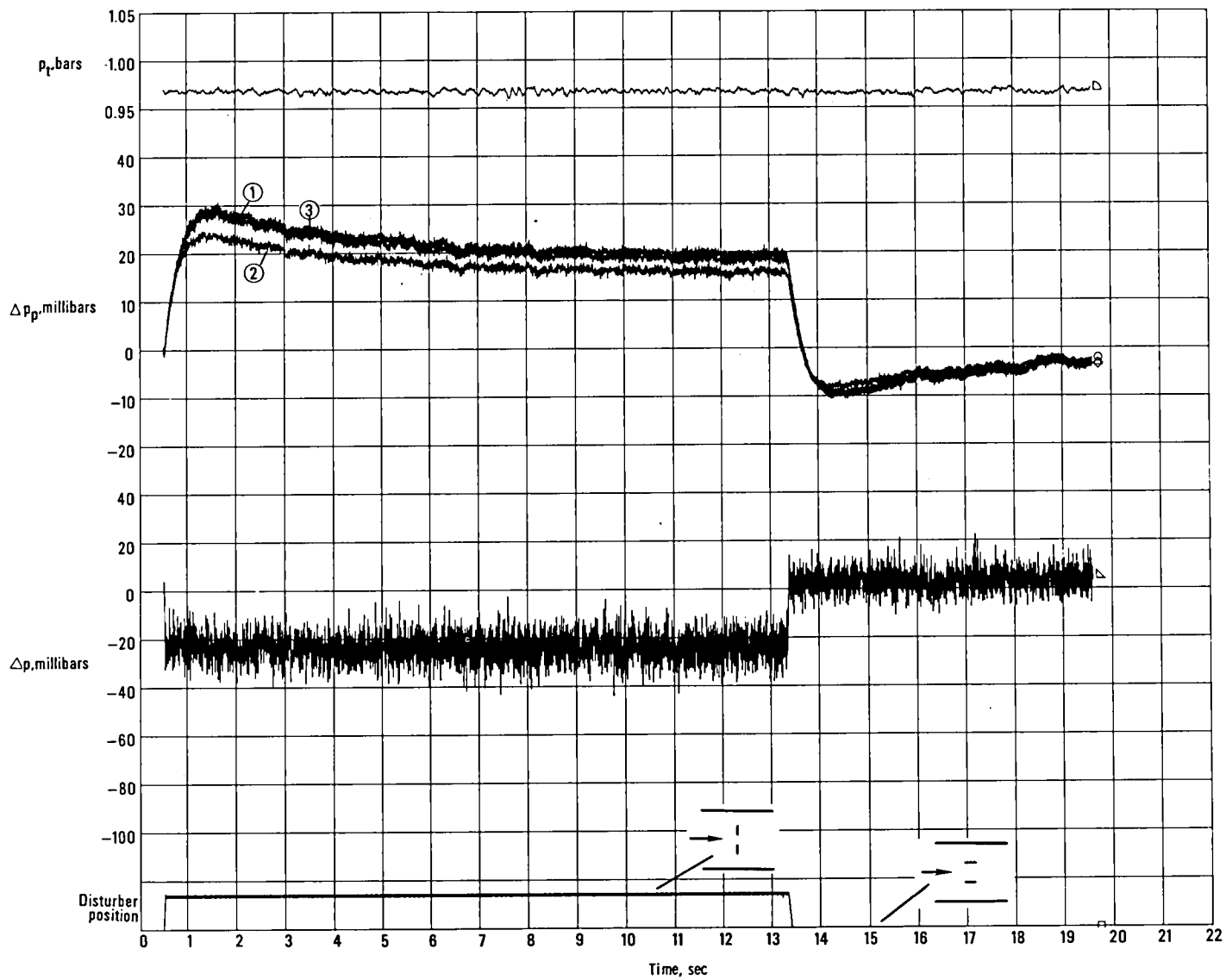
(a) M = 0.6.

Figure 7.- Plenum response for test section disturbance. Circled numbers are pressure gage locations (see fig. 6).



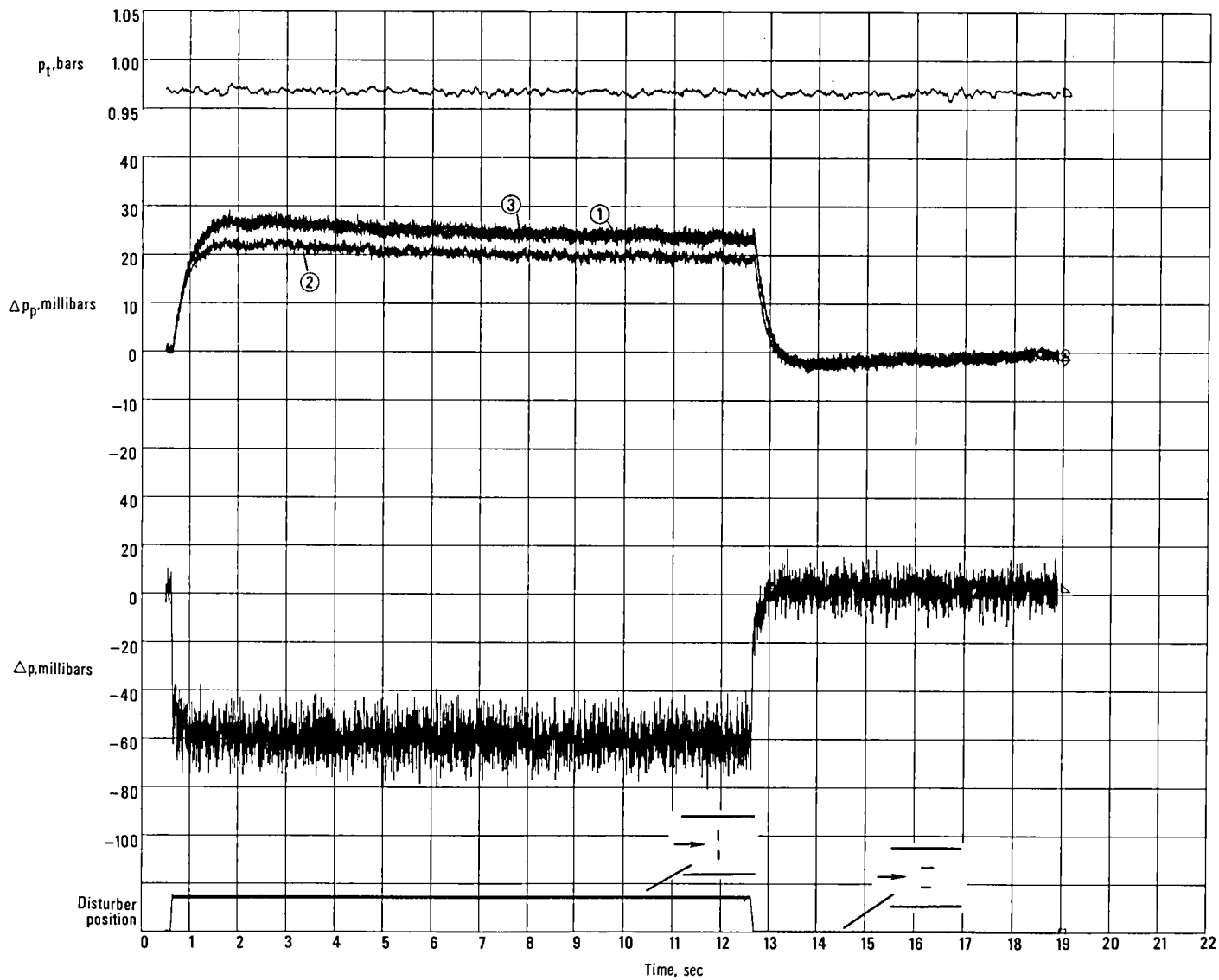
(b) M = 0.7.

Figure 7.- Continued.



(c) M = 0.8.

Figure 7.- Continued.



(d) M = 0.9.

Figure 7.- Concluded.

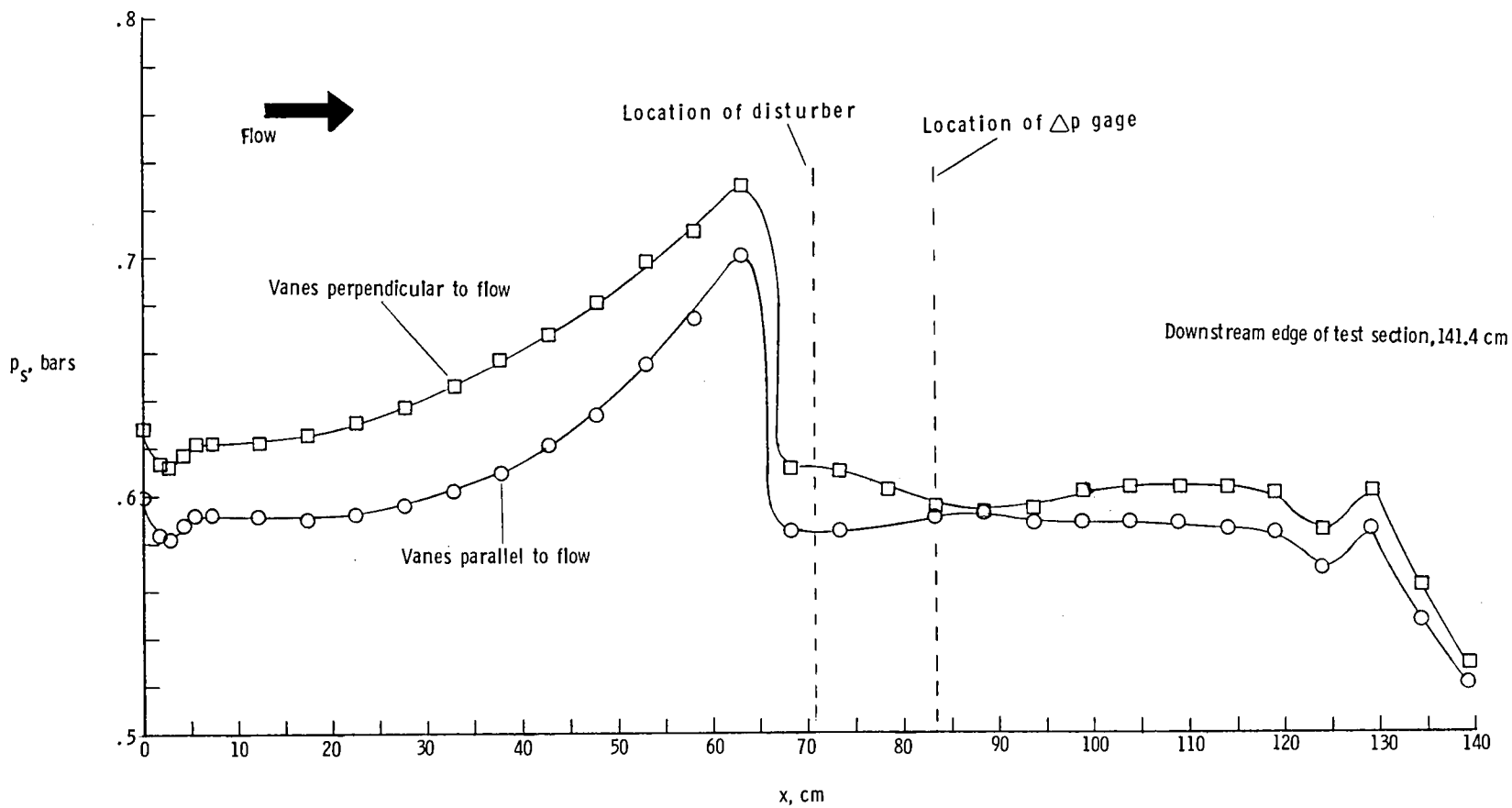


Figure 8.- Steady state test section wall pressures. M = 0.9.

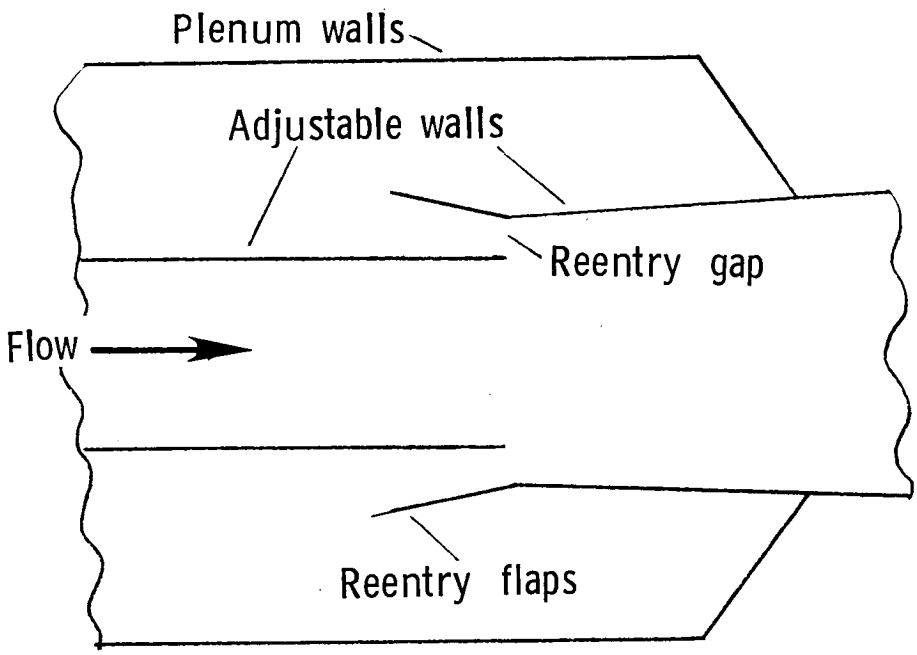
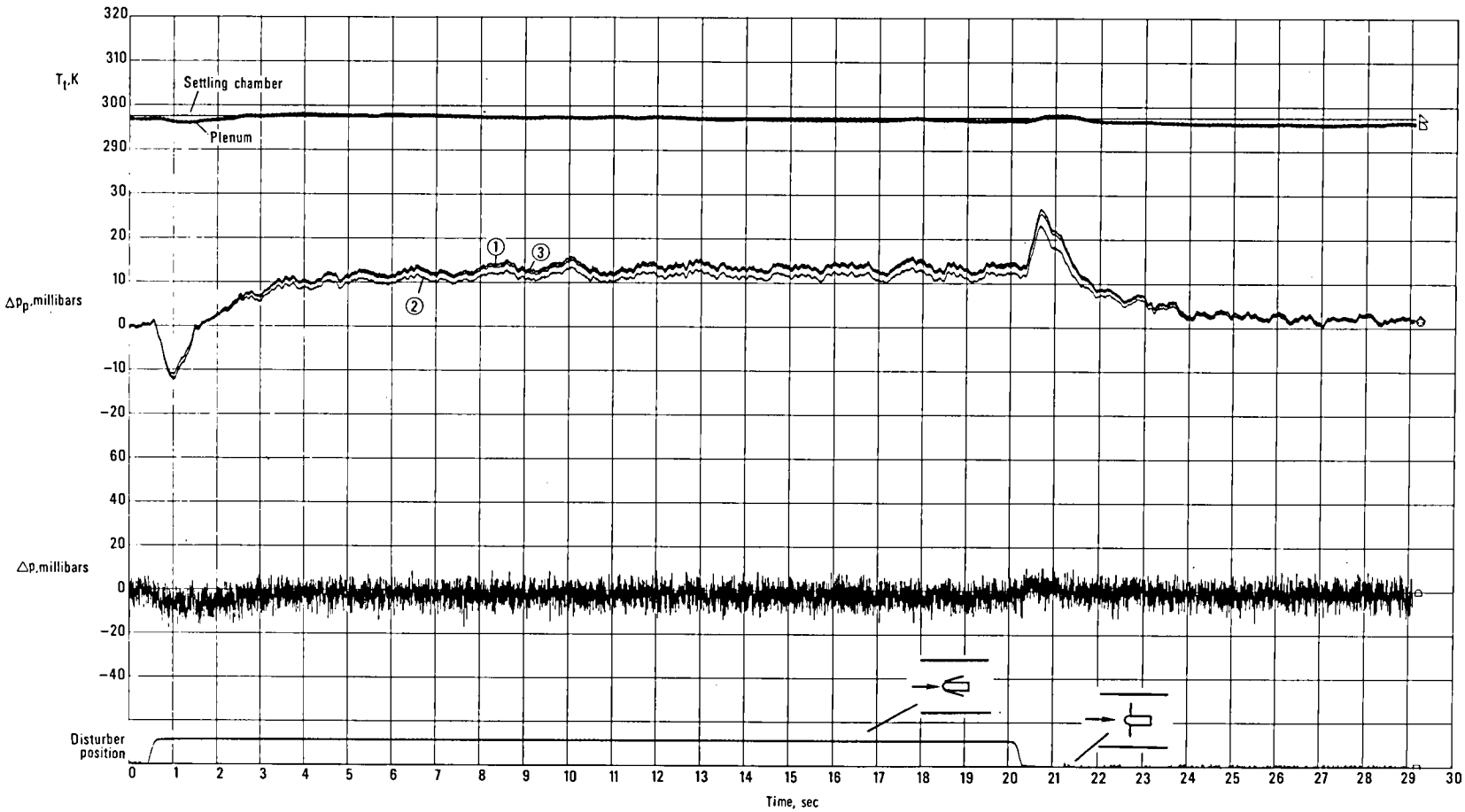
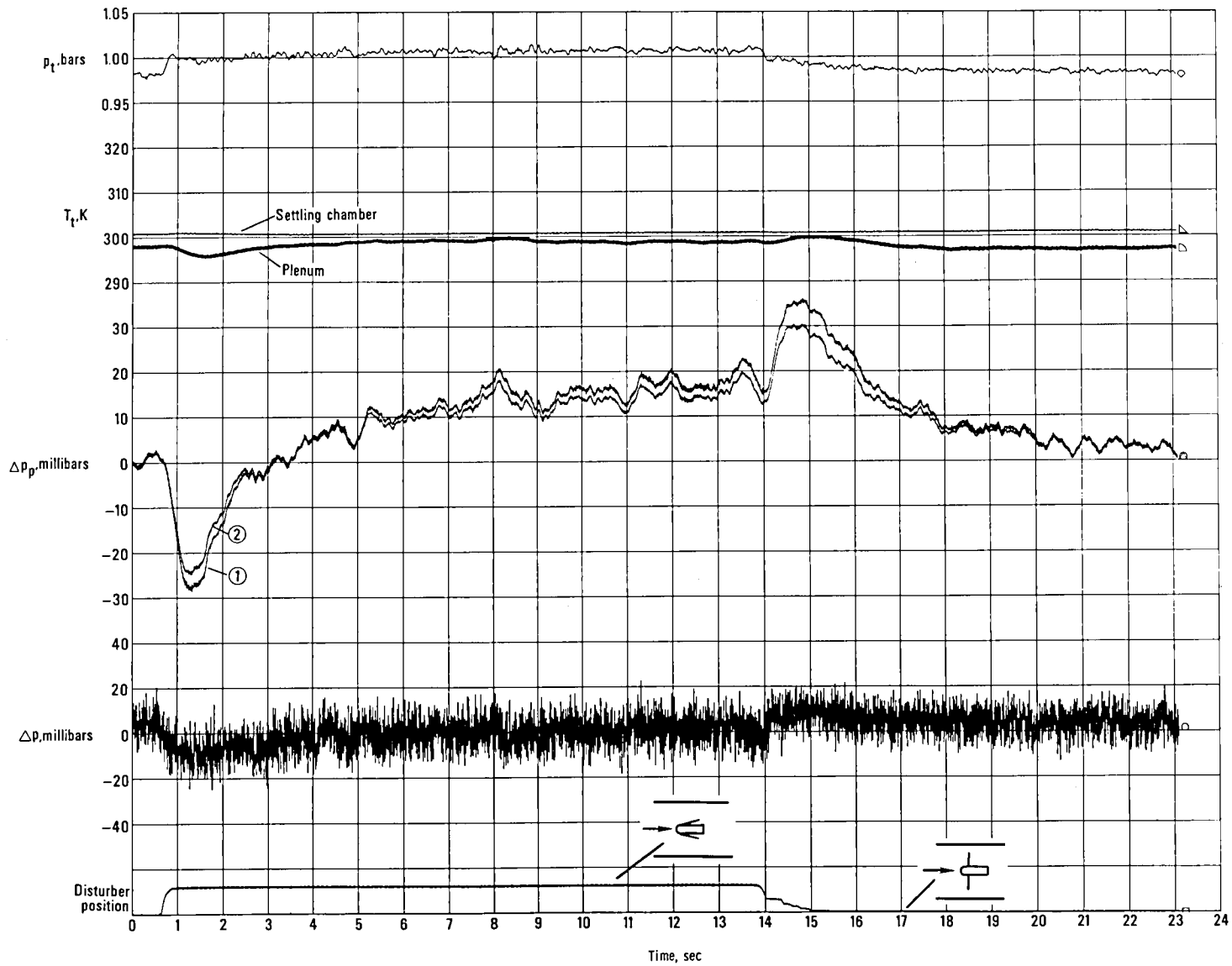


Figure 9.- Sketch of NTF plenum reentry region.



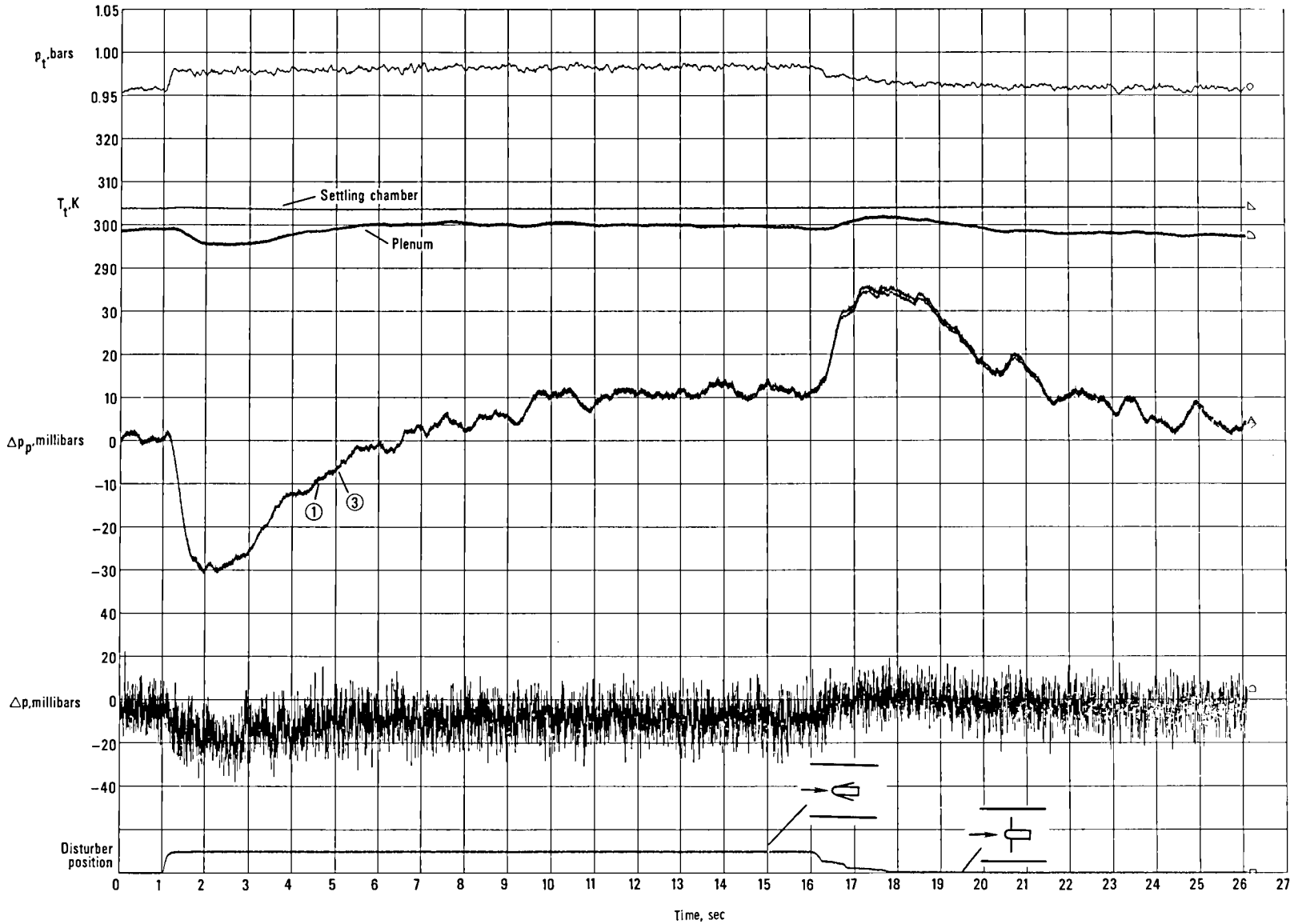
(a) M = 0.4.

Figure 10.- Plenum response for inlet guide vane type disturbance. Circled numbers are pressure gage locations (see fig. 6).



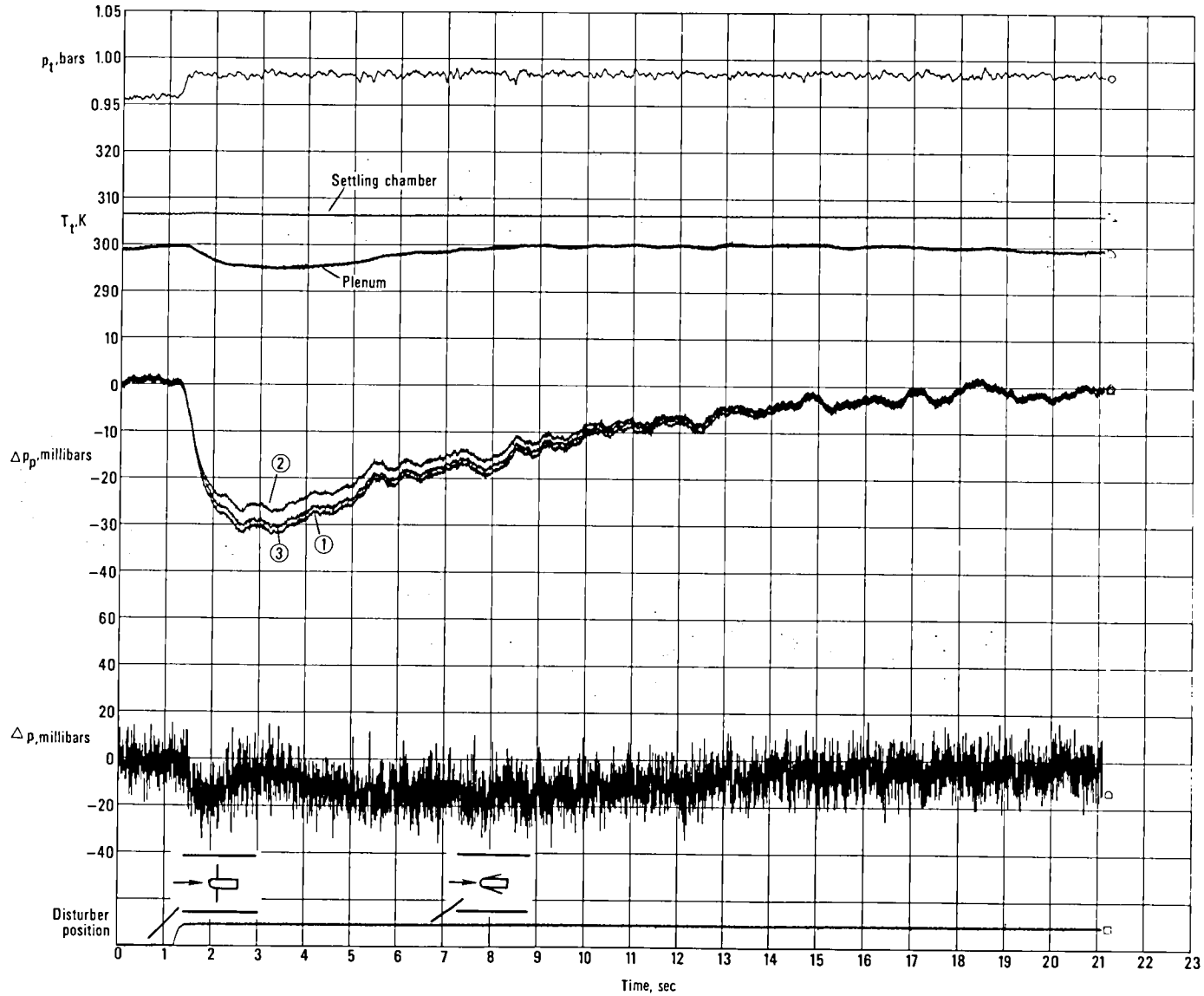
(b) M = 0.6.

Figure 10.- Continued.



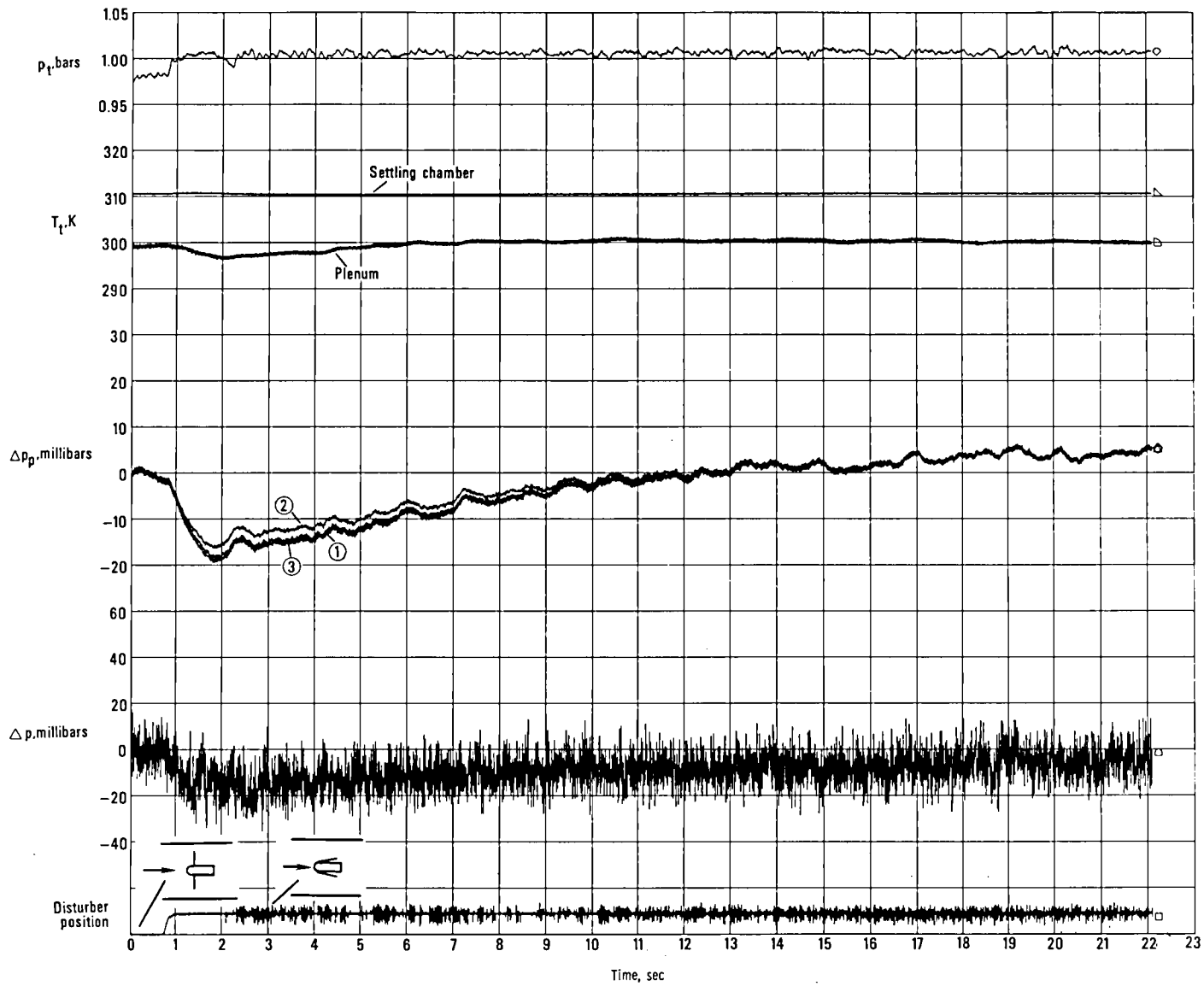
(c) M = 0.8.

Figure 10.- Continued.



(d) M = 1.0.

Figure 10.- Continued.



(e) M = 1.085.

Figure 10.- Concluded.

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15. Supplementary Notes

16. Abstract

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