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PRESSURE LAG IN TUBING USED IN FLIGHT RESEARCH

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SUMMARY

Limited tests on typical pressure-tubing systems used in flight research investigations have been made to determine the effects of lag due to single-direction and oscillating pressure changes. These tests were conducted on specific installations made for research purposes and are therefore limited in scope; the tests were conducted to provide a quantitative basis for estimating the magnitudes of the errors due to lag which are involved in recording pressures in flight. The pressure-tubing installations tested included the research installations of the recording airspeed systems of two pursuit-type aircraft and the orifice-pressure lines which were used in the pressure-distribution measurements over the wing and tail of one of these aircraft.

The investigation indicated that the magnitude of the error due to lag was negligible under flight-test conditions for all installations tested in which the cross-sectional area of the pressure lines was approximately the same as the cross-sectional area of the pressure orifices when the pressure changes were in a single direction. Under oscillating pressures of 5 to 28 cycles per second, installations

with varied sizes of tubing were found to have phase lags of 0.20 to 0.80 cycles and peak-pressure amplitude errors of 20 to 95 percent. Over the frequency range investigated resonance effects in the relatively unrestricted lines tested were found to result in recorded peak-pressure amplitudes, exceeding the corresponding applied pressures by as much as 60 percent. The average pressures recorded were the same as the average pressures applied, irrespective of the frequency or magnitude of the applied pressures or the lag effects in the specific pressure-tubing installation.

INTRODUCTION

The tests described in this report were undertaken to obtain a quantitative measure of the pressure lag in typical pressure-tubing systems used by the Ames Aeronautical Laboratory in flight research investigations. It was not practical to apply previous research work as reported in references 1 through 3 to this investigation because of the complex nature of pressure-tubing systems for which lag information was desired.

Lag measurements were made with both single-direction and oscillating pressure changes. Single-direction pressure changes were investigated to determine if the lag in orifice-pressure lines and in the research airspeed and altitude measuring systems of a pursuit-type airplane undergoing flight tests was sufficient to cause an appreciable error in the record of a sudden pressure change. Oscillating pressure changes were investigated with particular reference to the accuracy of pressure peaks in pressure-distribution measurements during the time of buffeting conditions as found in stalls.

APPARATUS AND PROCEDURE

Figures 1 and 2 are schematic diagrams of the apparatus used to study lag due to single-direction and oscillating pressure changes, respectively. The apparatus consisted essentially of a pressure-changing device connected to two airspeed-type pressure cells mounted in a standard NACA continuous-film recording instrument similar to those used in flight tests. The pressure lines to be tested were connected to the pressure device through both the static-pressure and total-pressure tubes of an NACA-type self-alining airspeed head, or a standard 1/8-inch-inside-diameter pressure orifice, depending upon the nature of the pressure lines tested.

The procedure followed for single-direction pressure changes was to bring the pressure in the chamber to a desired value and then release it through the exhaust line, the restriction in the line regulating the rate of change of the pressure in the chamber. For oscillating pressure changes the speed of the motor was varied to change the frequency, and the length of the stroke of the piston was varied to change the nominal peak pressures.

The pressure recorded by cell A was used as the reference pressure during the investigation. Since this cell was connected to the pressure chamber by a very short, straight, and unrestricted length of tubing, it was assumed that it recorded without lag.

Each line tested was a duplicate of a specific research installation. The physical characteristics of these lines are described in the appendix to this report. For the purpose of this report, the airplane for which typical wing and tail pressure-distribution orifice-pressure lines and the recording-airspeed-pressure lines were investigated has been designated airplane 1. The airplane for which the recording-airspeed-pressure lines only were investigated has been designated airplane 2.

It was possible to measure pressure oscillations to ±0.1 cycle per second and peak-pressure amplitude errors within ±0.1 inch of mercury. It was considered that the experimental accuracy of the data was within ±1.0 percent.

DISCUSSION

Lag in Typical Pressure Lines Due to Applied Single-Direction Pressure Changes

Lag for single-direction pressure changes was measured at the point where the pressure had dropped to 90 percent of its initial applied value in order to eliminate possible error due to difficulties in determining the point where 100-percent pressure drop was obtained. In the static-pressure, total-pressure, and wing orifice-pressure lines of airplane 1, within the limit of accuracy of the experimental equipment, the single-direction pressure lag was found to be zero.

Figure 3 shows time lag as a function of the time rate of change of the pressure being measured. Figure 4 shows the difference between the maximum pressure gradient recorded instantaneously and the gradient through the line being tested as a function of the time rate of change of the pressure being measured. Figure 5 is a series of time histories of the most severe pressure drop in each of the pressure lines. Lag in three different diameter pressure lines is shown in figure 6. For the pressure lines tested, it was found that the single-direction pressure lag decreased as the inside diameter of the pressure lines was decreased to approach the diameter of the pressure orifice.

Calculations show the flow in the lines to have been turbulent for this series of tests. The analysis of reference 1 is based on laminar flow within the tubes; therefore, the results of this investigation cannot be directly correlated with the results of reference 1. Furthermore, the present tests were made with greatest emphasis on the orifice-pressure lines; limitations in the test equipment resulted in the direction of air flow in the airspeed-pressure lines being opposite to the flow normally encountered in diving flight. However, it is believed that the values of lag obtained in this investigation are indicative of the lag in the specific installations. The airspeed-pressure lines of airplane 1 were symmetrical and were therefore believed to be little influenced by direction of flow. The airspeed-pressure lines of airplane 2 were so complex that the change in lag due to flow direction was believed negligible. The airspeed-head static orifices did not constitute an effective end restriction, as their gross area (0.0453 sq in.) was about three times the cross-sectional area of the 9/64-inch-inside-diameter aluminum tubing used.

Although extrapolation of the present data indicates that the magnitude of the pressure error due to lag in a well-designed research airspeed-measuring system would also be very small in the lower rate-of-change-of-pressure region, establishment of exact quantitative values of the error would require further tests under rates of pressure change equal in magnitude and direction to those normally encountered in dives.

Lag in Typical Pressure Lines Due to Applied Oscillating Pressure Changes

Lag due to oscillating pressures has been investigated with respect to errors in average pressures and nominal peak pressures. In the pressure lines tested it was found that the average pressures recorded were the same as the average pressures applied, irrespective of the frequency or magnitude of the applied pressures or the lag effects in the specific pressure-tubing installations.

The variations of phase lag with frequency are shown in figures 7 to 14. It was found that for the pressure lines investigated the minimum phase lag was in the relatively unrestricted lines of uniform cross section.

The variations of peak-pressure amplitude errors with frequency are shown in figures 15 to 22. The error in amplitude shown in figures 15 to 22 as Δa is defined by the following relationship:

$$\Delta a = \frac{\Delta a_{\text{cell A}} - \Delta a_{\text{cell(x-3)}}}{\Delta a_{\text{cell A}}} \times 100$$

The peak-pressure amplitude errors in the total- and static-pressure lines of airplane 1 (fig. 15 and 16 respectively) show a negative change with frequency, indicating that the peak pressures recorded by the test cell x-3 were greater than the impressed pressures as measured by cell A. The appendix shows these lines to be short, relatively unrestricted, and of uniform cross section. There was little damping action inherent with these pressure lines; rather a resonant effect was evident which tended to increase the values of the recorded peak pressures.

The peak-pressure amplitude errors in the elevator and aileron orifice-pressure lines of airplane 1 are shown in figures 17 and 18, respectively. The appendix shows these lines to be of complex construction. These lines have large values of lag and large reductions in recorded peak-pressure amplitudes, when subject to oscillating pressures, due to the volume changes and the damping action in the lines.

The resonant effect is also found in the wing and stabilizer orifice-pressure lines of airplane 1 (figs. 19 and 20, respectively). The reduction of the effect with increased frequency was due to the natural damping in the lines.

Figures 21 and 22 show the peak-pressure amplitude errors in the total- and static-pressure lines of the recording-airspeed system of airplane 2. The large values of lag are due to the damping in the system resulting from the abrupt volume changes between the varied sizes of tubes used in the lines.

CONCLUSIONS

The following conclusions were made from the data included herein and apply specifically to the pressure-tubing installations and the range of variables tested:

1. When the tubing diameter was greater than the orifice diameter, the single-direction pressure lag decreased as the cross-sectional area of the pressure line approached the cross-sectional area of the pressure orifice.

2. Varied sizes of tubing and numerous joints in the same pressure line lead to large values of pressure lag in instrument lines subjected to oscillating pressures.

3. Relatively unrestricted pressure lines of uniform cross section of large-diameter tubing yielded erroneous peak-pressure data when subjected to oscillating pressures because resonance caused the peak pressures to build up as much as 60 percent greater than the applied peak pressures.

4. The average pressures recorded were the same as the average pressures applied, irrespective of the frequency or magnitude of the impressed pressures on the lag effects of the specific pressure-tubing installations.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., March 31, 1945.

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Approved:

John F. Parsons,
Aeronautical Engineer.

APPENDIX

Description of Pressure Lines

The descriptions of the pressure lines used in this investigation are quantitative and are not necessarily representative of the order in which the different sizes of tubing were used in the lines. At the time of the investigation it was not believed necessary to make a record of the exact composition of the pressure lines because of the limited use for which the data were originally intended. Since that time the pressure lines have been salvaged for usable parts and no record exists of their exact composition other than the following quantitative descriptions:

1. Airplane 1, total-pressure line

   5.2 feet, 9/64-inch-inside-diameter aluminum tubing

   1.2 feet, 3/16-inch-inside-diameter rubber tubing

2. Airplane 1, static-pressure line

   5.2 feet, 9/64-inch-inside-diameter aluminum tubing

   1.2 feet, 3/16-inch-inside-diameter rubber tubing

3. Airplane 1, elevator orifice-pressure line

   8 feet, 9/64-inch-inside-diameter aluminum tubing

   2.4 feet, 3/16-inch-inside-diameter rubber tubing

   5.3 feet, 7/64-inch-inside-diameter rubber tubing

   6 joints

4. Airplane 1, aileron orifice-pressure line

   13 feet, 9/64-inch-inside-diameter aluminum tubing

   10.5 feet, 7/64-inch-inside-diameter rubber tubing

   2 feet, 3/16-inch-inside-diameter rubber tubing

   6 joints

5. Airplane 1, stabilizer orifice-pressure line

   15 feet, 9/64-inch-inside-diameter aluminum tubing

   3.4 feet, 3/16-inch-inside-diameter rubber tubing

   8 joints

6. Airplane 1, wing orifice-pressure line

   9 feet, 9/64-inch-inside-diameter aluminum tubing

   3.3 feet, 3/16-inch-inside-diameter rubber tubing

   6 joints

7. Airplane 2, total-pressure line

   23 feet, 7/64-inch-inside-diameter aluminum and brass tubing

   1 foot, 7/64-inch-inside-diameter rubber tubing

   8 feet, 9/64-inch-inside-diameter aluminum tubing

   1 foot, 3/16-inch-inside-diameter rubber tubing

6 joints, 4 rubber and 2 standard 9/64-inch 90° elbows

8. Airplane 2, static-pressure line

9.7 feet, 7/64-inch-inside-diameter brass tubing

7.2 feet, 9/64-inch-inside-diameter aluminum tubing

2 joints, 1 standard 9/64-inch 90° elbow

The airspeed head used in these tests was an NACA-type self-alining head with two static-pressure tubes and one total-pressure tube. The orifices on the static-pressure tube were 36 in number and 0.040 inch in diameter. The orifice inside diameter of the total-pressure tube was 3/16 inch.

For all lines, the terminal orifice or airspeed head, corresponding exactly to the type used in flight, was inserted into the pressure chamber. The volume of each recording pressure cell (x-3 and A) was approximately 1 cubic inch.

REFERENCES

1. Wildhack, W. A.: Pressure Drop in Tubing in Aircraft Instrument Installations. NACA TN No. 593, Feb. 1937.

2. De Juhasz, Kalman J.: Graphical Analysis of Delay of Response in Airspeed Indicators. Jour. Aero. Sci., vol. 10, no. 3, March 1943, pp. 91-97.

3. Norton, F. H., and Brown, W. G.: The Pressure Distribution Over the Horizontal Tail Surfaces of an Airplane, III. NACA Rep. No. 148, 1922.

FIGURE LEGENDS

Figure 1.- Schematic diagram of equipment used to study effects of single-cycle pressure changes on the indications of aircraft pressure-recording installations.

Figure 2.- Schematic diagram of equipment used to study effects of pressure oscillations on the indications of aircraft pressure-recording installations.

Figure 3.- The time lag in typical pressure recorder lines. (a) Airplane 1.

Figure 3.- Concluded. The time lag in typical pressure recorder lines. (b) Airplane 2.

Figure 4.- The lag in pressure in typical pressure-recorder lines, airplane 1.

Figure 5.- Time history showing lag due to abrupt pressure drop. (a) Wing orifice line, airplane 1.

Figure 5.- Continued. (b) Stabilizer orifice line, airplane 1.

Figure 5.- Continued. (c) Elevator orifice line, airplane 1.

Figure 5.- Continued. (d) Aileron orifice line, airplane 1.

Figure 5.- Continued. (e) Airspeed static-head line, airplane 2.

Figure 5.- Concluded. (f) Airspeed total-head line, airplane 2.

Figure 6.- Variation of pressure lag with tubing diameter for single-direction pressure changes through an 0.040-inch orifice.

Figure 7.- Variation of phase lag with frequency at four pressures; total-head line airspeed system, airplane 1.

Figure 8.- Variation of phase lag with frequency at four pressures; static-head line airspeed system, airplane 1.

Figure 9.- Variation of phase lag with frequency at four pressures; elevator orifice line, airplane 1.

Figure 10.- Variation of phase lag with frequency at four pressures; aileron orifice line, airplane 1.

Figure 11.- Variation of phase lag with frequency at four pressures; stabilizer orifice line, airplane 1.

Figure 12.- Variation of phase lag with frequency at four pressures; wing orifice line, airplane 1.

Figure 13.- Phase lag variation with frequency at four different pressures; total-head line airspeed system, airplane 2.

Figure 14.- Variation of phase lag with frequency at four pressures; static head-line airspeed system, airplane 2.

Figure 15.- Variation of amplitude error with frequency at four pressures; total-head line airspeed system, airplane 1.

Figure 16.- Variation of amplitude error with frequency at four pressures; static-head line airspeed system, airplane 1.

Figure 17.- Variation of amplitude error with frequency at four pressures; elevator-orifice line, airplane 1.

Figure 18.- Variation of amplitude error with frequency at four pressures aileron-orifice line, airplane 1.

Figure 19.- Variation of amplitude error with frequency at four pressures; wing orifice line, airplane 1.

Figure 20.- Variation of amplitude error with frequency at four pressures; stabilizer orifice line, airplane 1.

Figure 21.- Variation of amplitude error with frequency at four pressures; total-head line airspeed system, airplane 2.

Figure 22.- Variation of amplitude error with frequency at four pressures; static-head line airspeed system, airplane 2.

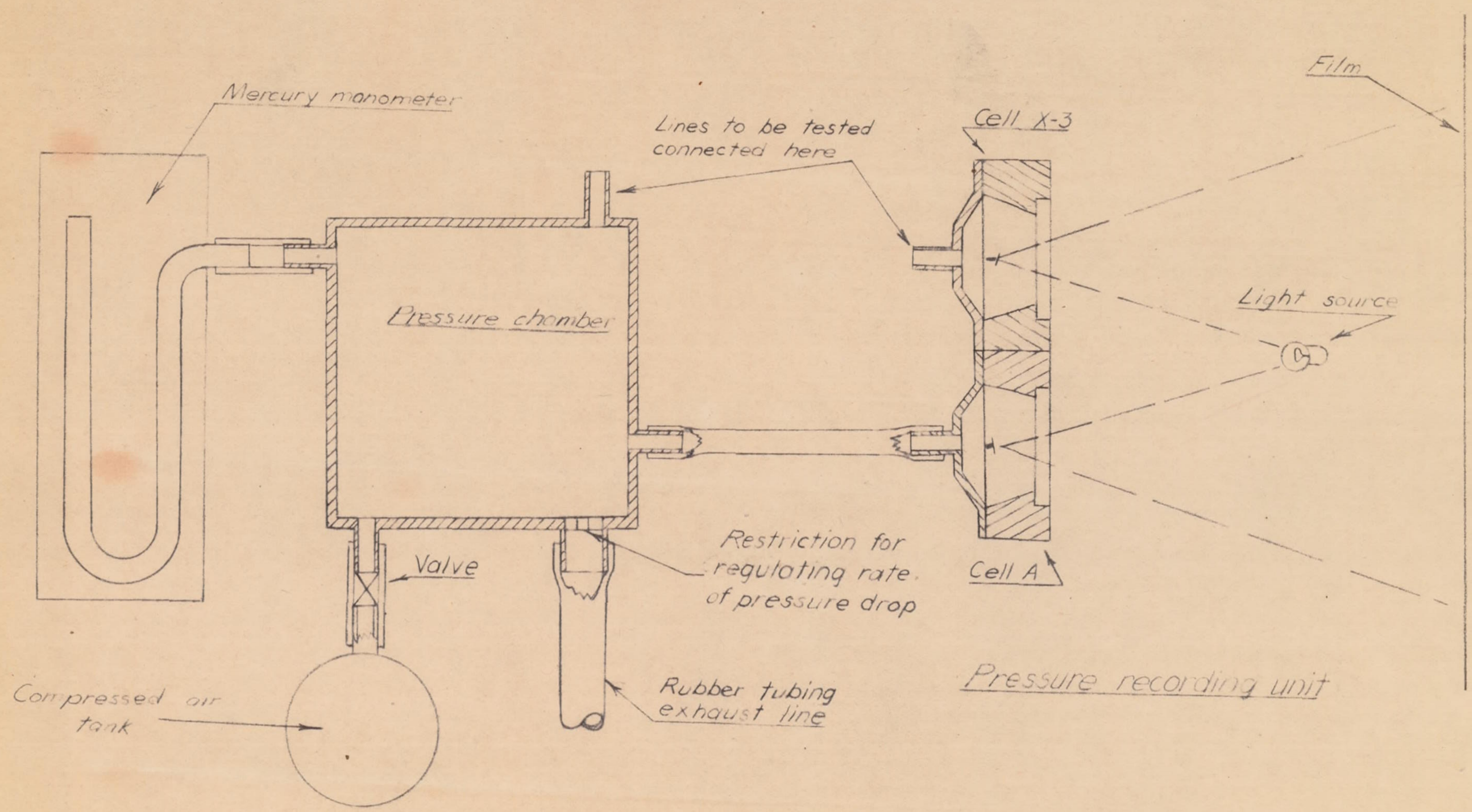

Figure 1.- Schematic diagram of equipment used to study effects of single-cycle pressure changes on the indications of aircraft pressure-recording installations.

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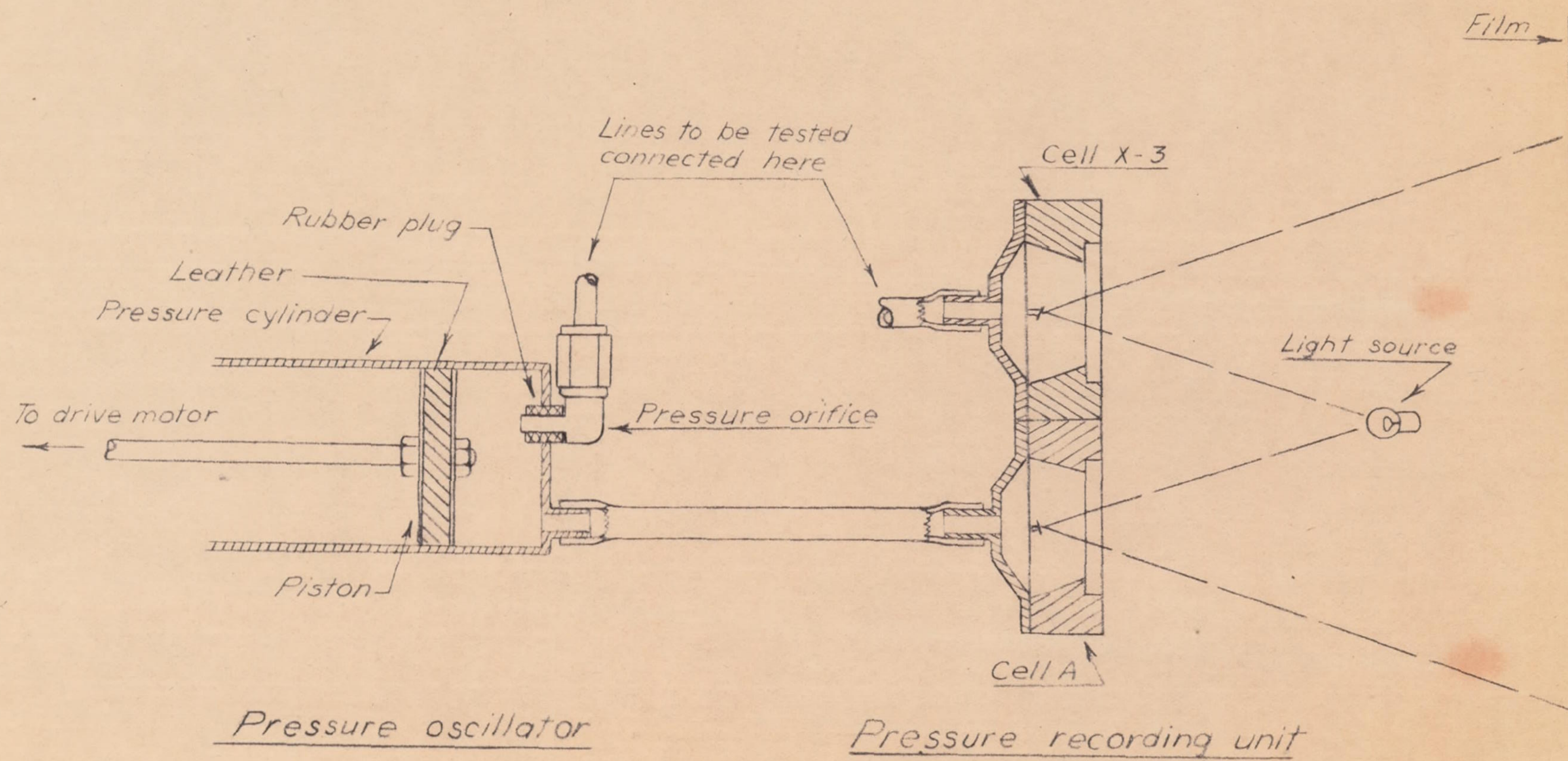
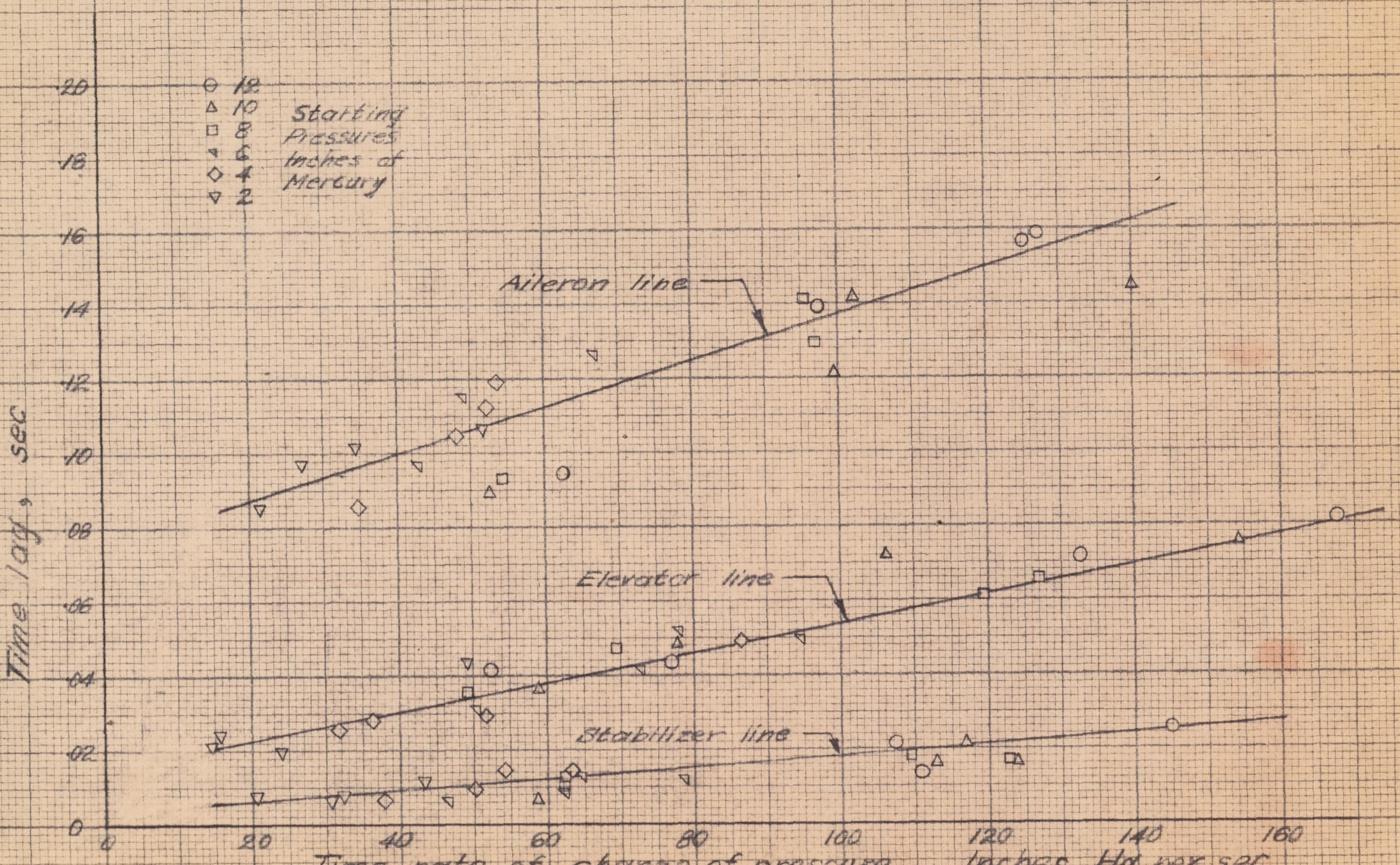
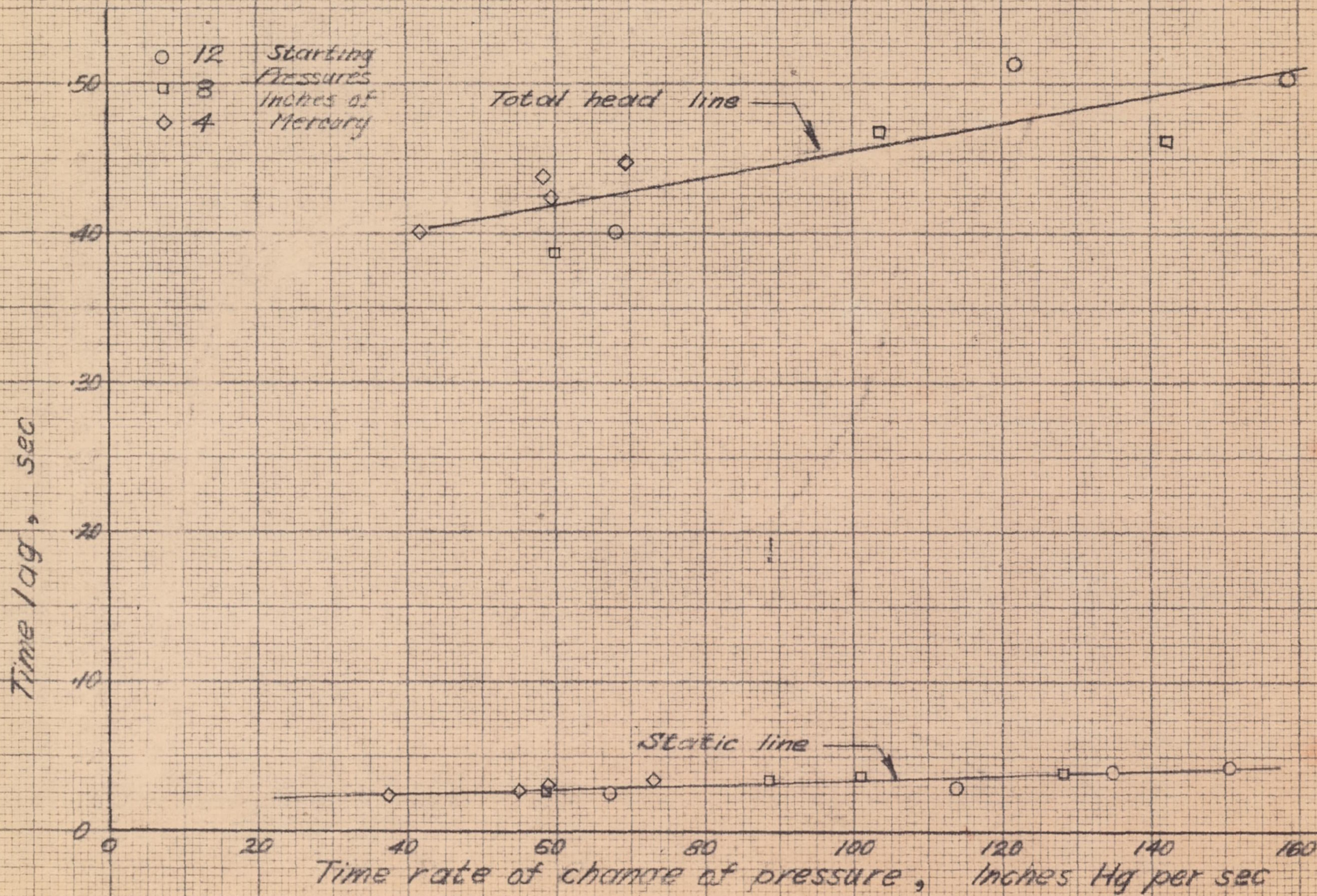


Figure 2.- Schematic diagram of equipment used to study effects of pressure oscillations on the indications of aircraft pressure-recording installations.



(a) Airplane 1.

Figure 3. — The time lag in typical pressure recorder lines.



(b) Airplane 2

Figure 3.(Conc.): The time lag in typical pressure recorder lines

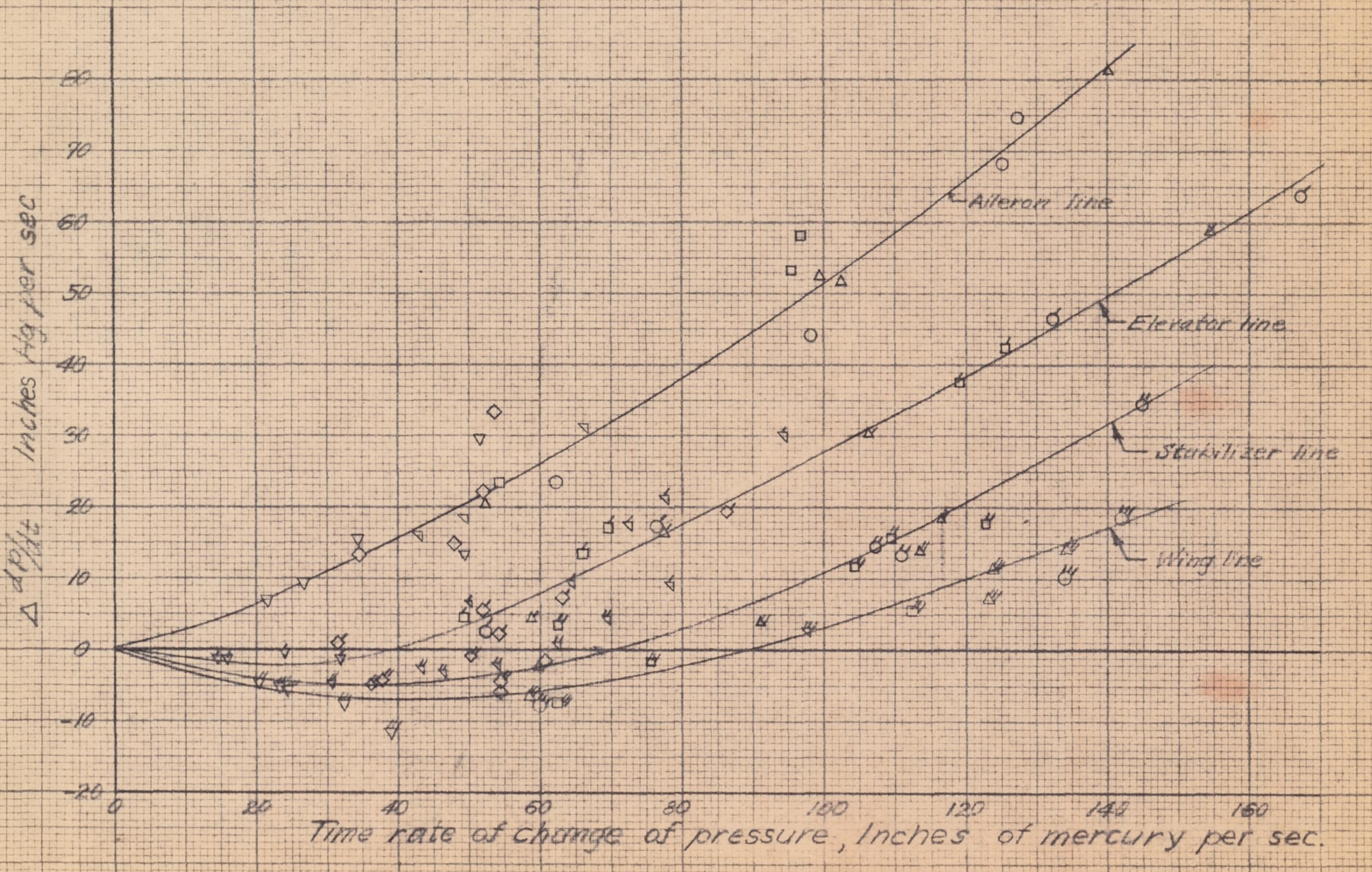
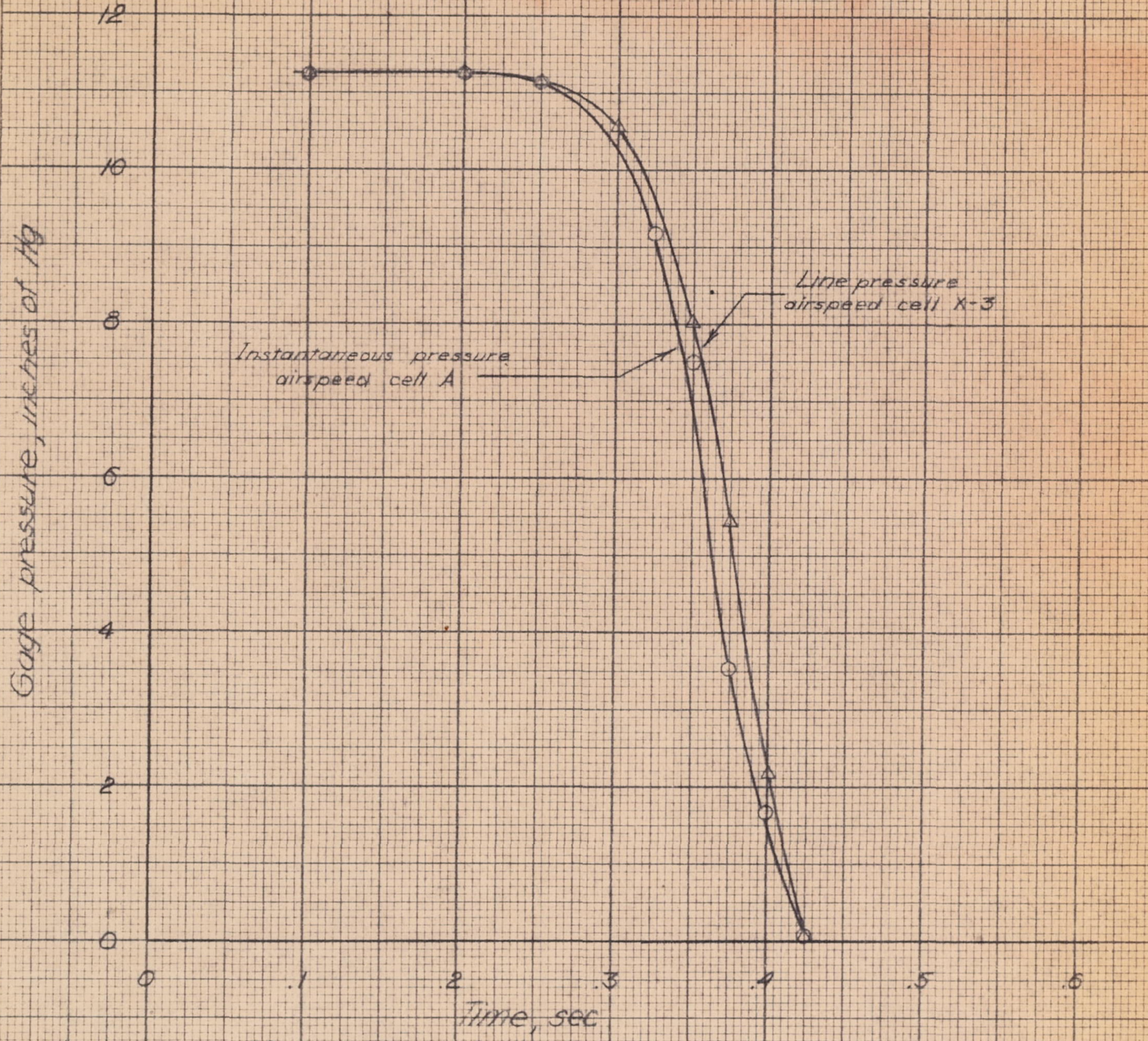
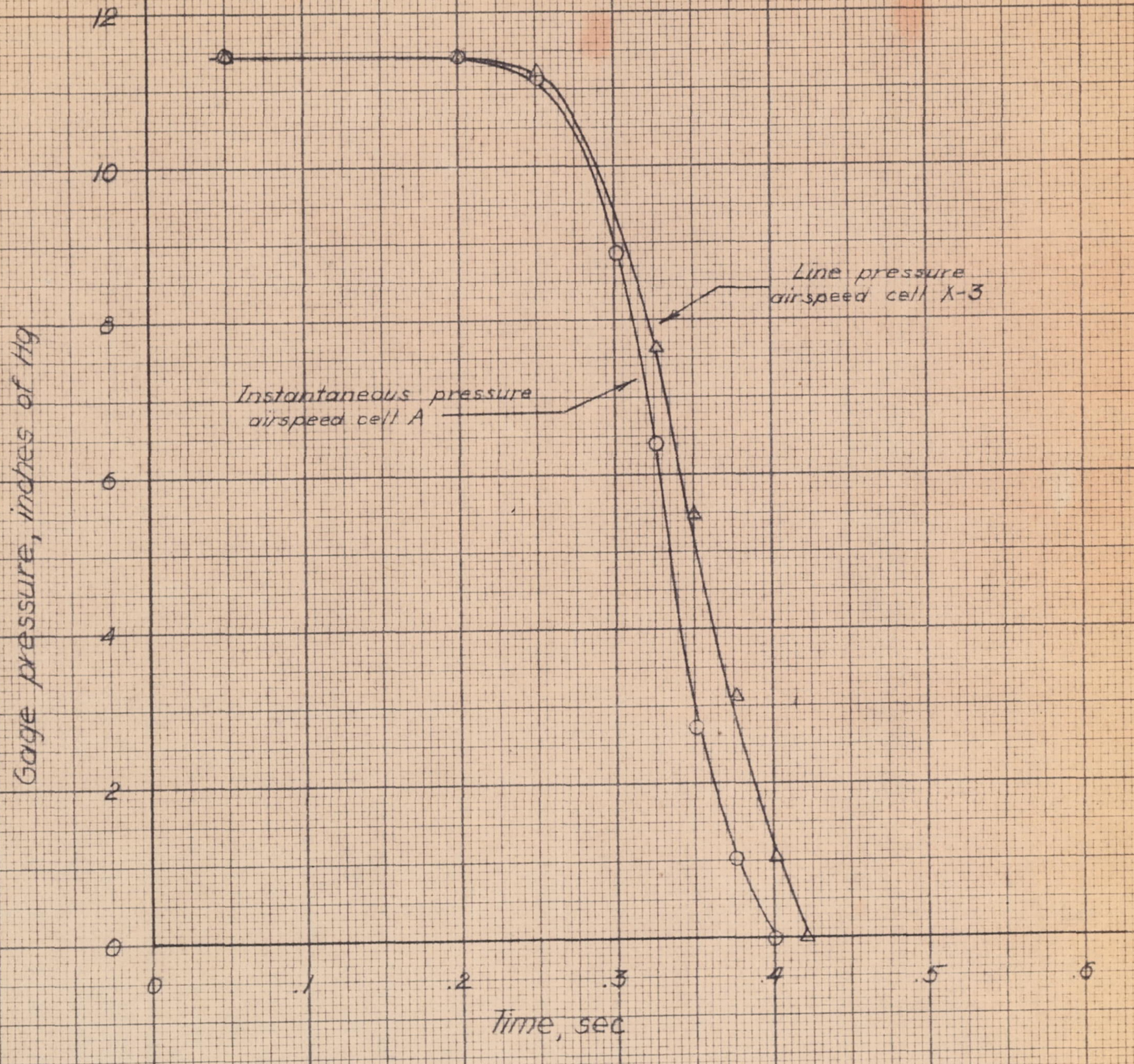


Figure 4. — The lag in pressure in typical pressure-recorder lines, airplane 1.



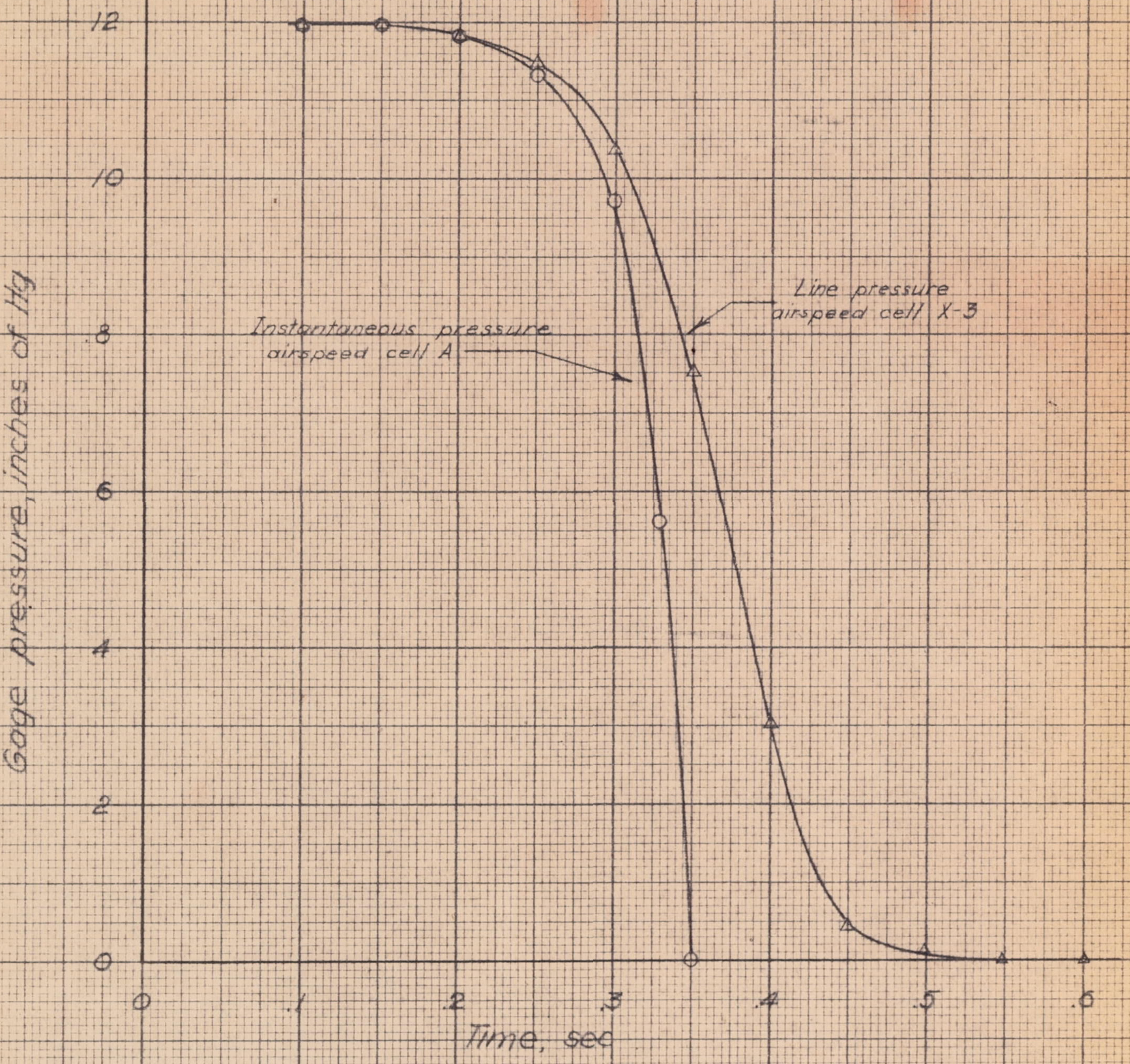
(a) Wing orifice line, airplane I.

Figure 5.- Time history showing lag due to abrupt pressure drop.



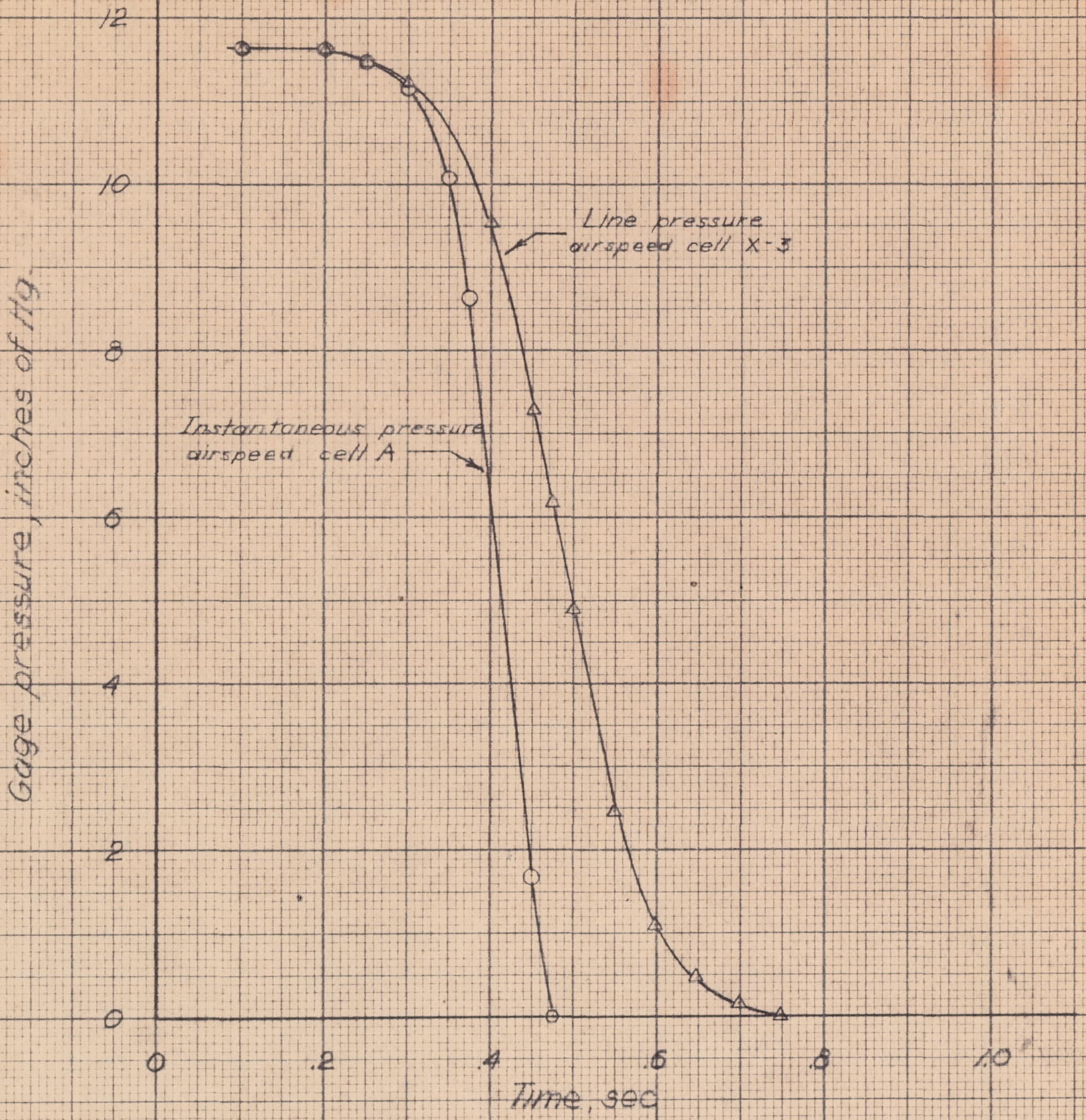
(b) Stabilizer orifice line, airplane I.

Figure 5.- Continued.



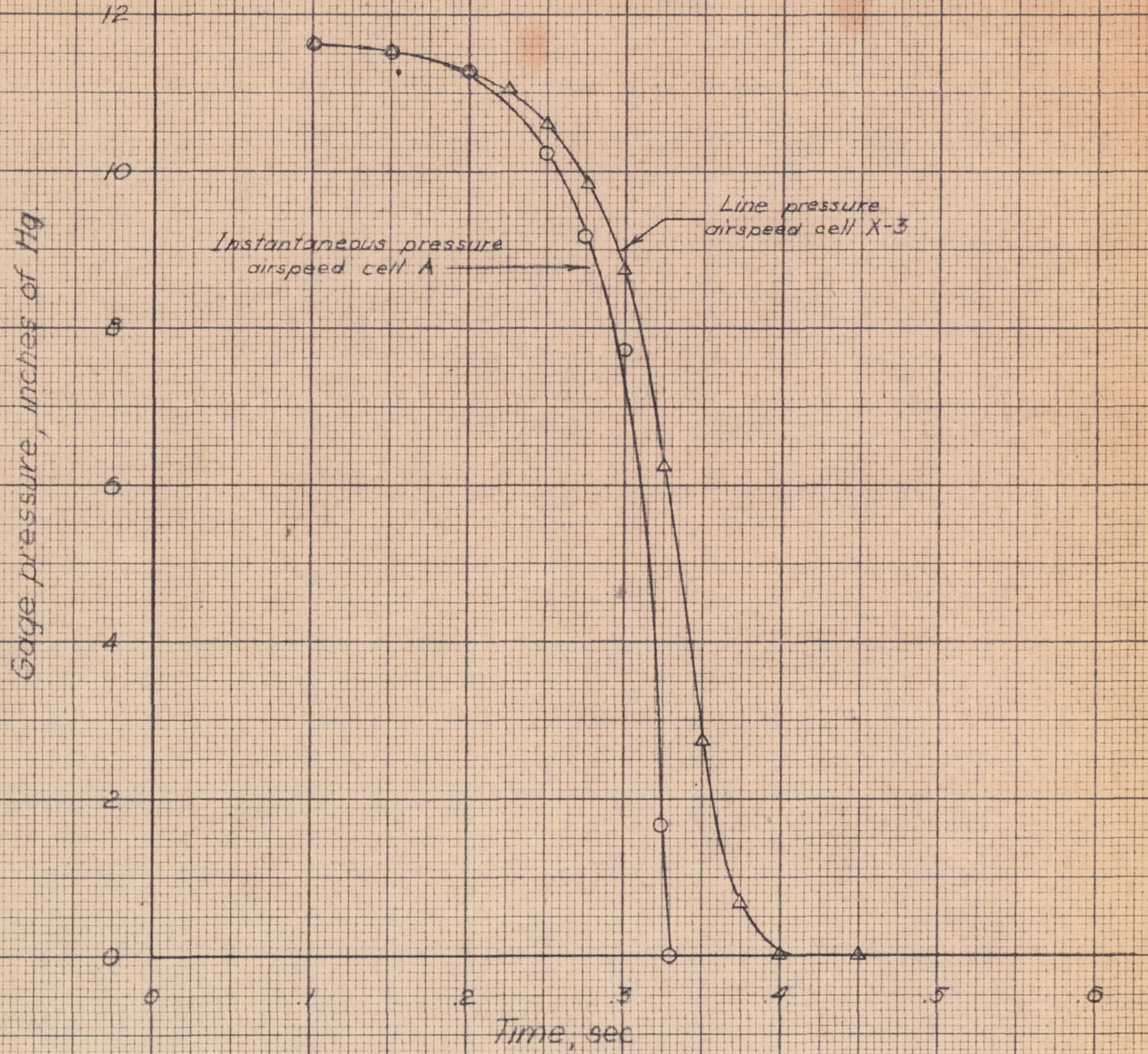
(c) Elevator orifice line, airplane I.

Figure 5 . Continued.



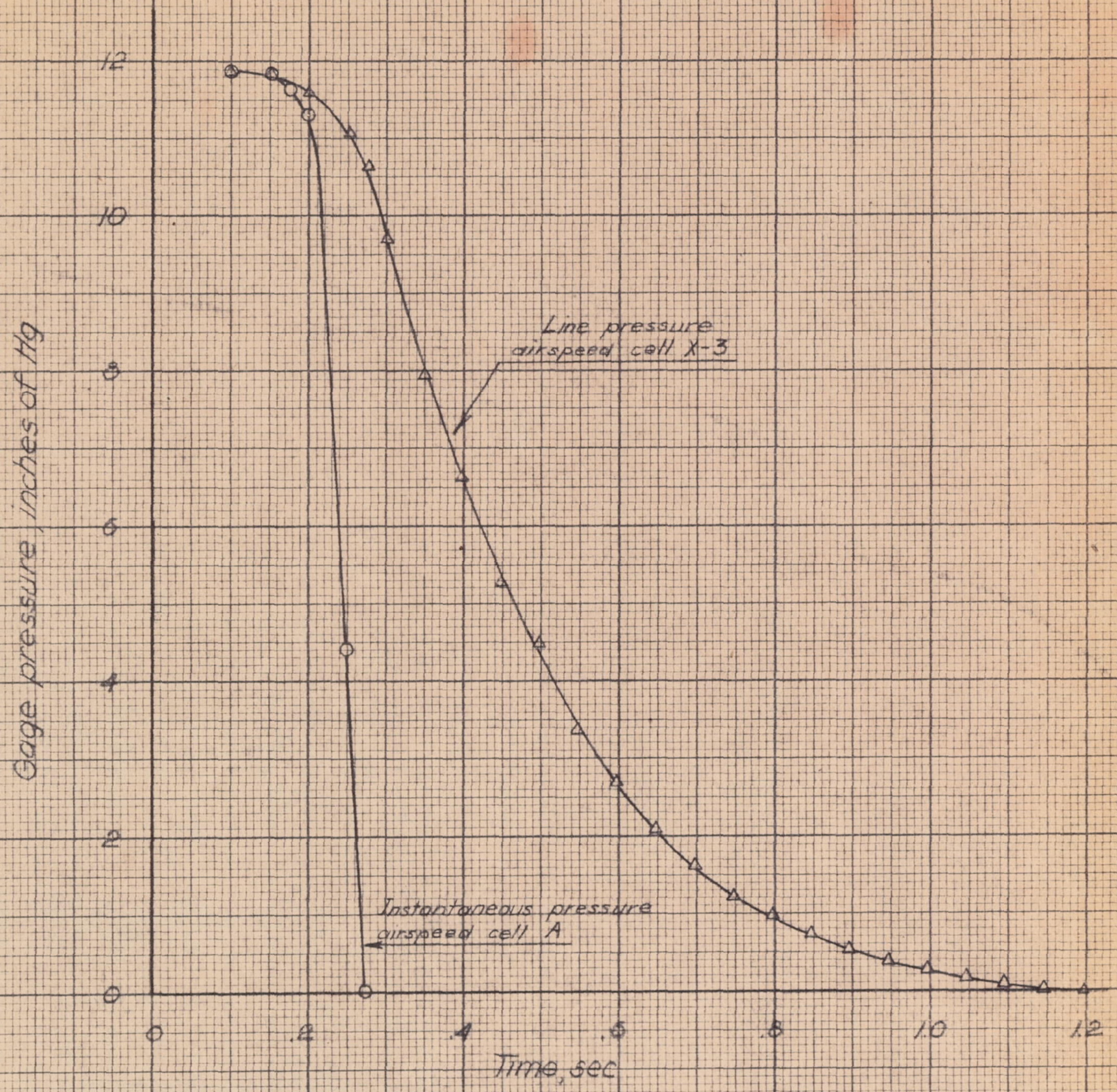
(d) Aileron orifice line, airplane 1.

Figure 5.- Continued



(e) Airspeed static-head line, airplane 2.

Figure 5.- Continued



(f) Airspeed total head line, airplane 2.

Figure 5.- Concluded

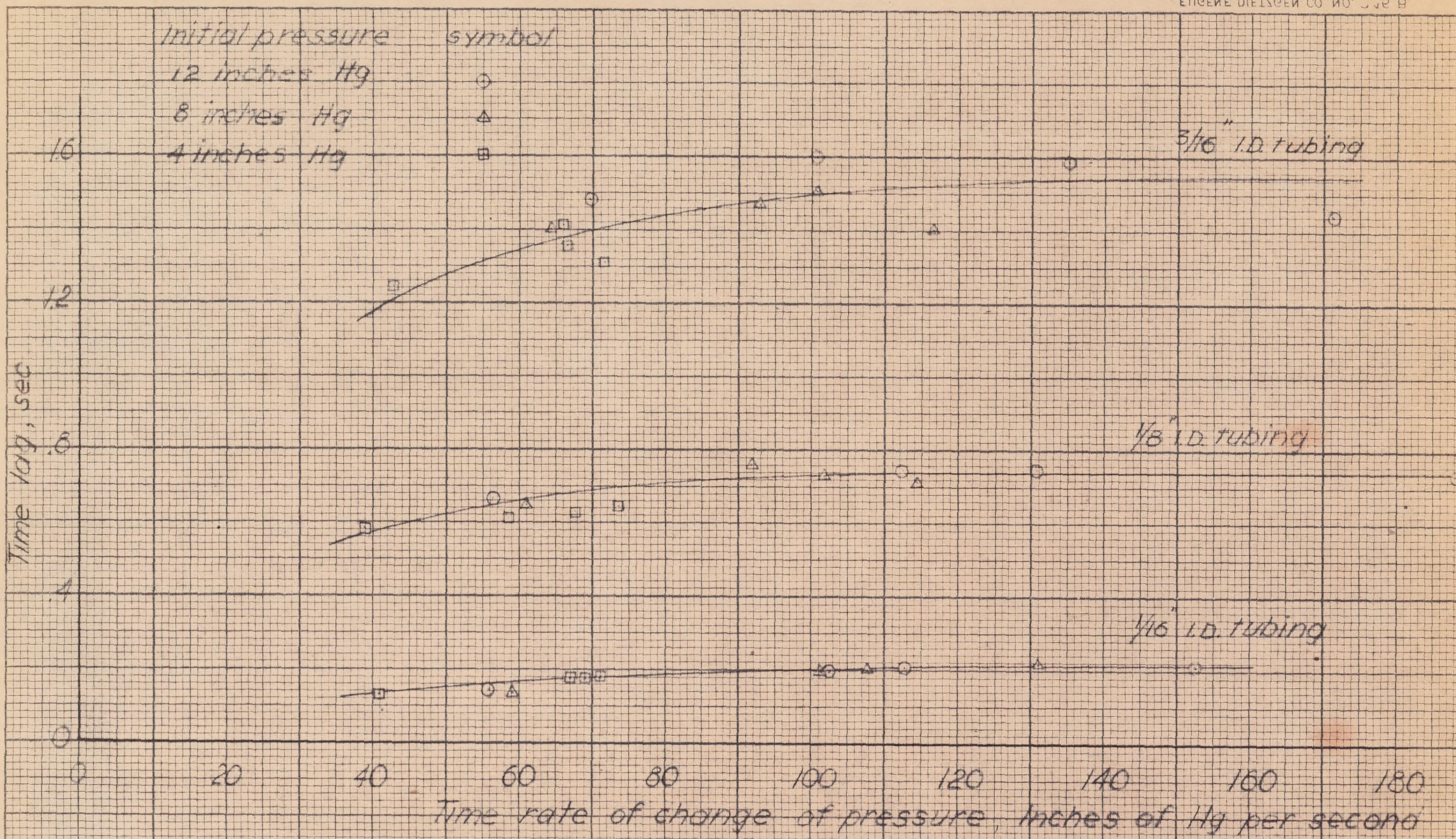


Figure 6.- Variation of pressure lag with tubing diameter for single-direction pressure changes through an 0.040-inch orifice.

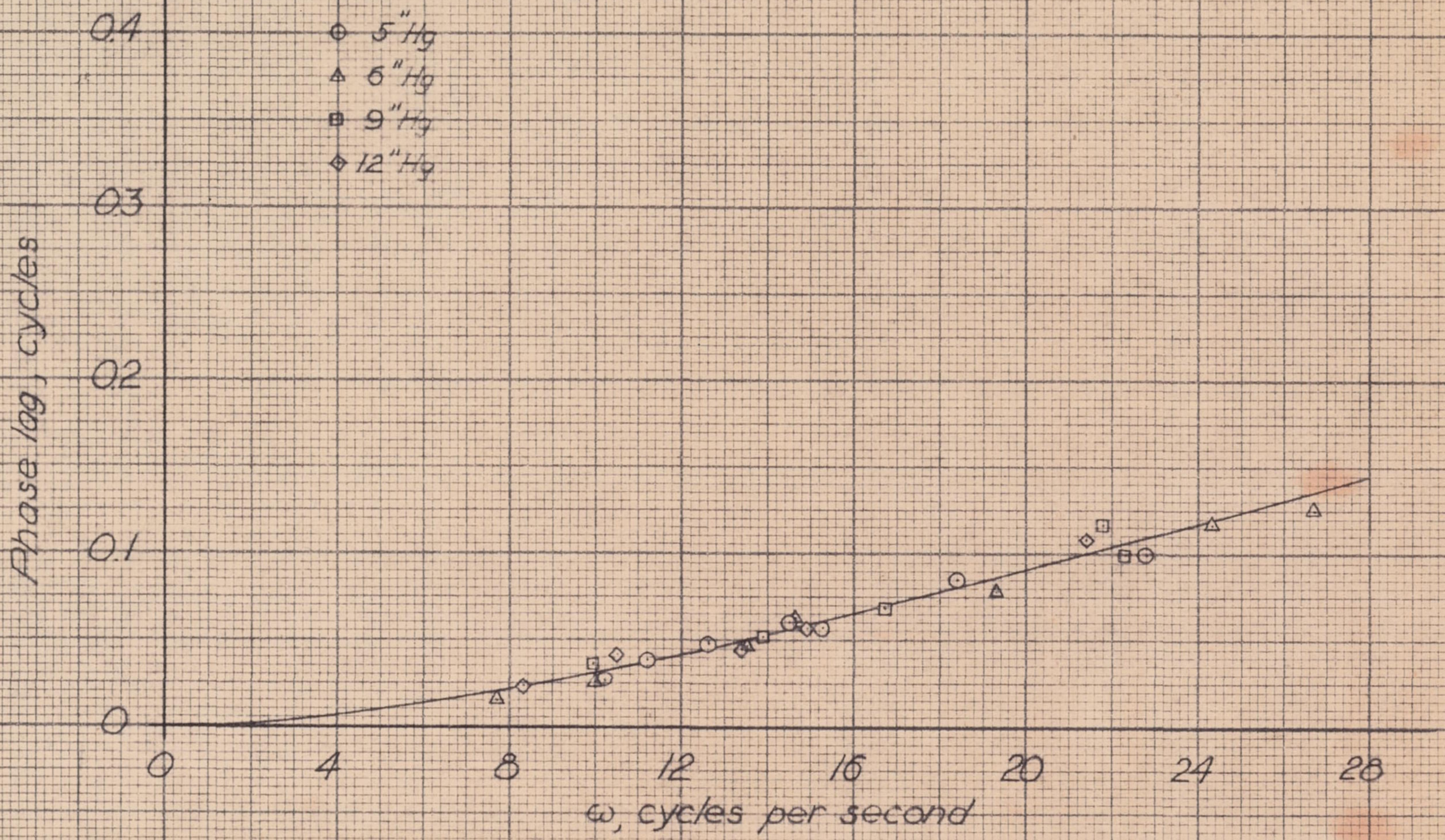


Figure 7.- Variation of phase lag with frequency at four pressures; total-head line airspeed system, airplane 1.

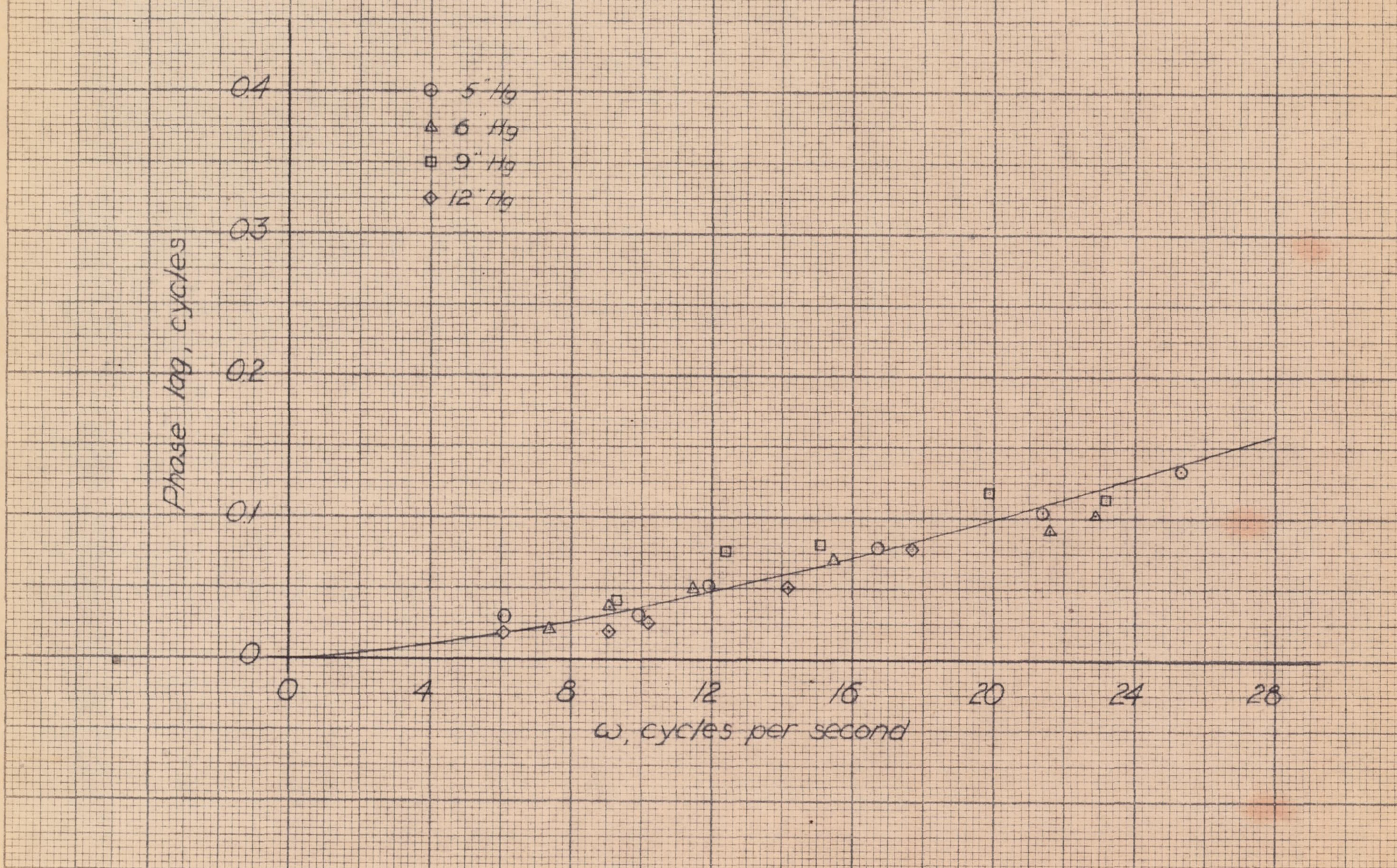


Figure 8.- Variation of phase lag with frequency at four pressures; static-head line airspeed system, airplane 1.

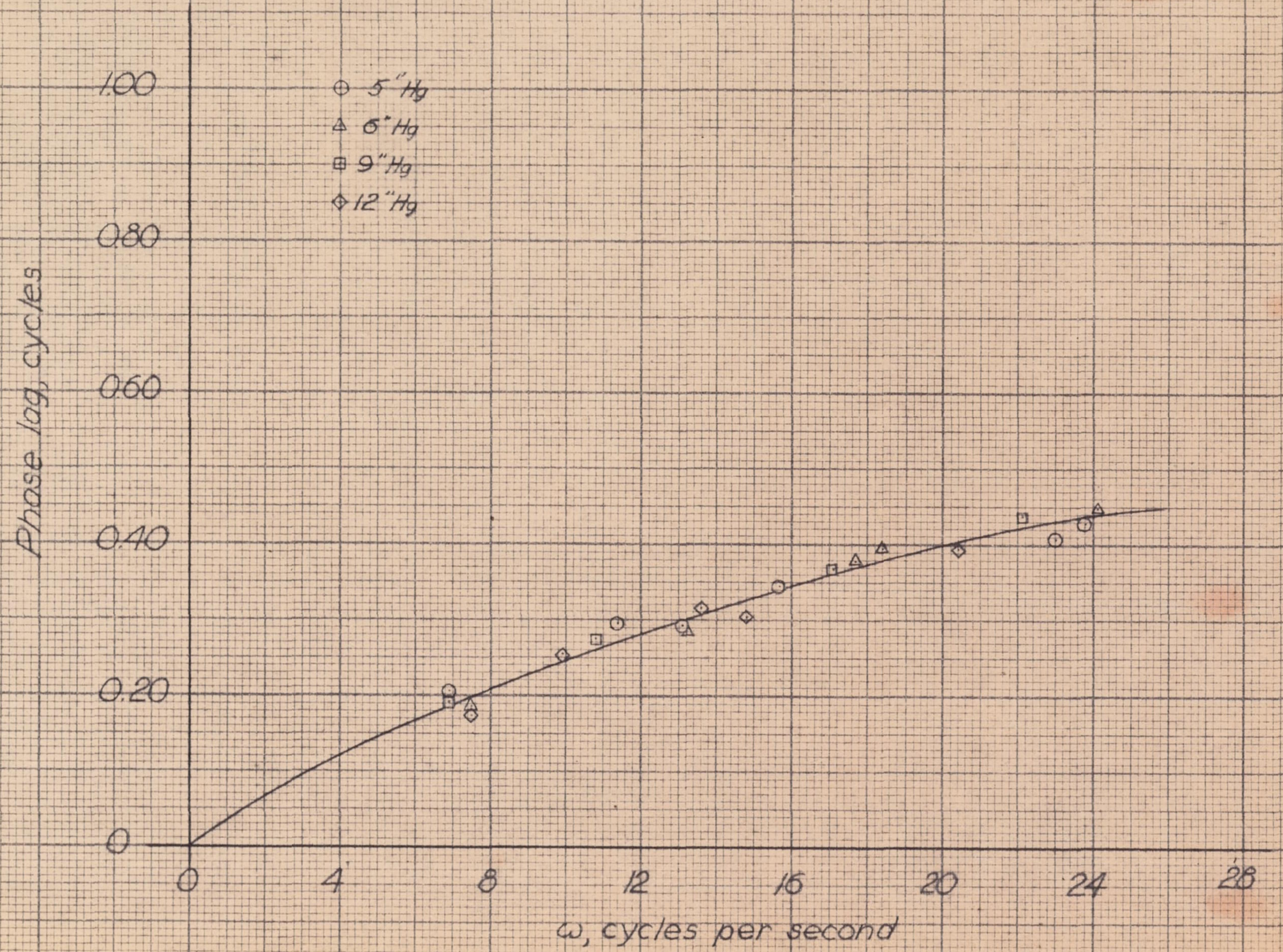


Figure 9.- Variation of phase lag with frequency at four pressures; elevator orifice line, airplane I.

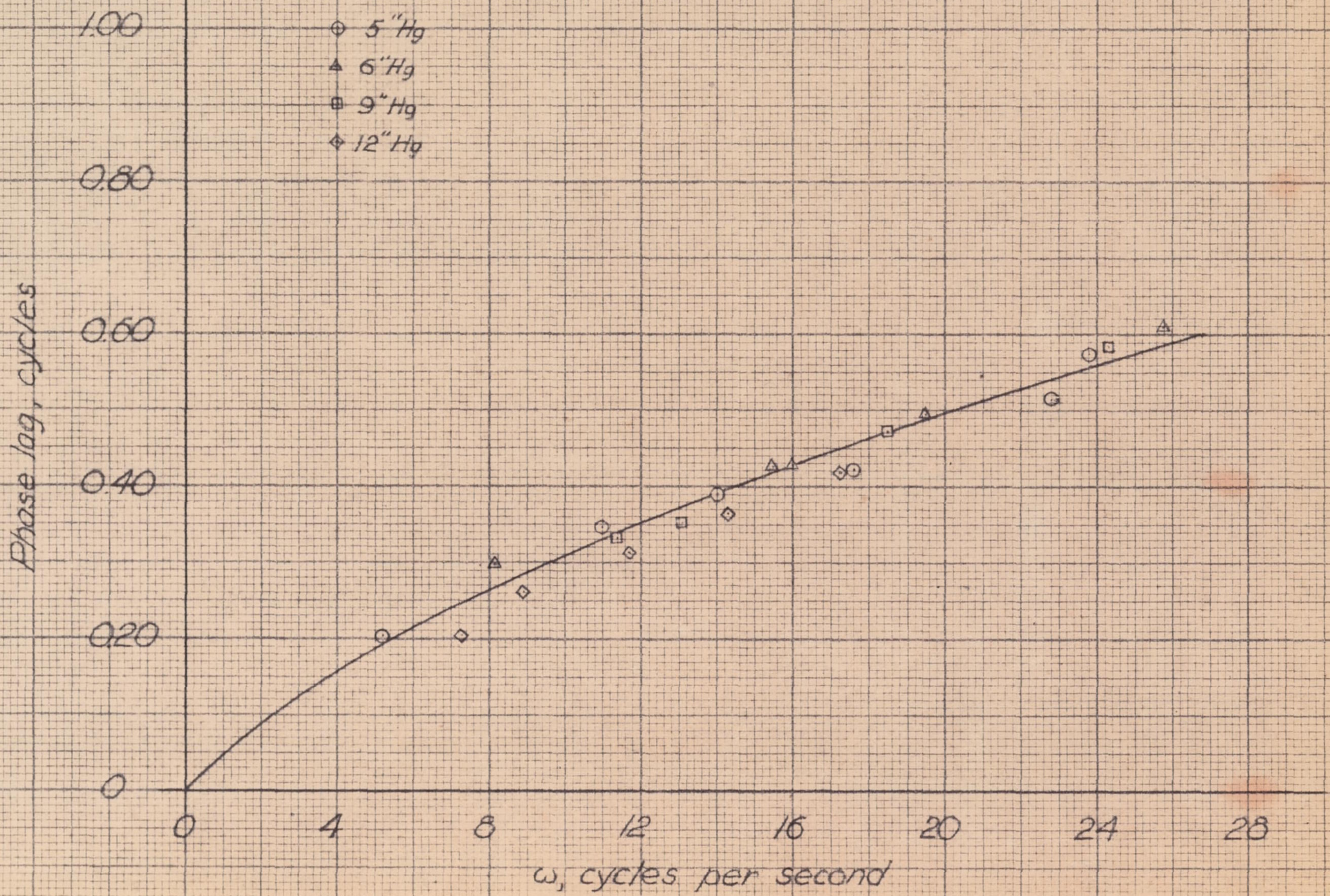


Figure 10. -- Variation of phase lag with frequency at four pressures; aileron orifice line, airplane 1.

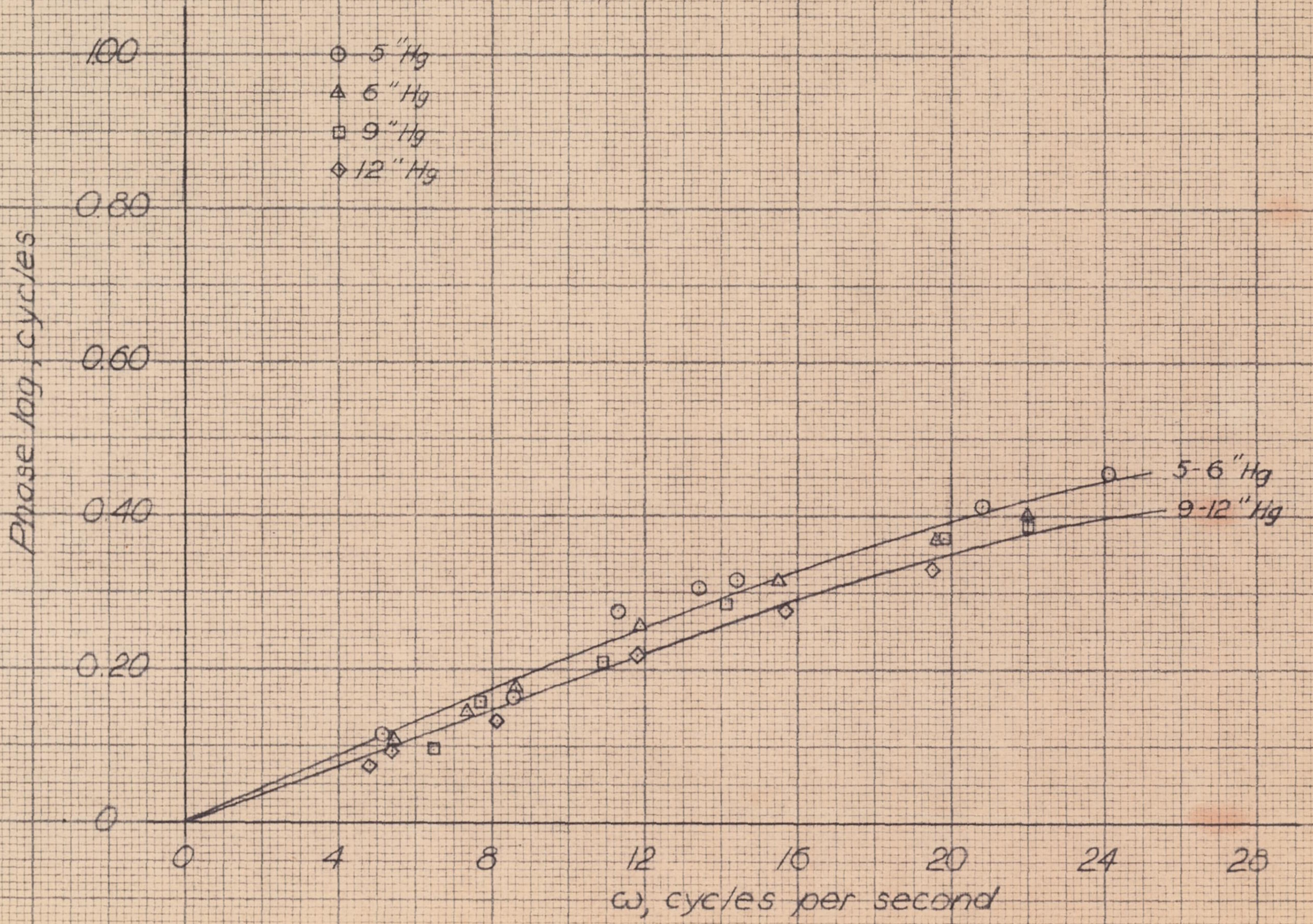


Figure 11. - Variation of phase lag with frequency at four pressures; stabilizer orifice line, airplane 1.

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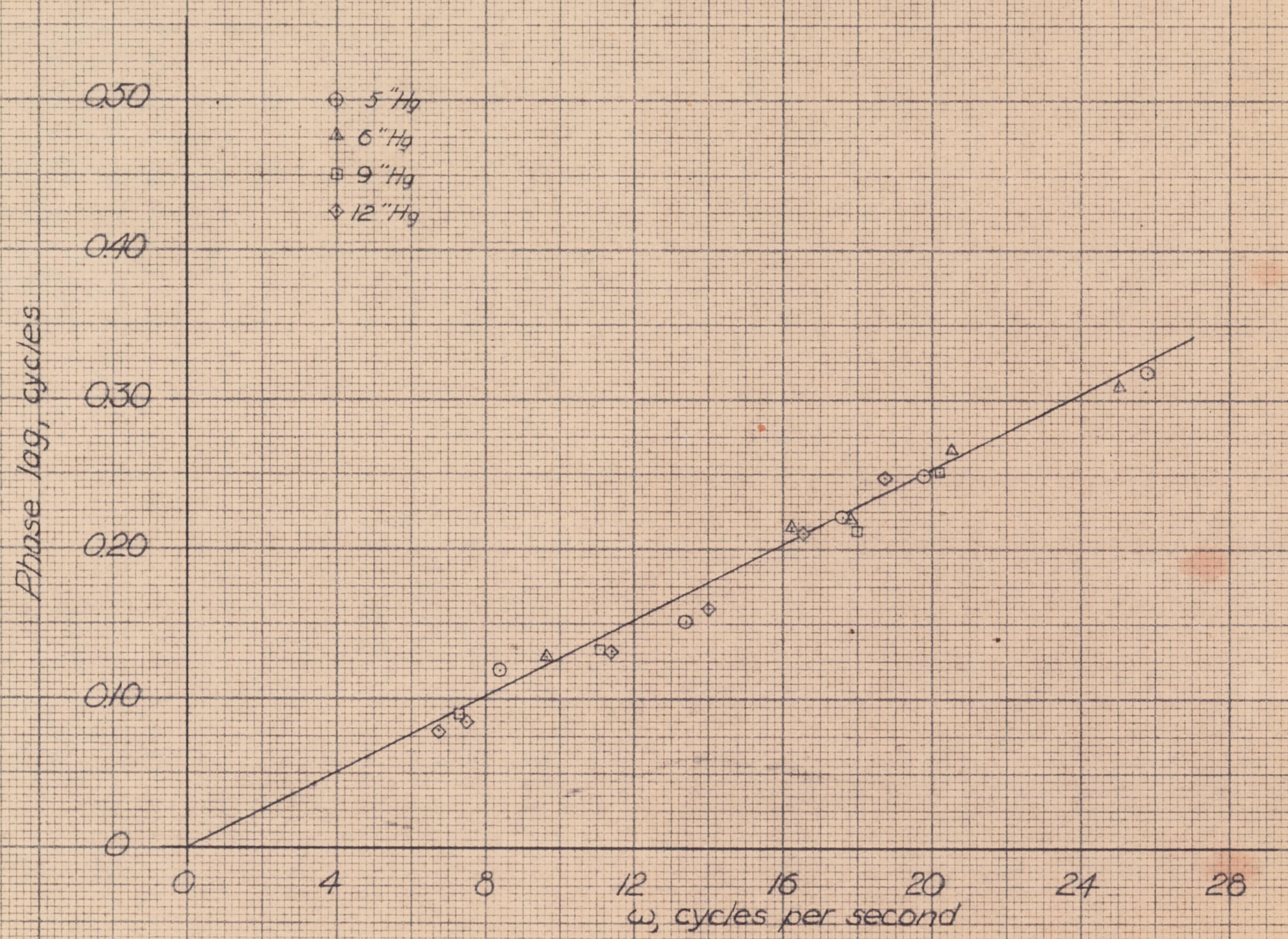

Figure 12 .- Variation of phase lag with frequency at four pressures; wing orifice line, airplane 1.

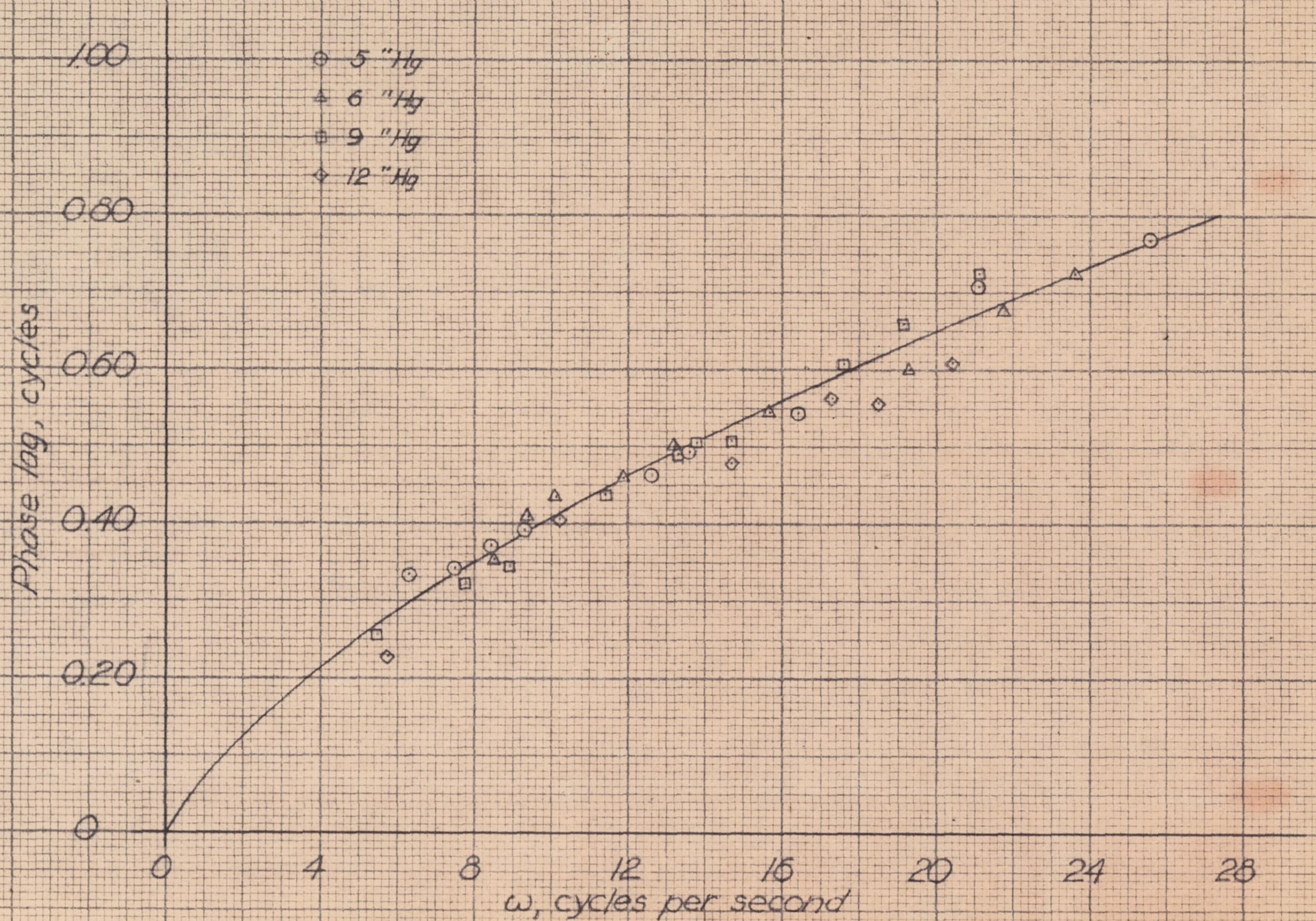

Figure 13.- Phase lag variation with frequency at four different pressures; total-head line airspeed system, airplane 2.

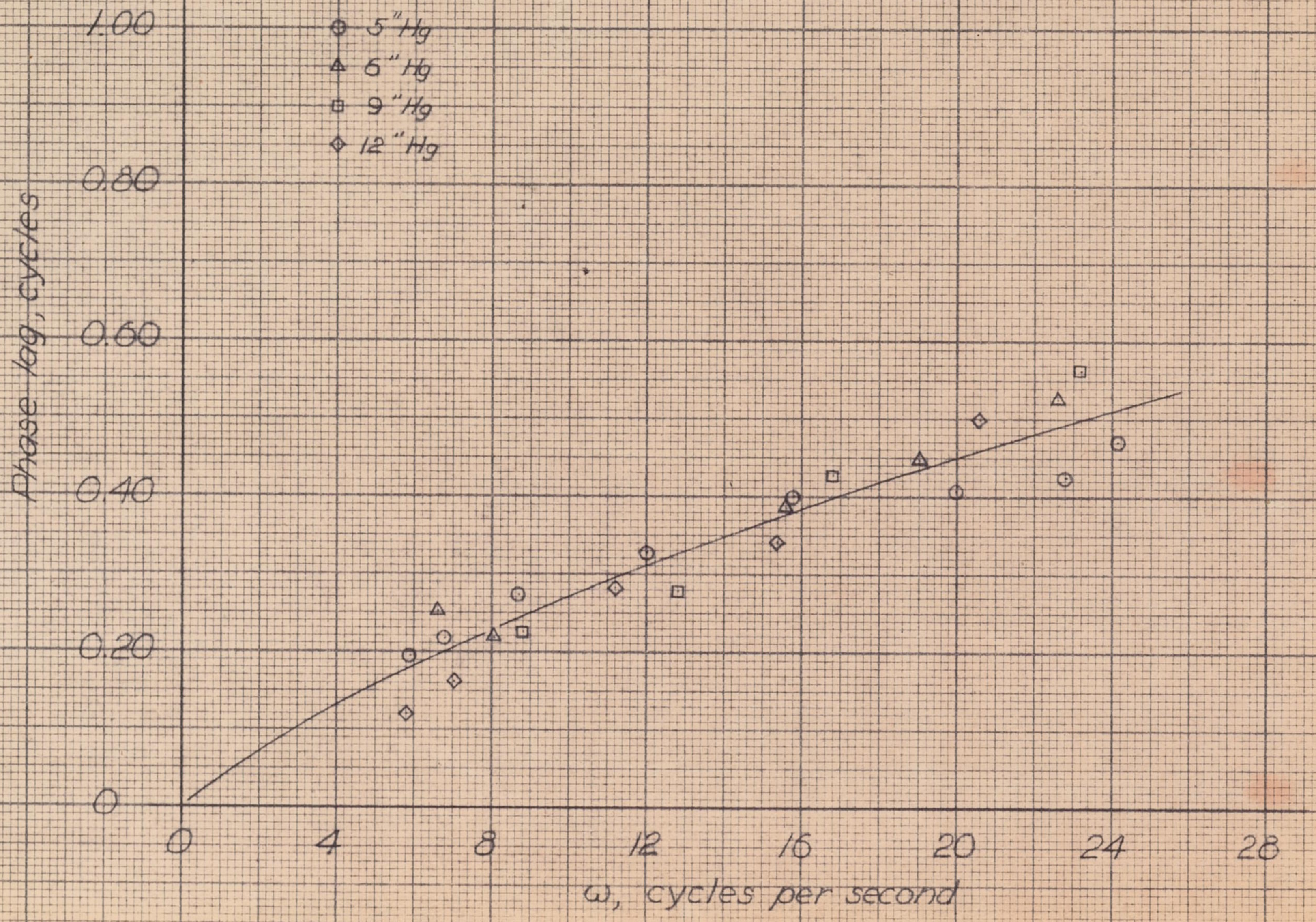

Figure 14.- Variation of phase lag with frequency at four pressures; static head-line airspeed system, airplane 2.

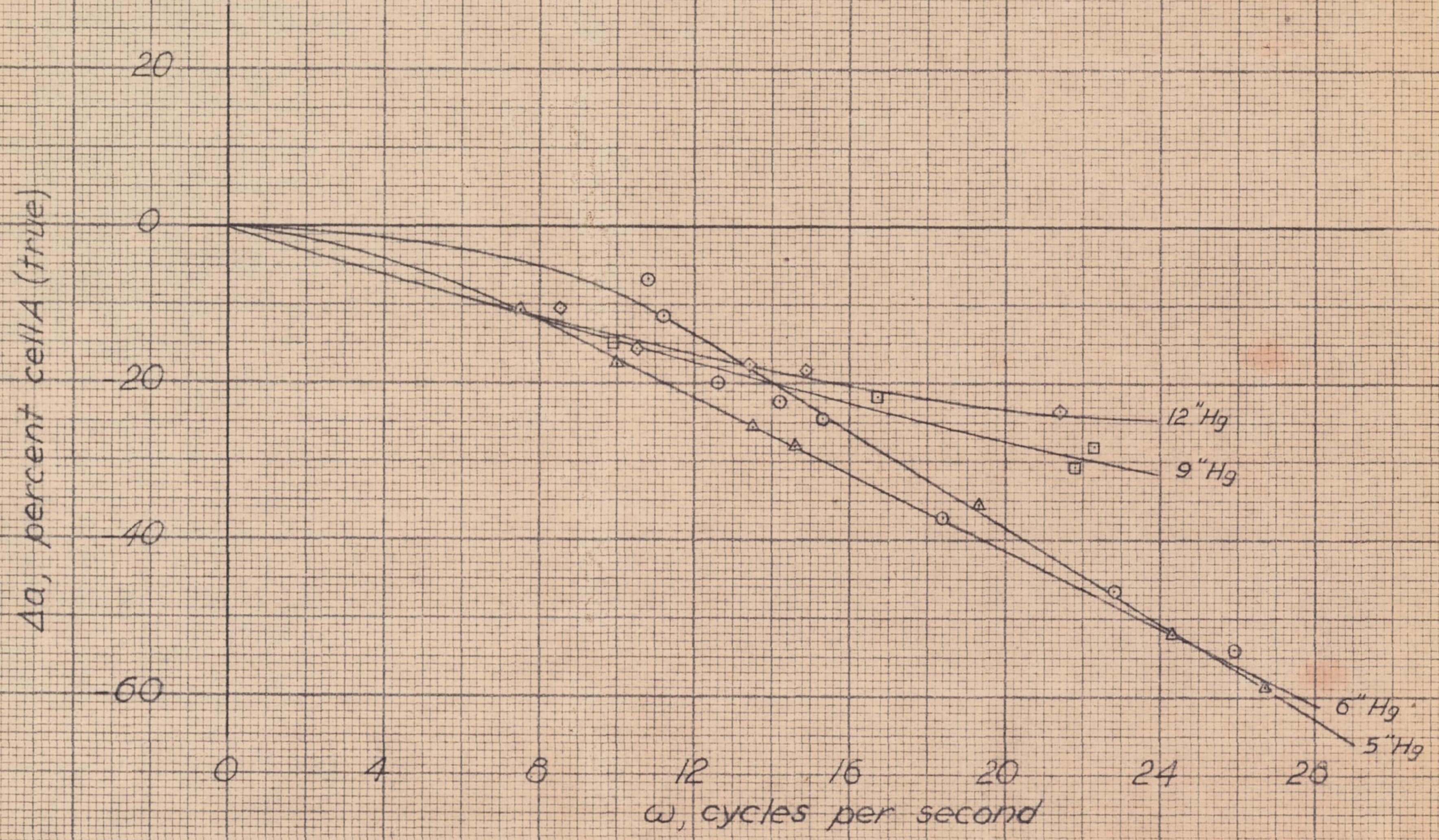

Figure 15.- Variation of amplitude error with frequency at four pressures; total-head line airspeed system, airplane 1.

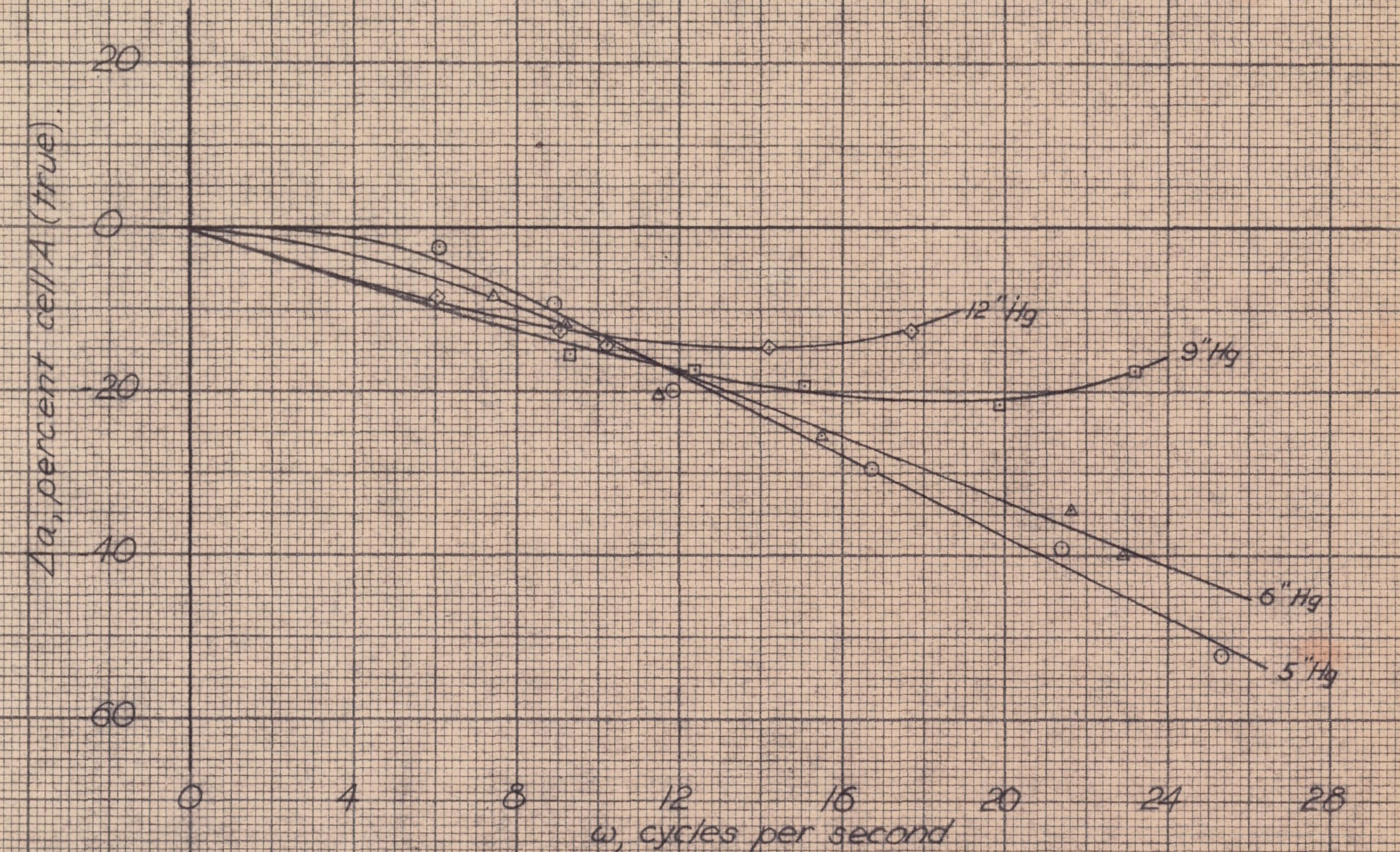

Figure 16.- Variation of amplitude error with frequency at four pressures; static-head line airspeed system, airplane 1.

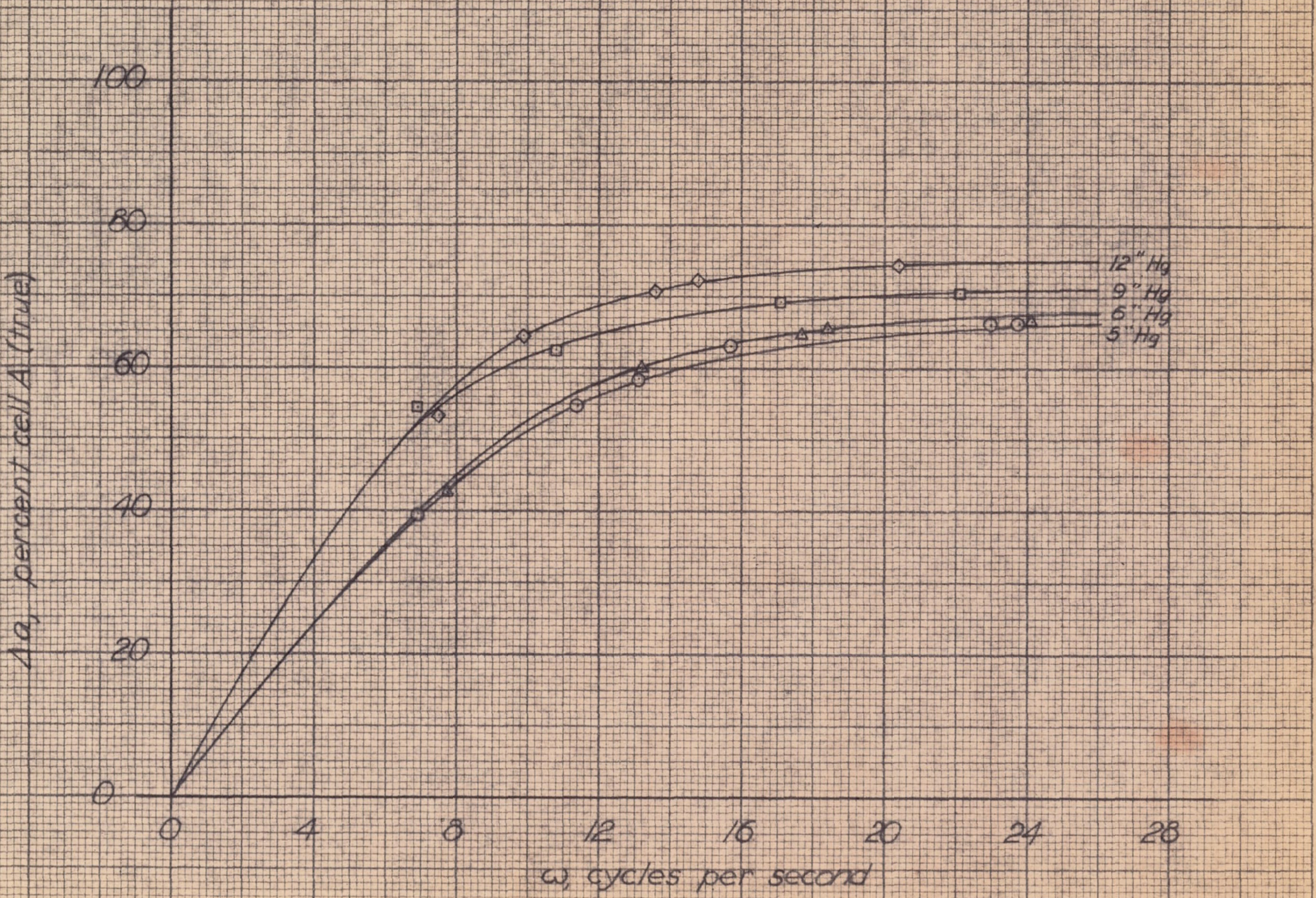

Figure 17.- Variation of amplitude error with frequency at four pressures; elevator-orifice line, airplane 1.

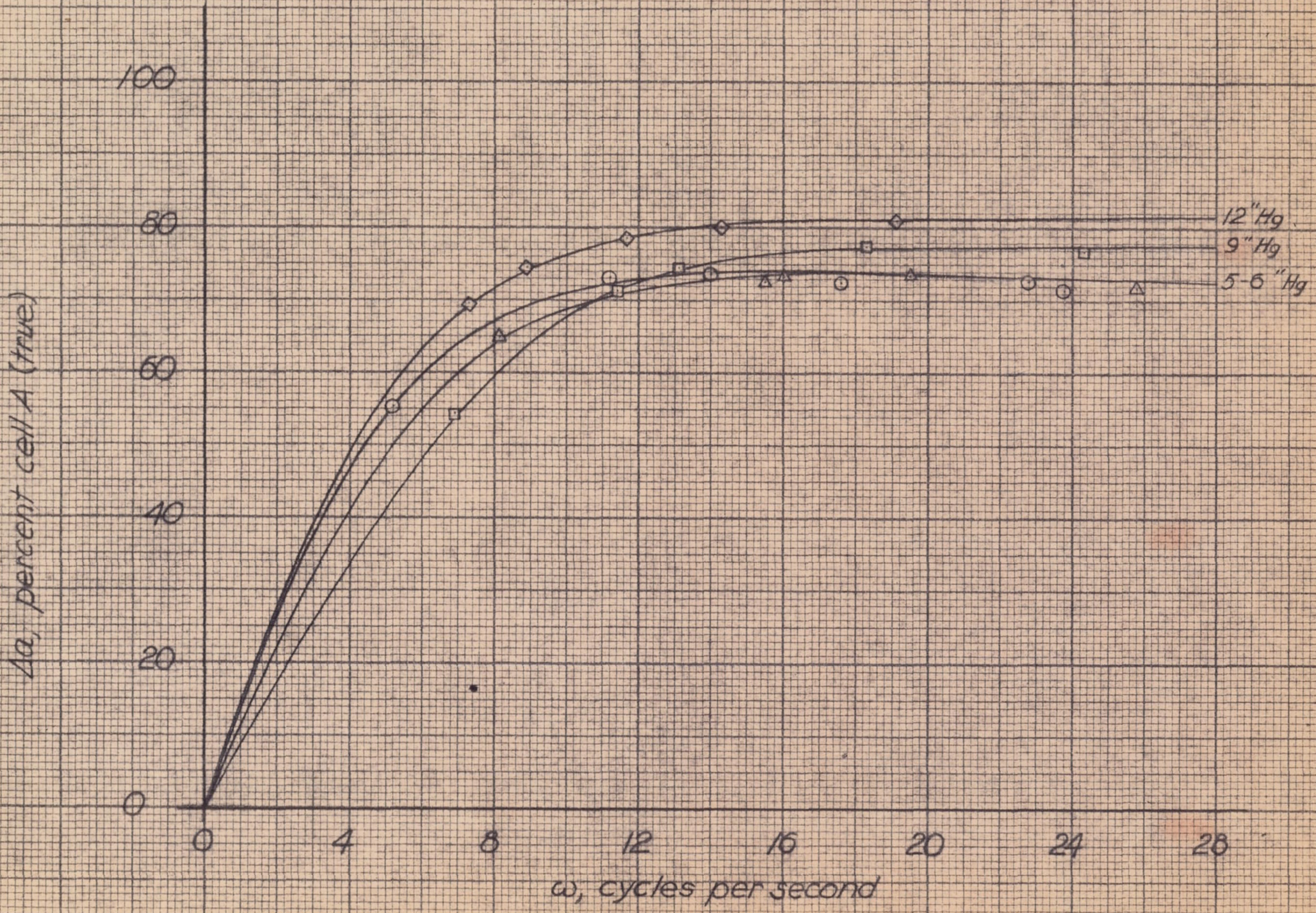

Figure 18.-- Variation of amplitude error with frequency at four pressures; aileron orifice line, airplane 1.

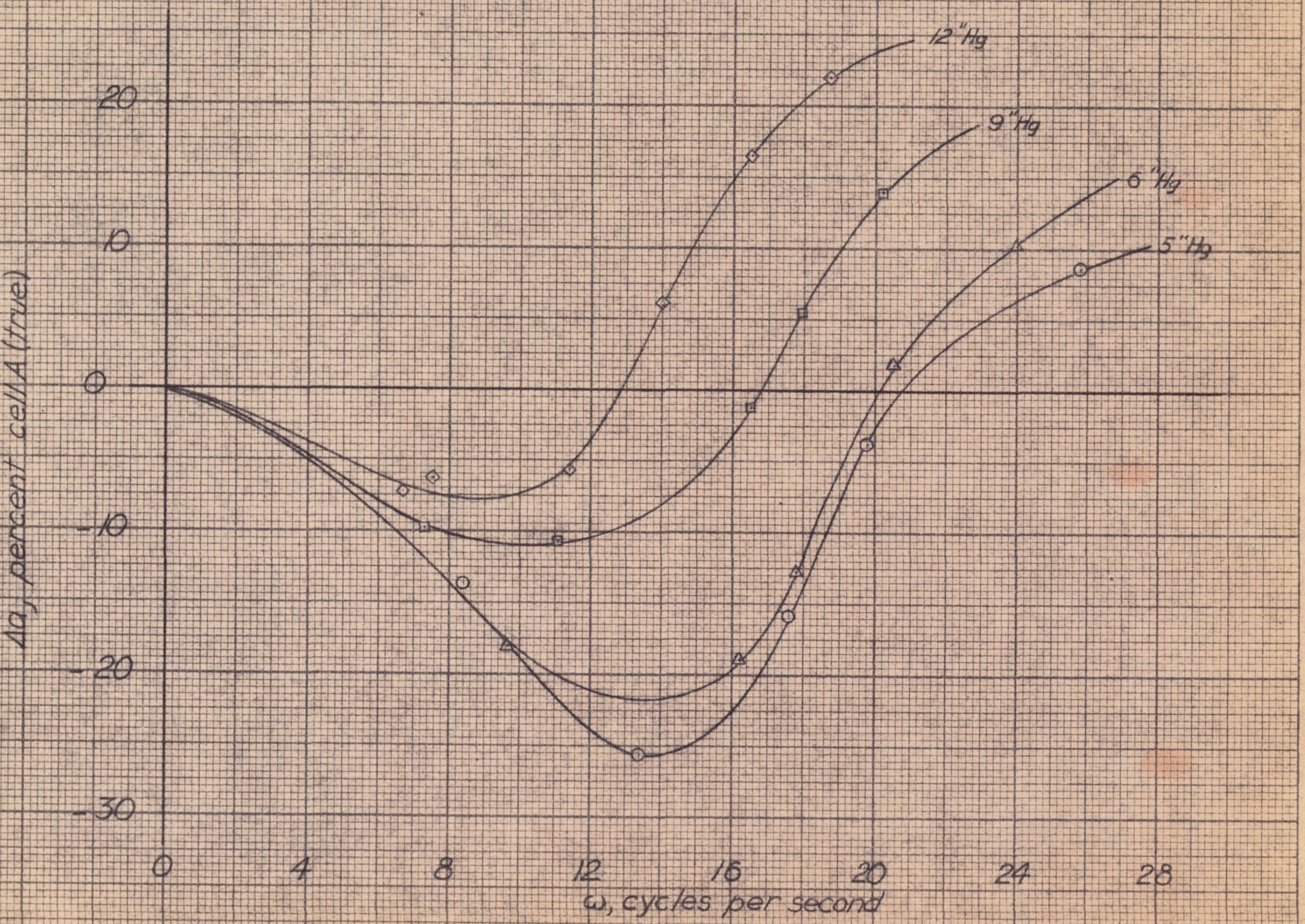

Figure 19.- Variation of amplitude error with frequency at four pressures; wing orifice line, airplane 1.

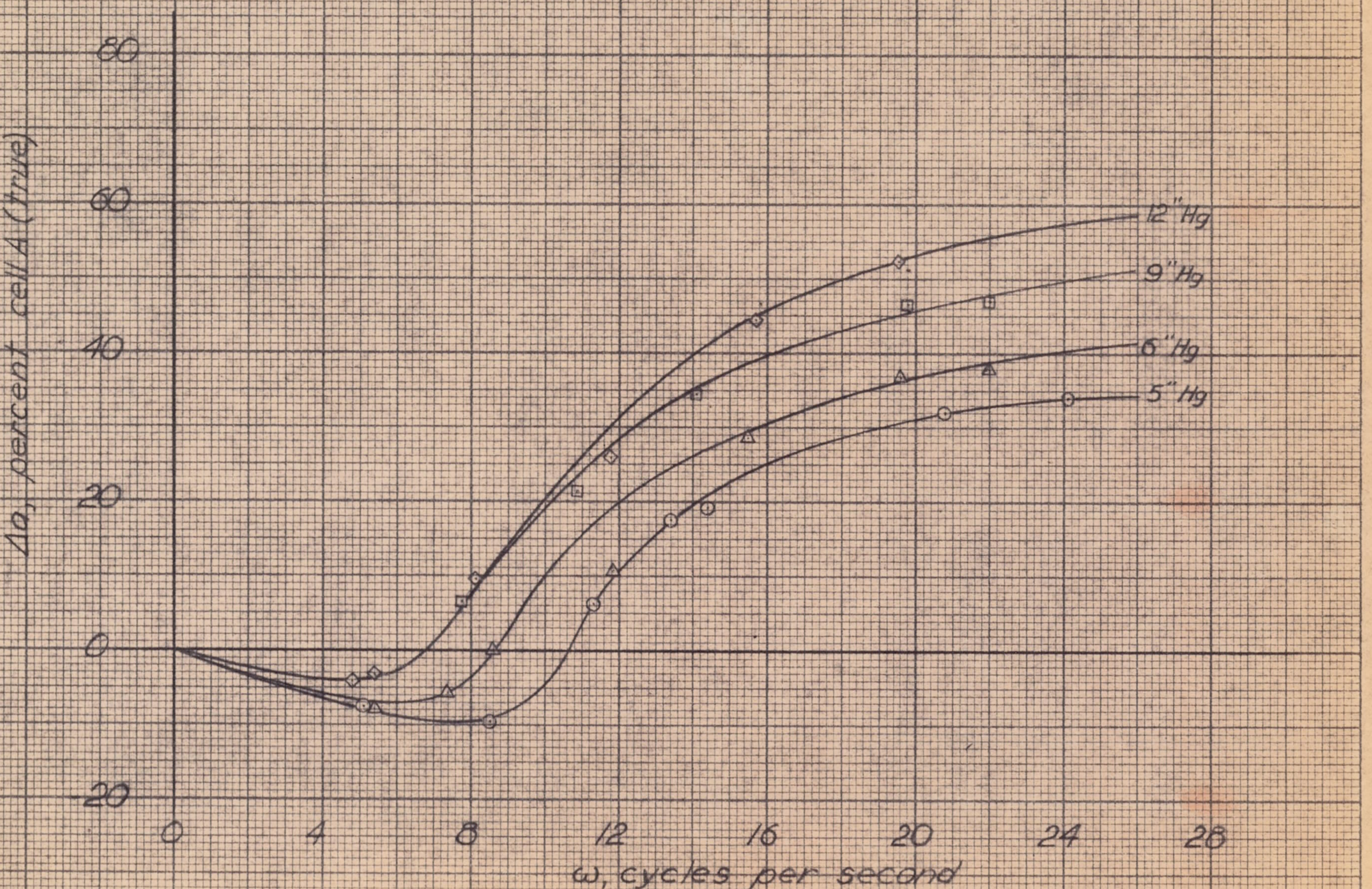

Figure 20.- Variation of amplitude error with frequency at four pressures; stabilizer orifice line, airplane 1.

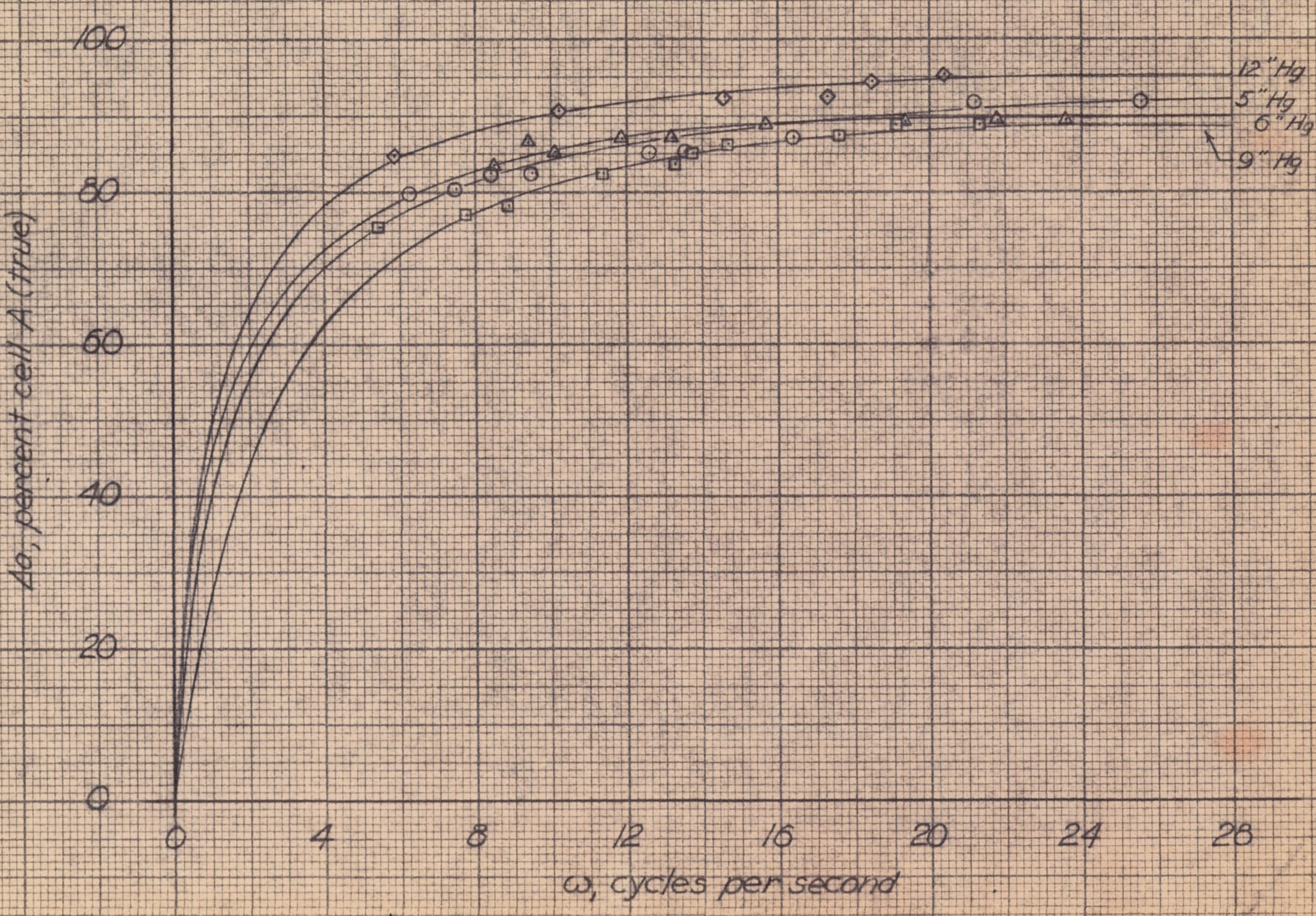

Figure 21.- Variation of amplitude error with frequency at four pressures; total head line airspeed system, airplane 2.

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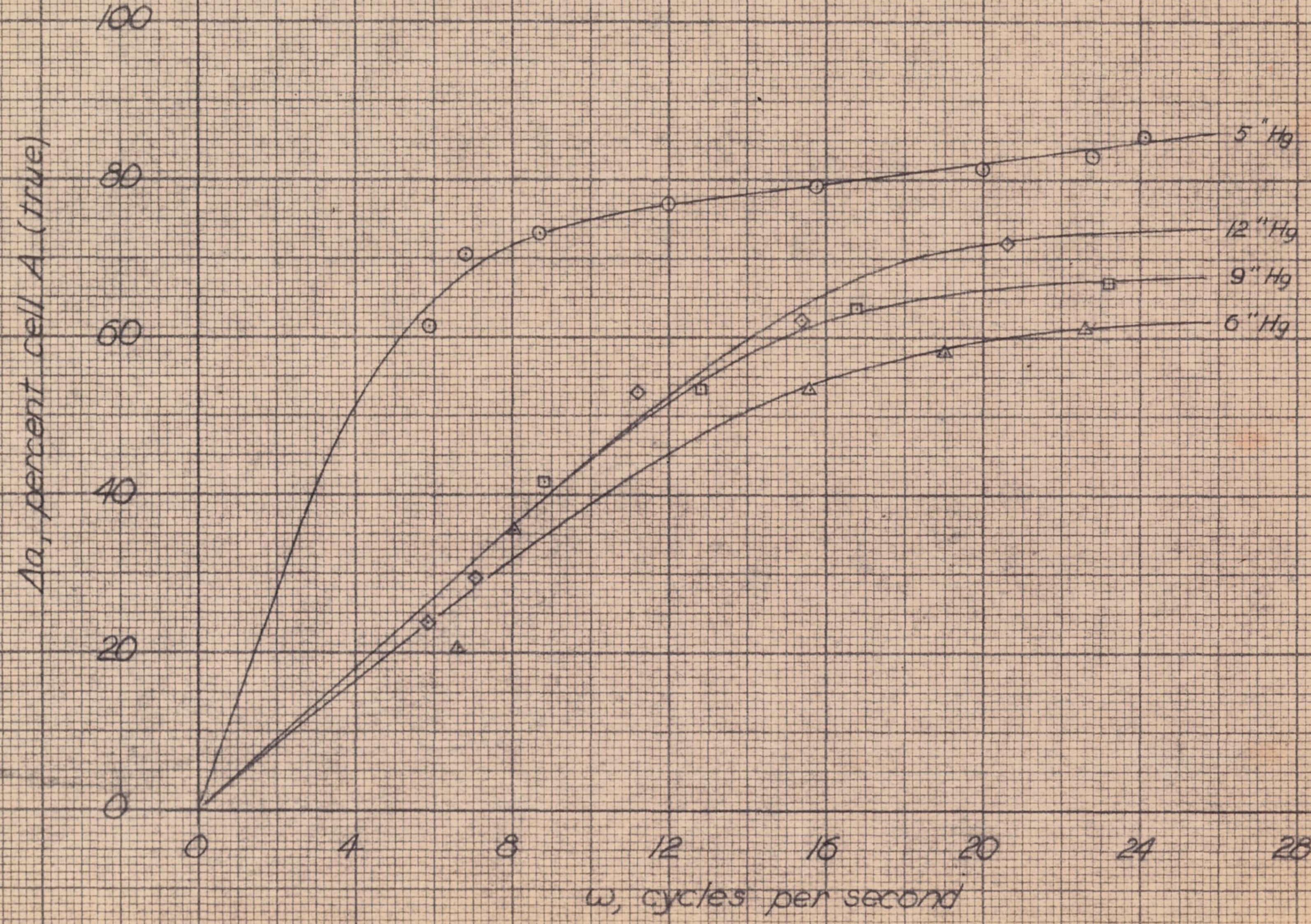

Figure 22.- Variation of amplitude error with frequency at four pressures; static head line, airspeed system, airplane 2.