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Boulder Laboratories

LOAD CARRYING CAPACITY OF GAS-LUBRICATED BEARINGS WITH INHERENT ORIFICE COMPENSATION USING NITROGEN AND HELIUM GAS

BY

H. SIXSMITH, W. A. WILSON, B. W. BIRMINGHAM

U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

A static flat plate test apparatus was used to determine the load carrying capacity of circular thrust plates. The load carrying capacities of nine different pad and orifice combinations were determined experimentally using nitrogen and helium gas as the pressurizing medium. Actual load vs. plate separation curves were developed at plate supply pressures ranging from 25 to 250 psig. The paper includes a description of the apparatus in addition to the curves which were developed for gas-lubricated bearing design.

1. INTRODUCTION

A gas-lubricated bearing can provide shaft support which is particularly suitable for high speed applications such as gyroscopes or expansion turbines where a support with negligible friction is required. A gas-lubricated bearing may be either self-acting (hydrodynamic) or externally pressurized (hydrostatic). In applications where a load must be carried over a wide range of speeds, the externally pressurized type is often found to be more satisfactory. Externally pressurized bearings may be of the recessed pool type or of the inherently compensated orifice type. Inherently compensated orifice type bearings are easier to fabricate and are more stable than bearings which have a recessed pool volume.

A knowledge of the load carrying capacity and gas film stiffness is required by the designer in order to design bearings to perform a specific function. The applications of such bearings cover a wide range of conditions for which reliable data must be available. Inherently compensated orifice type bearings have been studied by [Midwood and Duncan, 1957], [Woztech and Deuker, 1951], [Grinnell and Richardson, 1955], [Comolet, 1959], [Mori, 1960], [Licht and Fuller, 1954], [Robinson, 1957] and others. These authors have presented theoretical analyses for determining the flow patterns and load carrying capacities of gas-lubricated bearings. To make the theoretical computations these investigators had to make certain assumptions, and in some cases these assumptions do not agree implying that a valid computation is not yet possible. Where the flow in the bearing is laminar there appears to be good agreement between experiment and theory; however, the authors of this paper do not know of a simple theoretical treatment which will reliably predict the performance of a gas-lubricated bearing in the non-laminar region. In this region inertia effects and shock waves complicate the treatment and it was considered desirable to experimentally develop a set of design charts to show the relationship between load carrying capacity and plate separation as a function of bearing supply pressure, the type of gas, and injector hole size. Such charts clearly can not cover an unlimited range of variables; however, they should provide a basis to assist in the correlation of theory and experiment in the non-laminar region.

This paper is a precise, experimental study of the simplest type of inherently compensated bearing covering a wide range of variables. The apparatus consists of a pair of static, circular opposed flat plates with gas supplied under pressure to an orifice in the center of one of the plates. Flat plates of three different diameters were employed, 3/8", 1-1/8", and 3-3/8". Experiments were made with three different sizes of orifices in each plate: one-third, one-ninth, and one-twenty seventh of the diameter of the plate. Thus, there were nine different plates. The load vs. plate separation curves were obtained for each plate using a range of supply pressures from 25 to 250 psig. In order to provide data which can be used for the design of gas-lubricated bearings in certain cryogenic applications, the tests were conducted using nitrogen and helium gas. The temperature of the gas was held constant at 16°C by the use of a heat exchanger submerged in a water bath. [Richardson, 1958] and others have concluded that information obtained with circular thrust plates is applicable to rotating, multiple pad journal bearings when differences in geometry are taken into account.

As mentioned above, there is duplication in the laminar flow region with work done by other investigators. However, it is in the non-laminar region that the data provided here should be most valuable.

Since the specific objective of this experiment was to establish load carrying capacity and stiffness (slope of load carrying capacity vs. clearance curves) of the gas film, the added complication of measuring gas flow was not considered justified for this particular experiment. While gas flow is ultimately needed in any gas bearing design, it can be estimated reasonably well assuming that sonic flow conditions exist at the constriction described by the circumference of the injector hole and the plate clearance.

2. TEST APPARATUS

Figure 1 is a diagram of the simple thrust bearing where D is the pad diameter d is the orifice diameter, and h is the plate separation. Gas is supplied to the central orifice and flows radially outward in the gap formed by the clearance between the two plates. The flat plates under investigation were fabricated from stainless steel and consist of a stationary member and a movable member. The movable plate is in the form of a cylindrical piston 3-1/2" in diameter and 1-1/2" long. The piston is radially positioned by a gas-lubricated journal bearing, the gas being supplied through eighteen -1/16" diameter holes equally spaced around the periphery of its mating cylinder.

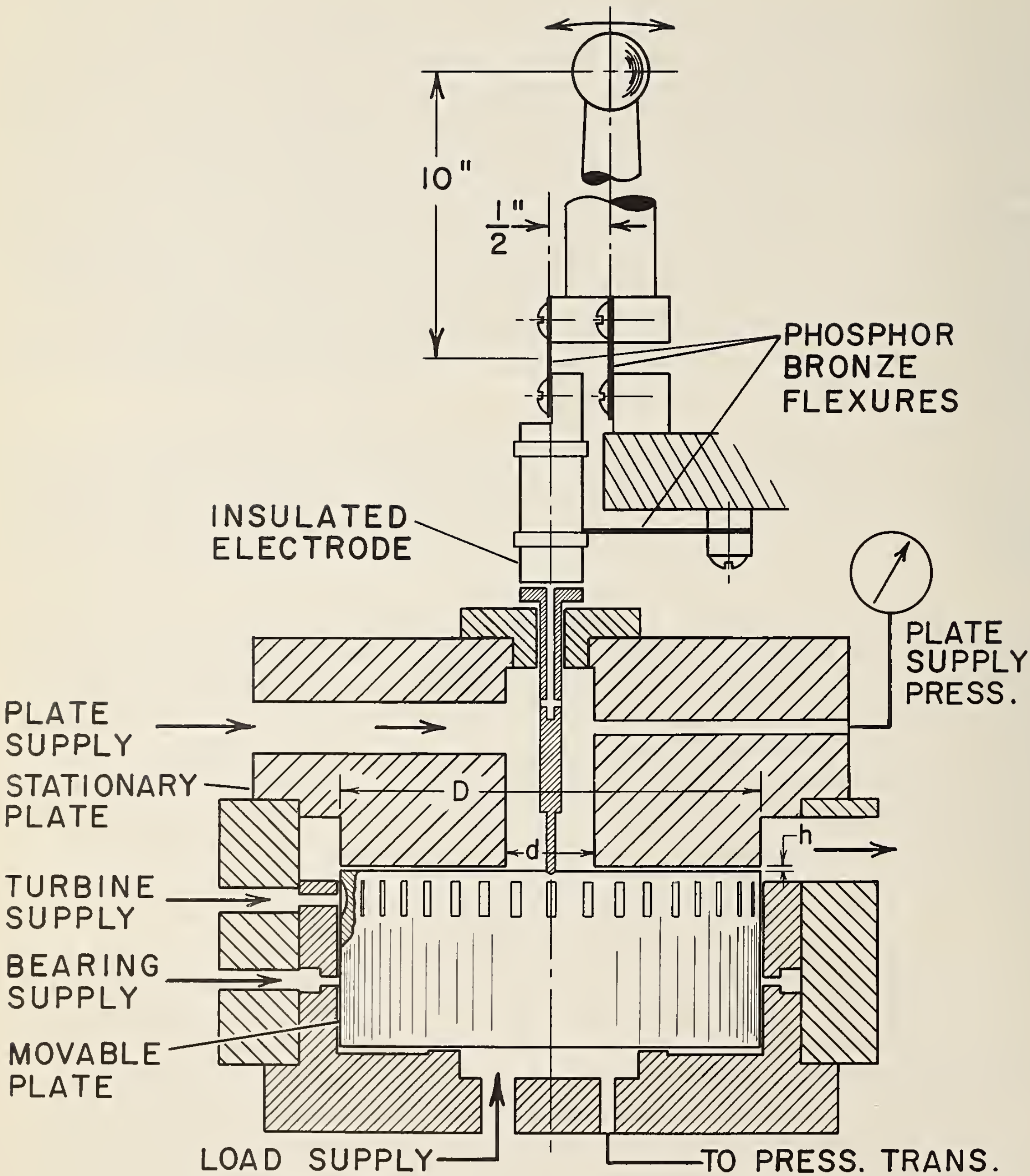

Figure 1 - Schematic Diagram of Test Fixture

The radial clearance between the piston and cylinder is .002". The load is applied to the thrust plates by supplying gas to the bottom of the piston.

Figure 2 is a photograph of the nine different stationary plates and the loading piston. The plates are shown upside down relative to their orientation in the test fixture. For the smaller pad diameters, a multiplicity of pads was used to insure that the mating pads remain parallel during a test. The mating surfaces of both the stationary plates and the piston were lapped true and flat within 1 to 2 light bands in order to obtain as perfect a surface as possible.

The dimensions of the flat plates and orifices as given in figures 6 through 27 were actual sizes as measured with precision instruments. The plate diameters were accurate within ±0.3% while the orifice diameters were accurate within ±1.5% of the recorded sizes.

A diagram of the complete test apparatus, including the test fixture, the gas supply arrangement, and the supporting instrumentation, is shown in figure 3. The clearance between the active surfaces of gas-lubricated bearings is of the order of .001". As it is desired to measure the plate separation to an accuracy of 1%, a measuring device that is sensitive to about 10 microinches is required. The measuring device described in the following paragraphs was therefore used.

An invar pin passes through the center of the upper plate and rests on the surface of the lower plate (see figure 1). The diameter of the pin is 5/32" and the diameter of its cylindrical head is 3/8". An insulated electrode 7/16" diameter is situated about .001" distant from the top surface of the invar pin. The pin is drilled axially and transversely so that some of the supply gas escapes through the clearance space between the top of the pin and the electrode. The pressure of the escaping gas in the clearance space provides a force which keeps the pin in contact with the lower plate.

The insulated electrode is fixed to a movable carriage with a vertical excursion of about .012". The carriage is mounted on flexures and coupled to a micrometer screw gauge through a mechanical linkage (see figure 3). The reduction ratio of the linkage is 20:1. Thus a movement of 0.001" of the micrometer screw gauge corresponds to a movement of 50 microinches of the electrode. The micrometer screw gauge is coupled to a servo motor through gears with a ratio of 1:1.

Figure 2 - Flat Plate Test Pads and Loading Piston

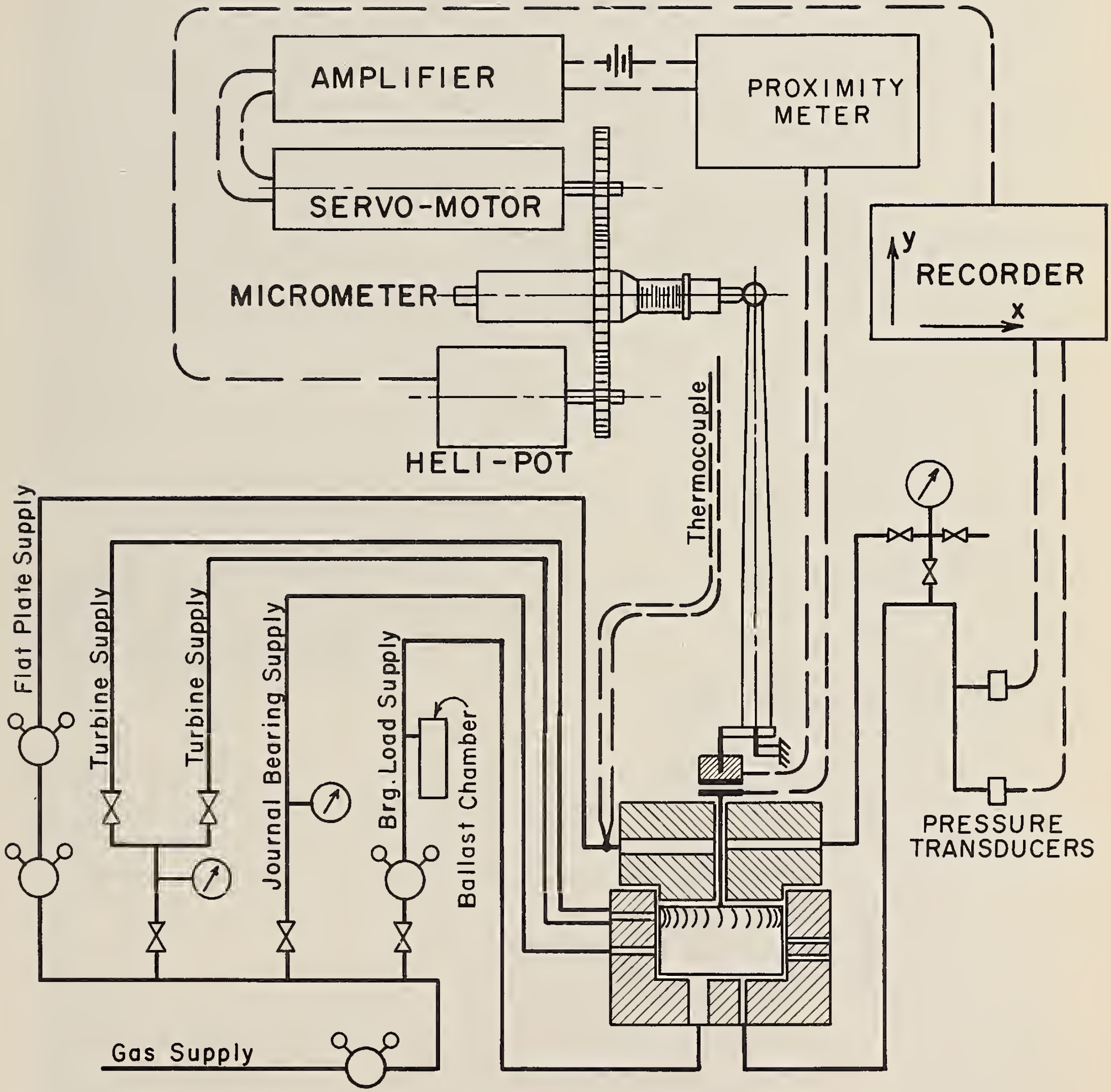

Figure 3 - Diagram of Test Apparatus

The capacitance between the invar pin and the insulated electrode forms part of the capacitance of the bridge circuit of a proximity meter. As the signal from the proximity meter has the same polarity on either side of the balance point of the capacitance bridge, it is unsuitable for feeding directly to the input of the servo amplifier. In order to obtain a suitable signal, on opposing bias of 30 volts is included in the output circuit of the proximity meter. The battery is connected with its polarity in opposition to the output signal from the proximity meter. With this modification, the input signal to the servo amplifier on either side of this adjustment results in signals of opposite polarity as required at the input to the servo amplifier. The servo control is stable on one side of zero and unstable on the other side; the stable side is chosen by trial and error. With this servo system any movement of the invar pin is followed by the insulated electrode. A 10-turn linear potentiometer is coupled to the micrometer screw through gears with a 1:1 ratio. The potentiometer provides an electrical signal which is directly proportional to the plate separation. This signal is used to control the x-axis of an x-y recorder.

The load is applied by means of gas pressure supplied to the bottom side of the piston. The magnitude of the load is a function of this pressure and the area of the piston. The pressure is measured by means of a pressure transducer and the signal from the transducer is fed to the y-axis of the recorder. Two pressure transducers of different ranges were used to obtain precision measurements over a broad range.

In order to obtain reliable and reproducible results it is imperative that the supply gas is pure, clean, and held at a constant temperature. Both the nitrogen and helium gas used had a purity of better than 99.8%. The gas was passed through a 10-13 micron sintered bronze filter and through a water bath heat exchanger to maintain constant temperature prior to entering the test fixture.

Figure 4 is a photograph of the test apparatus and supporting components. The supply gas manifold and controlling equipment are shown on the right and the sensing and recording instrumentation on the left. The gas cylinder was connected to the piston loading supply line and used as a ballast volume to obtain very close control of the loading pressure. Figure 5 is a photograph showing the test fixture in more detail.

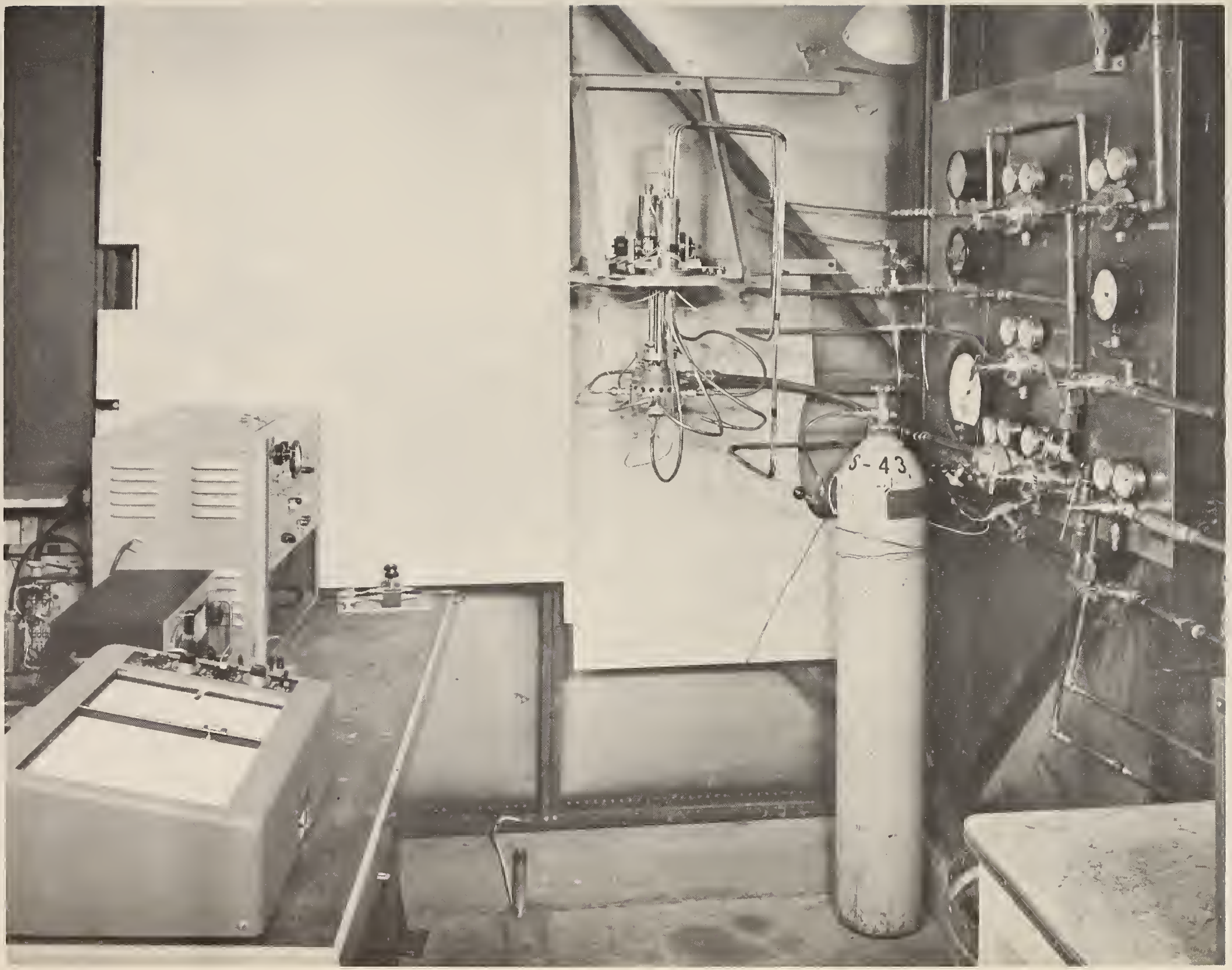

Figure 4 - Flat Plate Test Facility

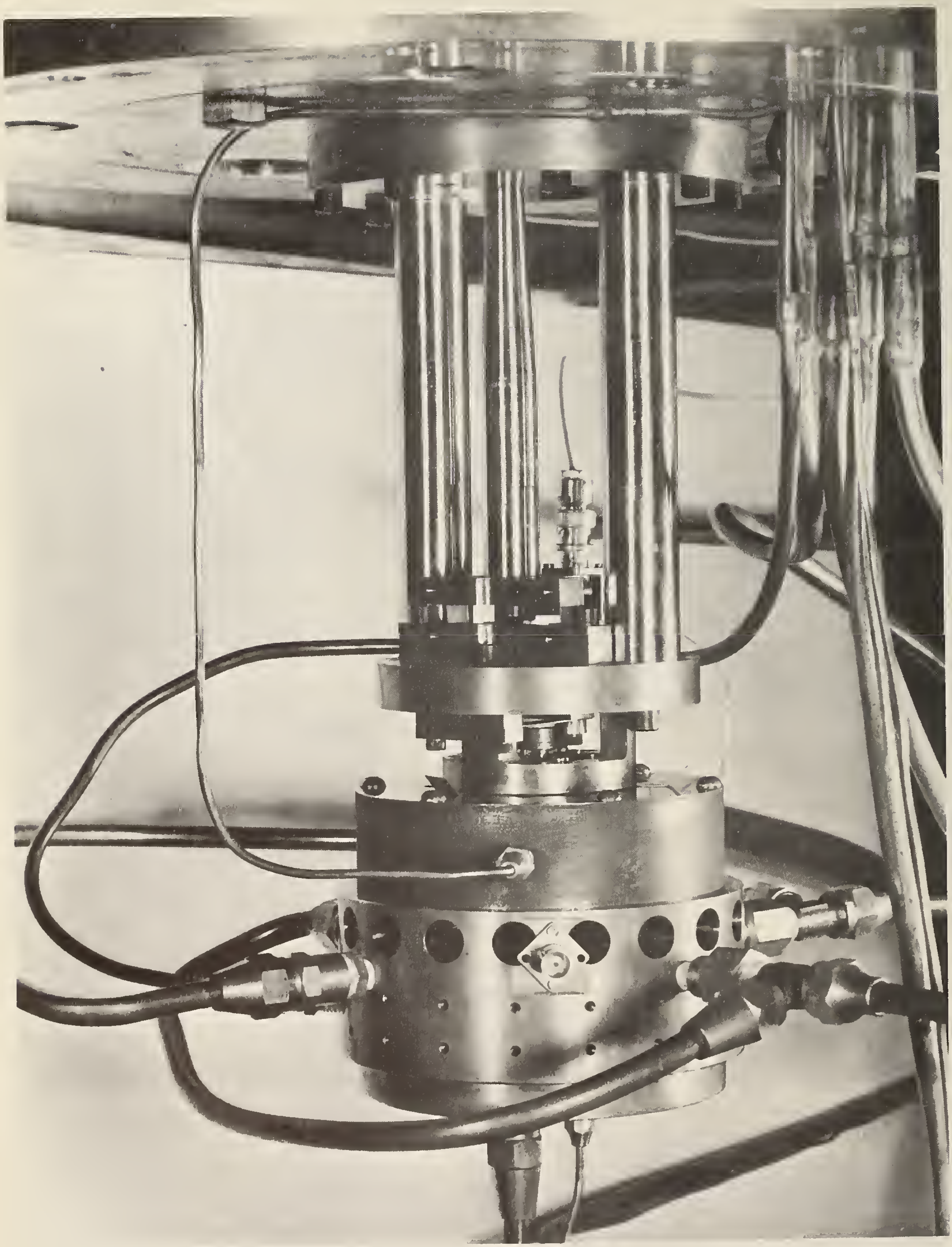

Figure 5 - Flat Plate Test Fixture

3. TEST PROCEDURE

Prior to starting a particular series of tests, both axes of the x-y recorder were calibrated. The x-axis was calibrated against the precision micrometer screw gauge. The y-axis was calibrated against an area-corrected, precision pressure gauge reading. The bearing load was determined by multiplying the pressure on the piston by the ratio of the piston area to the total pad area.

In order to obtain reliable results it was necessary that the piston be floating freely within its cylindrical housing when supported with a load and positioned by the gas-lubricated journal bearings. Such a condition was insured by spinning the piston with a jet of gas directed on the small blades machined in the outside of the piston. When it was determined by visual observation that the piston was free and floating, the rotation was stopped and a test started.

The load was initially set to obtain zero separation between the plates for a specific plate supply pressure. The load was then reduced gradually by manual operation, while maintaining a constant plate supply pressure. As the load was decreased, the plate separation increased and a plot of load vs. plate separation was obtained on the x-y recorder. This operation was continued until the constant plate supply pressure could no longer be maintained. Thus the test for a specific set of conditions was completed. For each set of conditions the tests were conducted first using nitrogen gas and then using helium gas. A set of curves for each orifice and pad combination was developed with both gases at plate supply pressures ranging from 25 to 250 psig.

Every effort was made to minimize the experimental error in conducting these tests. In many cases the tests were repeated to insure that the results were reproducible.

4. TEST RESULTS

The results of this experimental program are presented in figures 6 through 27, which are graphs of load vs. plate separation, with plate supply pressure as a parameter. Curves for both nitrogen and helium gas are included. The slope of these curves provides a measure of bearing stiffness at any selected point.

The curves in figures 17, 18, and 27 show changes in the regular shape of the curves as the plate separation is increased. This change in shape occurs only with plates having orifice diameters and plate separations that are large relative to the plate diameter. This change is a function of the supply pressure as well as the plate separation and indicates that a definite change in the gas flow occurs. Audio observation during the tests confirmed that a change in gas flow did in fact occur. The normal sound of escaping gas suddenly increased at the point of change of slope in the above curves. Both Mori [1960] and Robinson [1957] have suggested that a shock wave could exist within the effective areas of a flat plate thrust bearing. If this is the case, the above observation suggests that the compression shock wave moved to the outside of the plates and that only a supersonic flow condition exists between the plates.

Laub [1960] has developed a set of experimental curves for a plate and orifice combination with dimensions close to those shown in figure 13. He used air as the pressurizing medium but limited the maximum supply pressure to 48 psig. His results were similar to those obtained here.

5. CONCLUSIONS

It is concluded that the curves presented herein can be used for the design of gas-lubricated bearings within the range of orifice to plate diameter ratios, gas medium, and gas supply pressures investigated. To the authors' knowledge this information has not been published previously.

This design information is not readily determined by theoretical computation; consequently, it should prove useful to the designer of gas-lubricated bearings for practical applications. The intervals of plate supply pressure are relatively small permitting linear interpolations accurate to within 3%.

6. ACKNOWLEDGMENT

The authors wish to acknowledge the contributions to this work made by J. A. Brennan of the National Bureau of Standards' staff. His able assistance in the design, fabrication and, installation of this test apparatus has been greatly appreciated.

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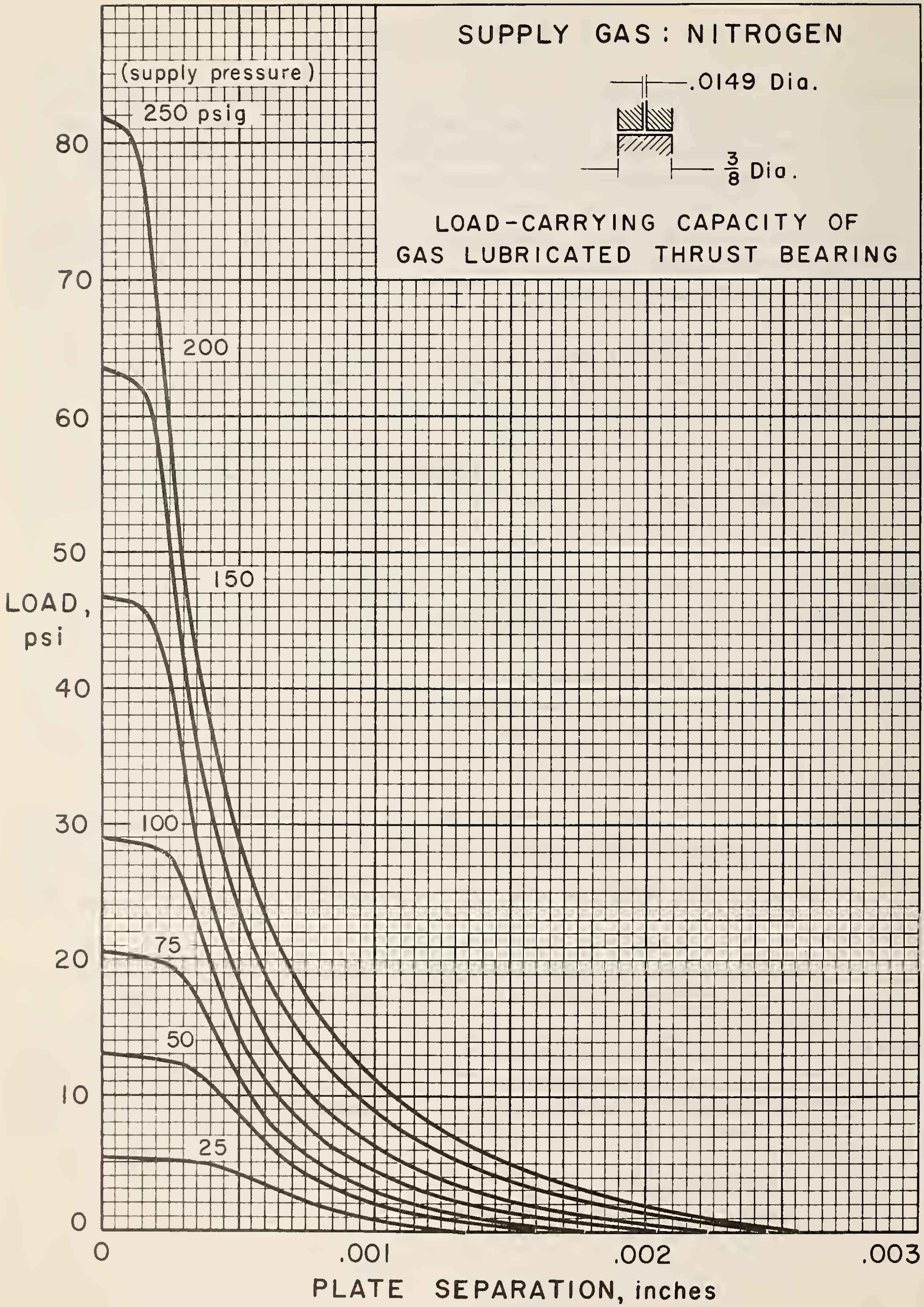


Figure 6 - Load vs. Plate Separation Curves

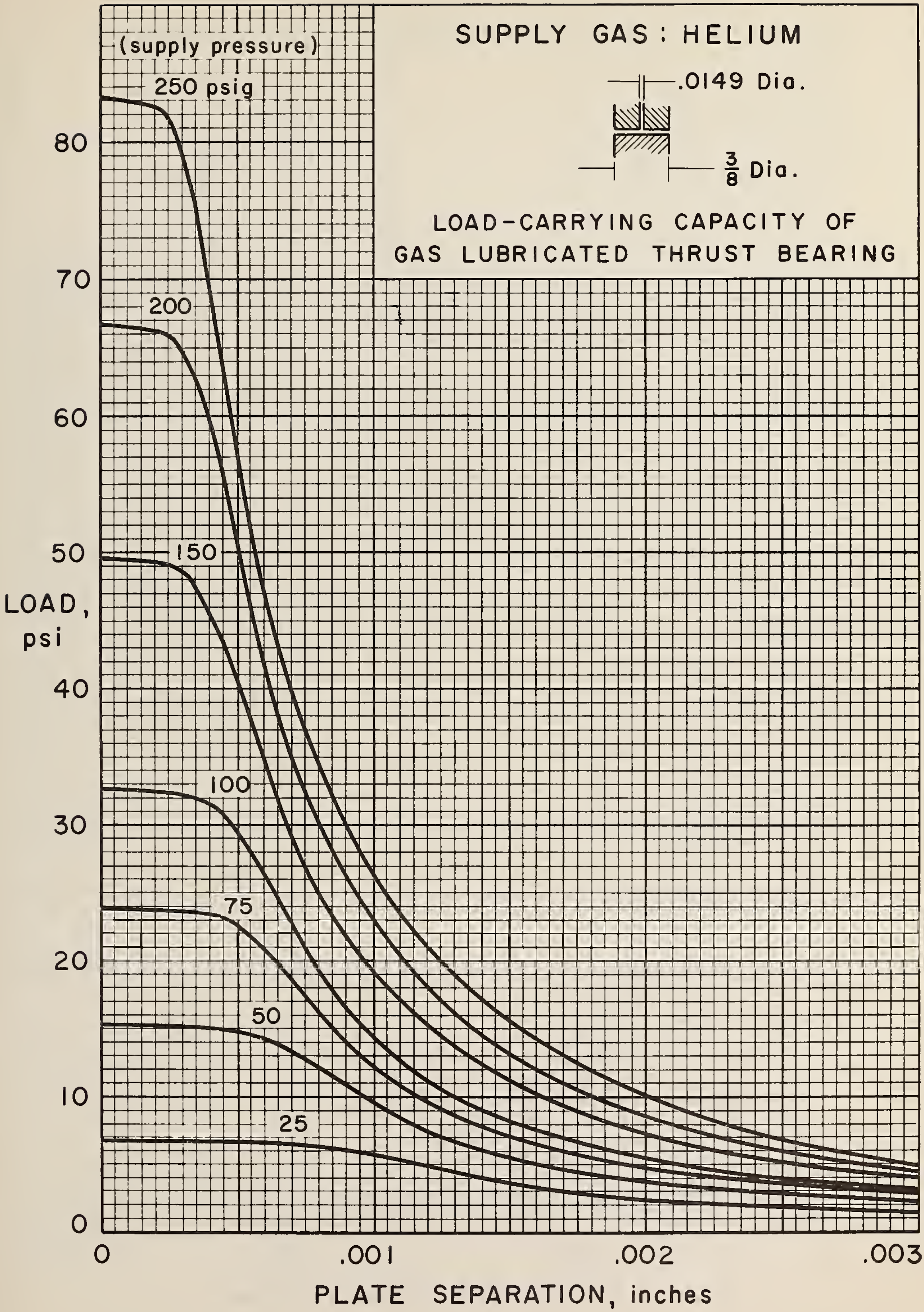


Figure 7 - Load vs. Plate Separation Curves

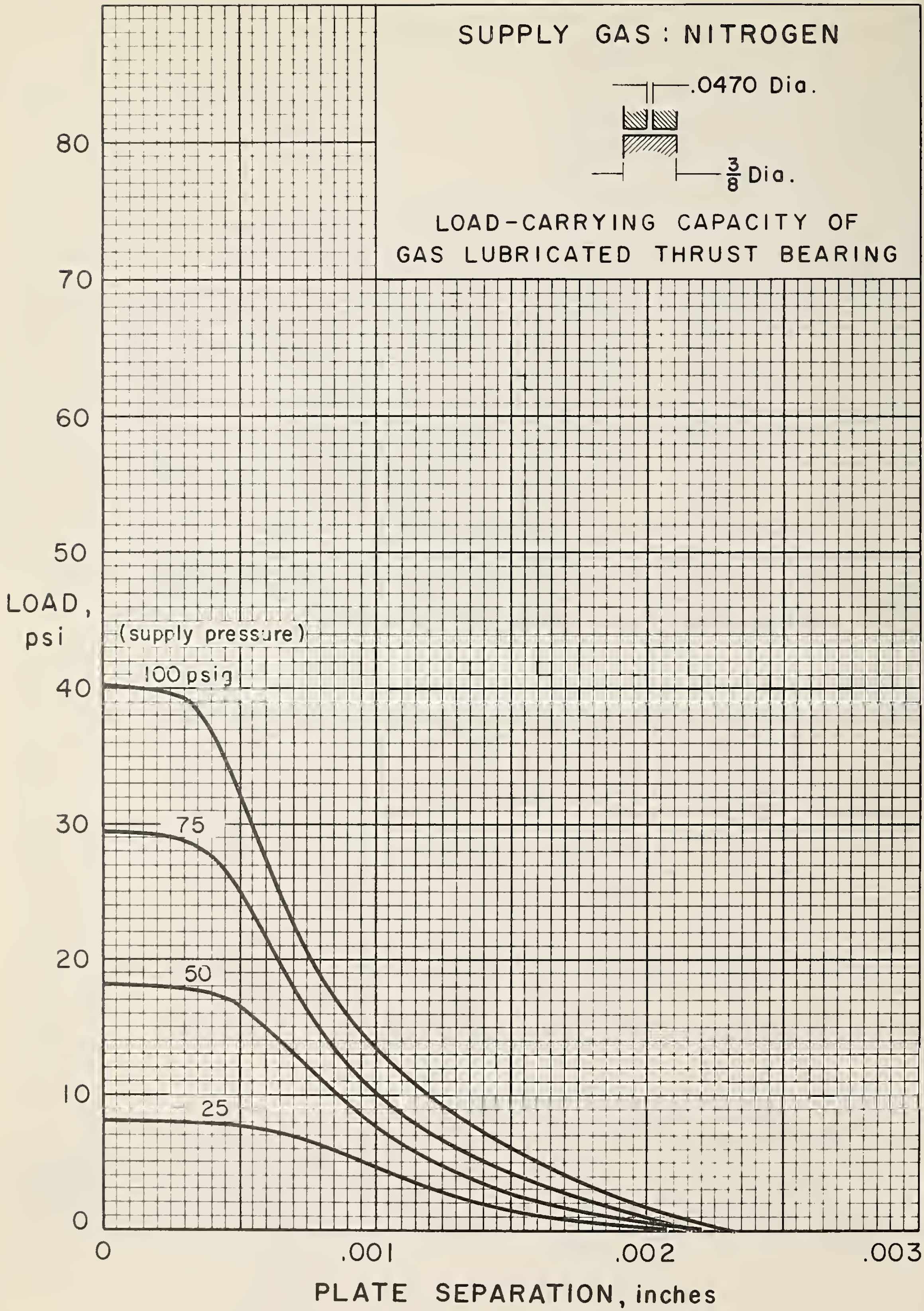


Figure 8 - Load vs. Plate Separation Curves

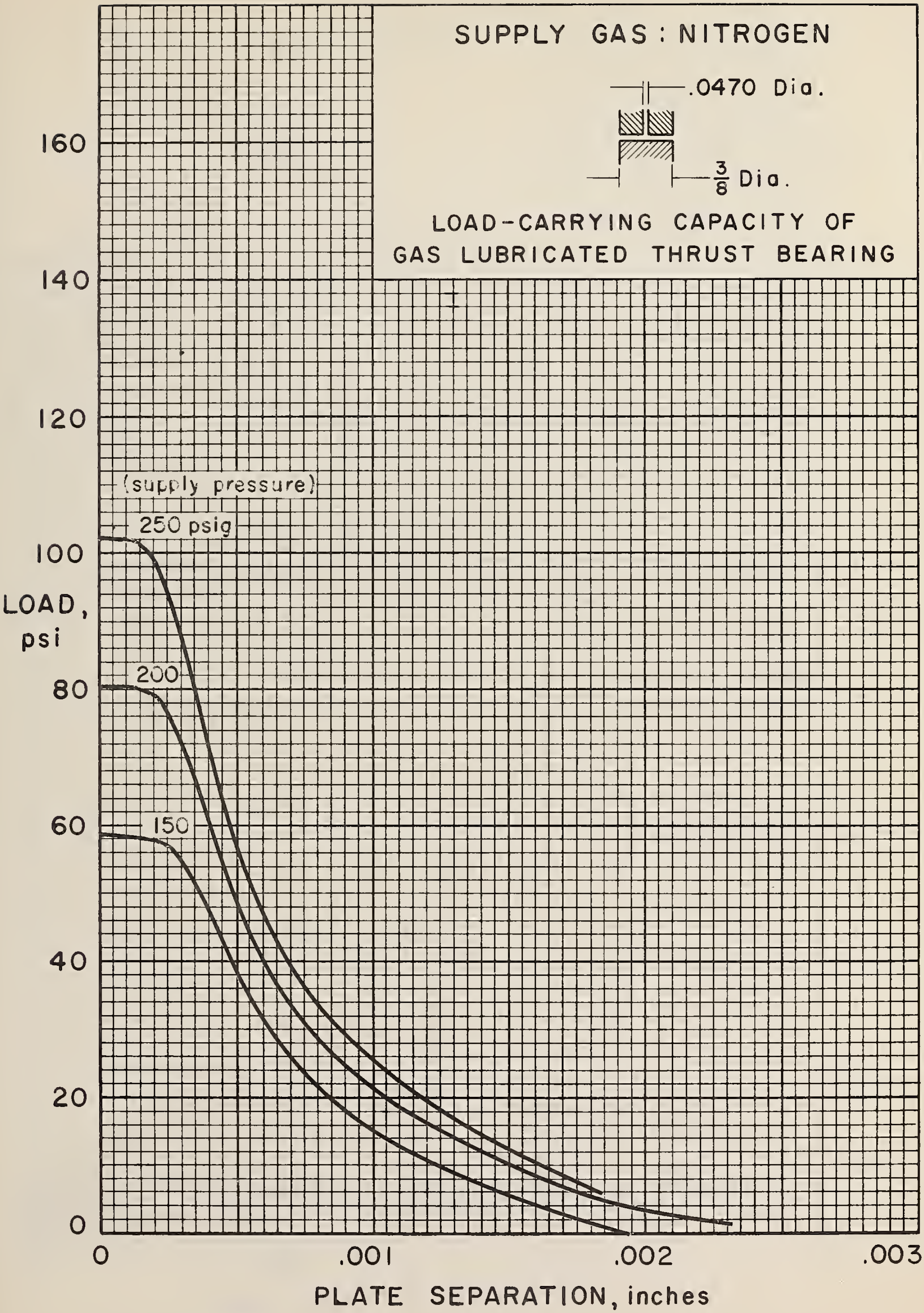


Figure 9 - Load vs. Plate Separation Curves

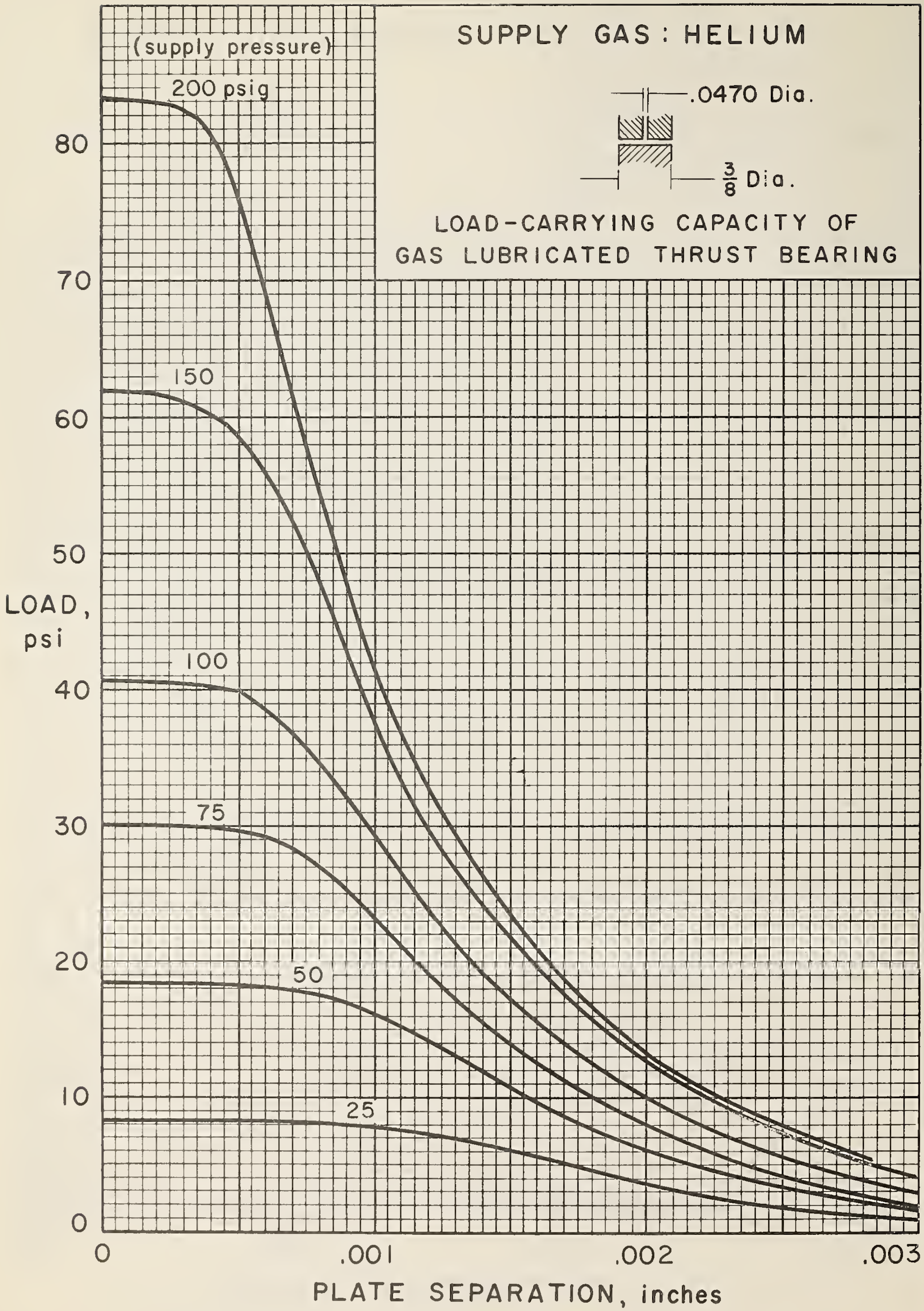


Figure 10 - Load vs. Plate Separation Curves

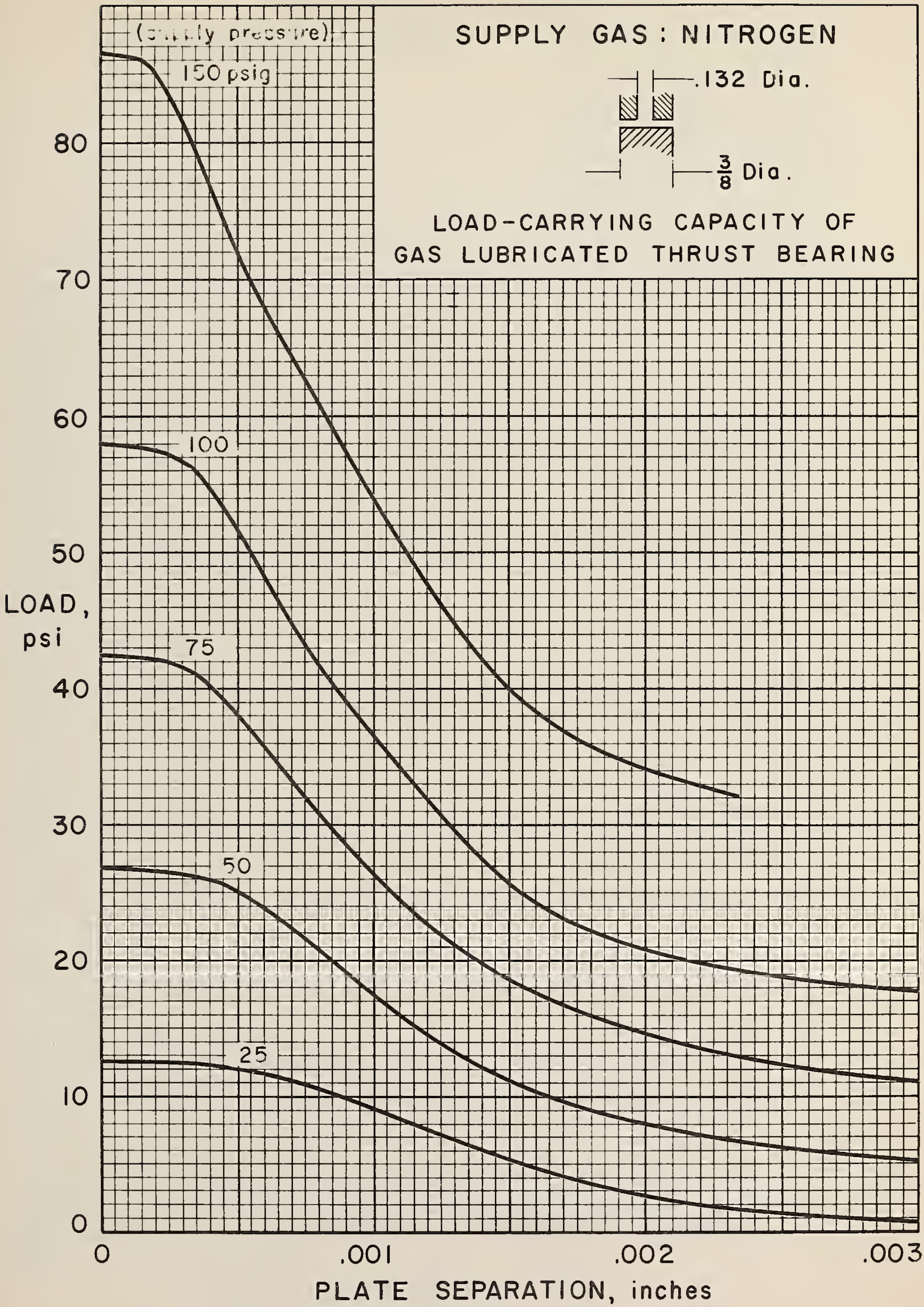


Figure 11 - Load vs. Plate Separation Curves

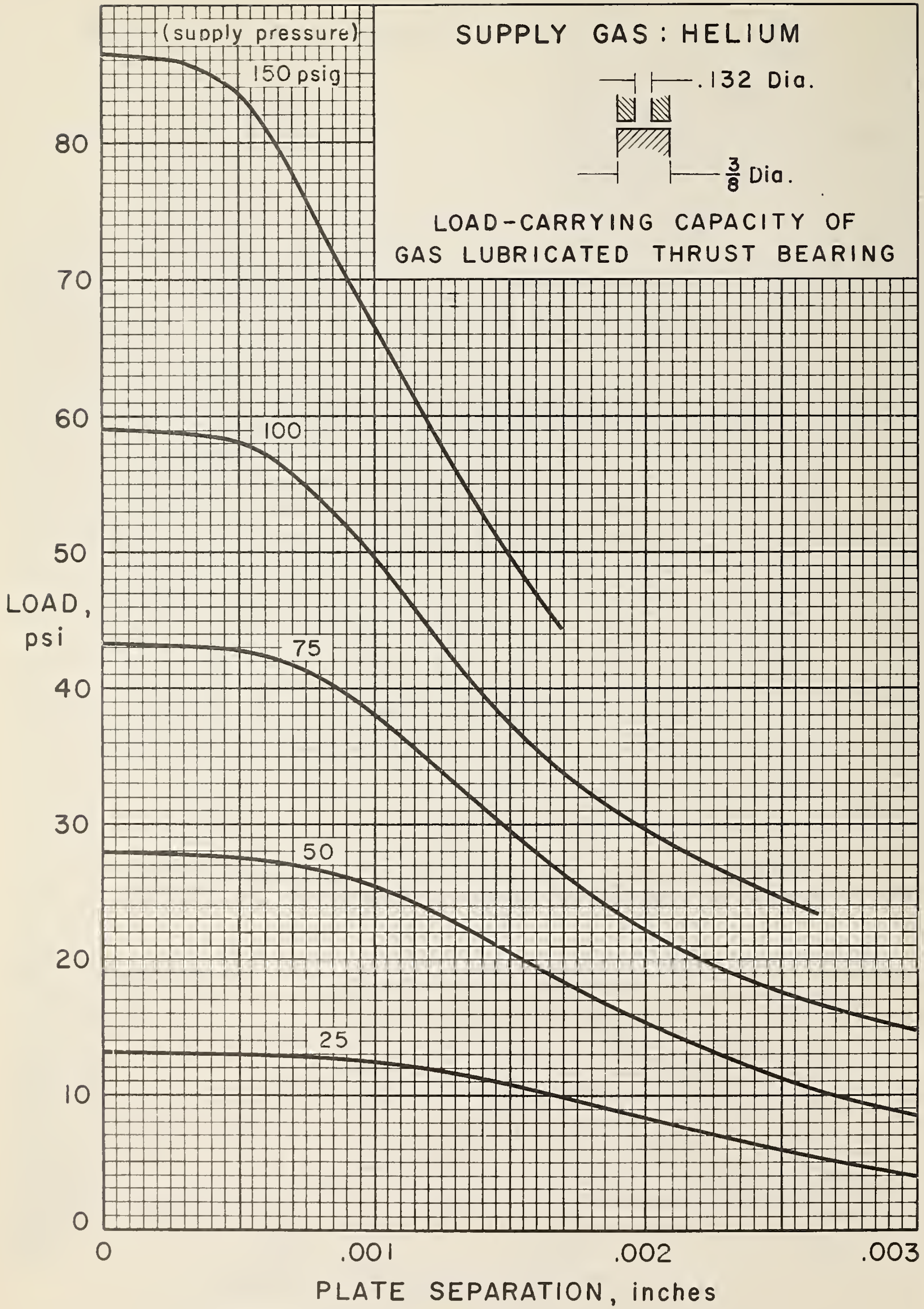


Figure 12 - Load vs. Plate Separation Curves

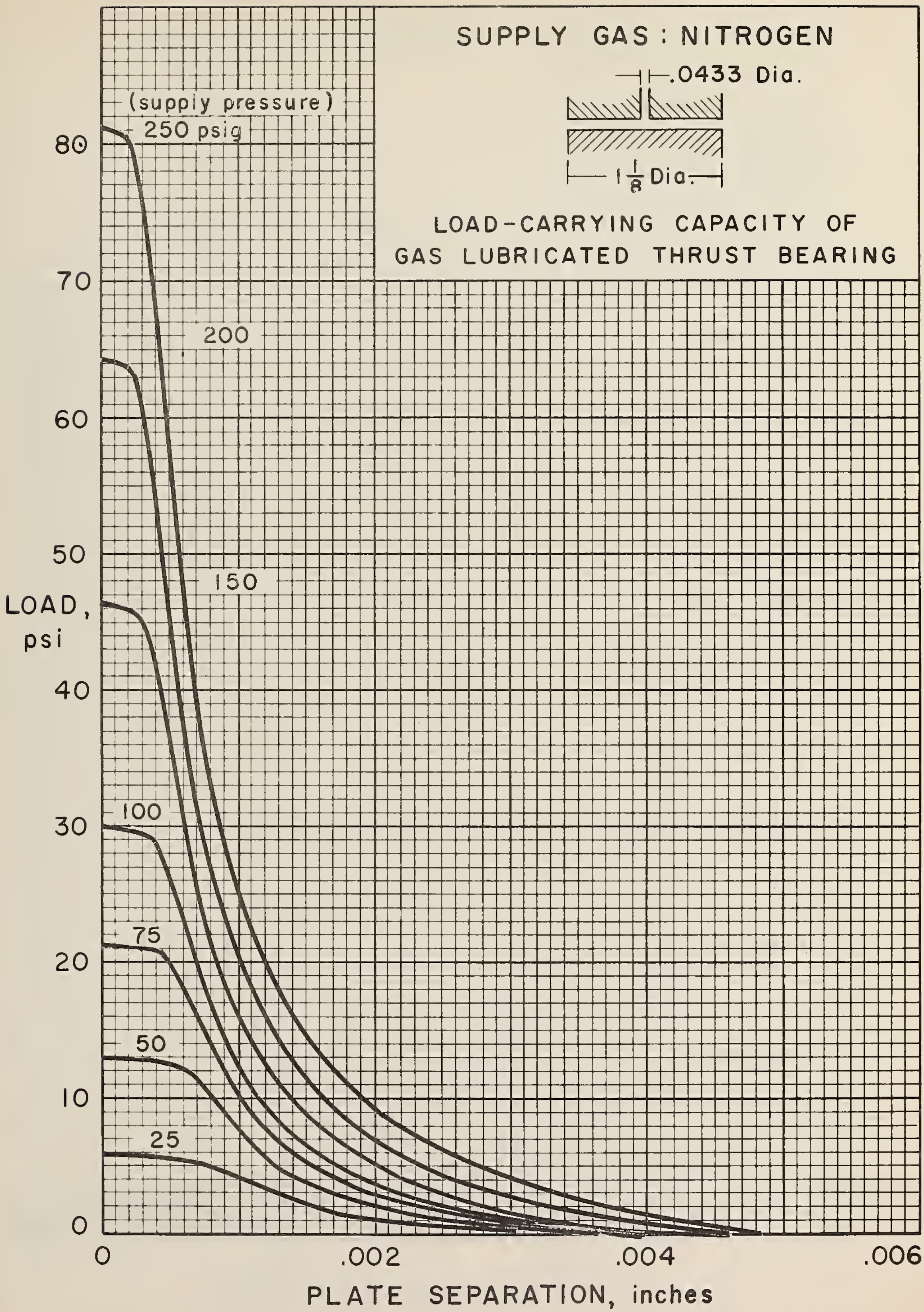


Figure 13 - Load vs. Plate Separation Curves

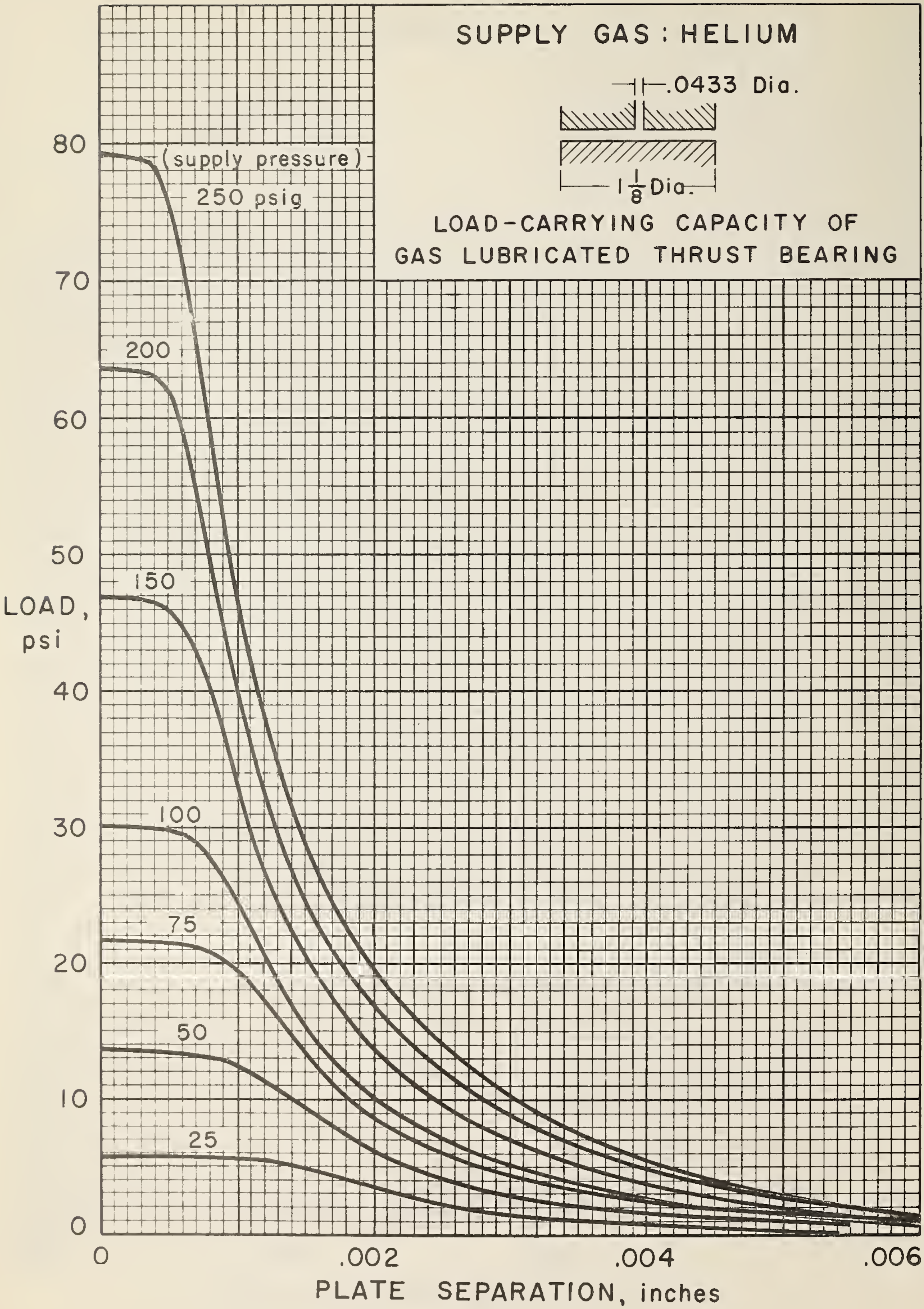


Figure 14 - Load vs. Plate Separation Curves

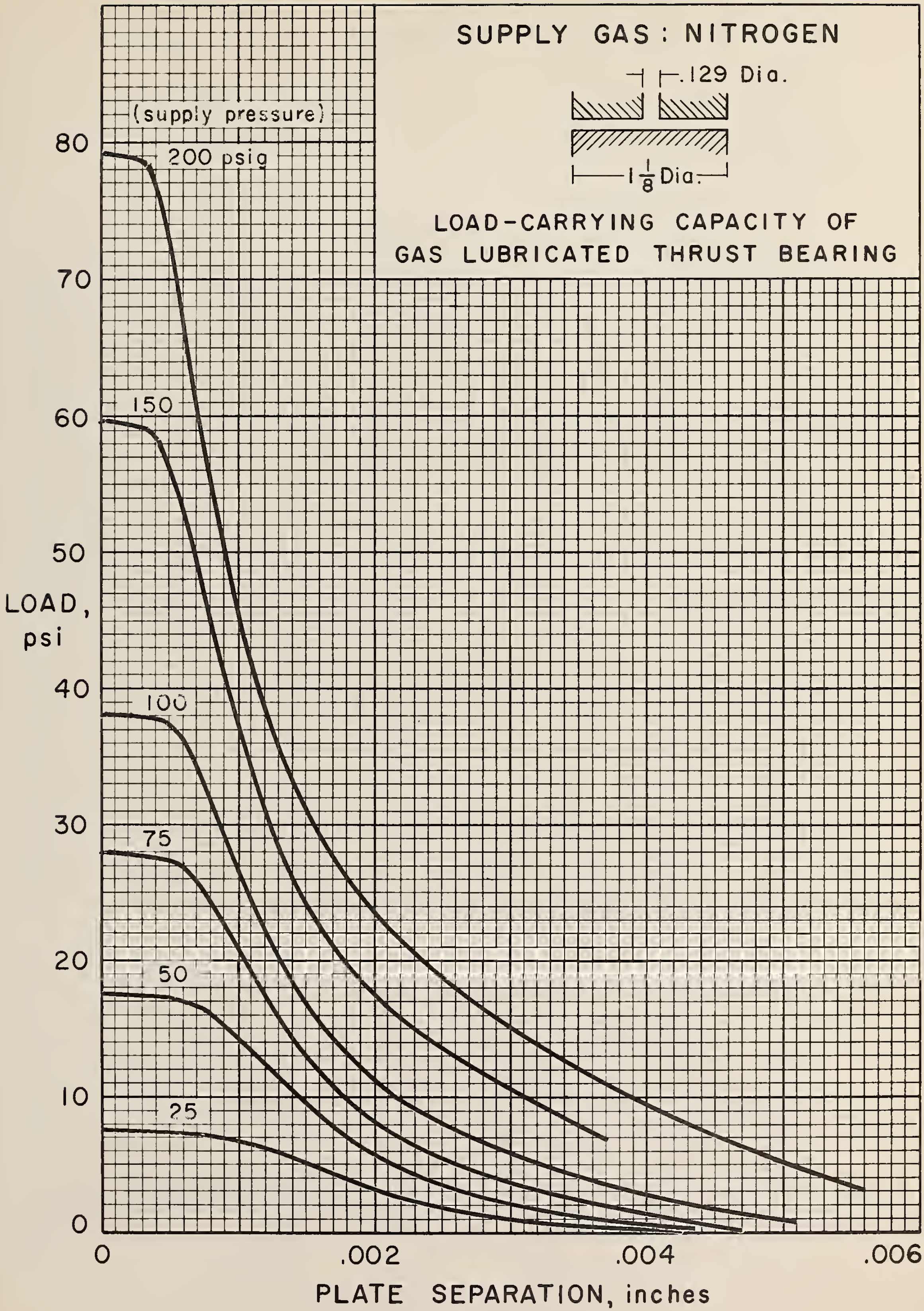


Figure 15 - Load vs. Plate Separation Curves

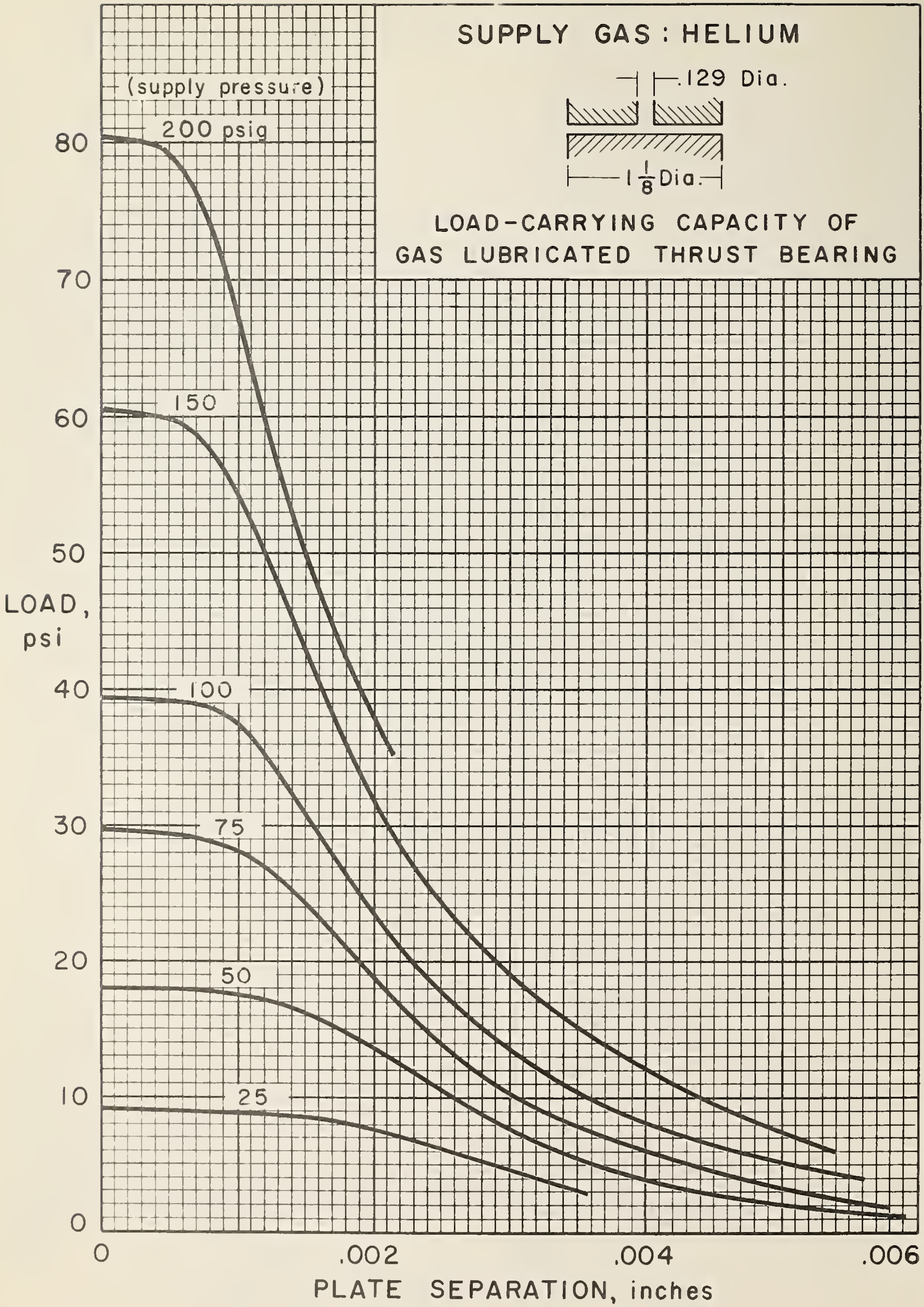


Figure 16 - Load vs. Plate Separation Curves

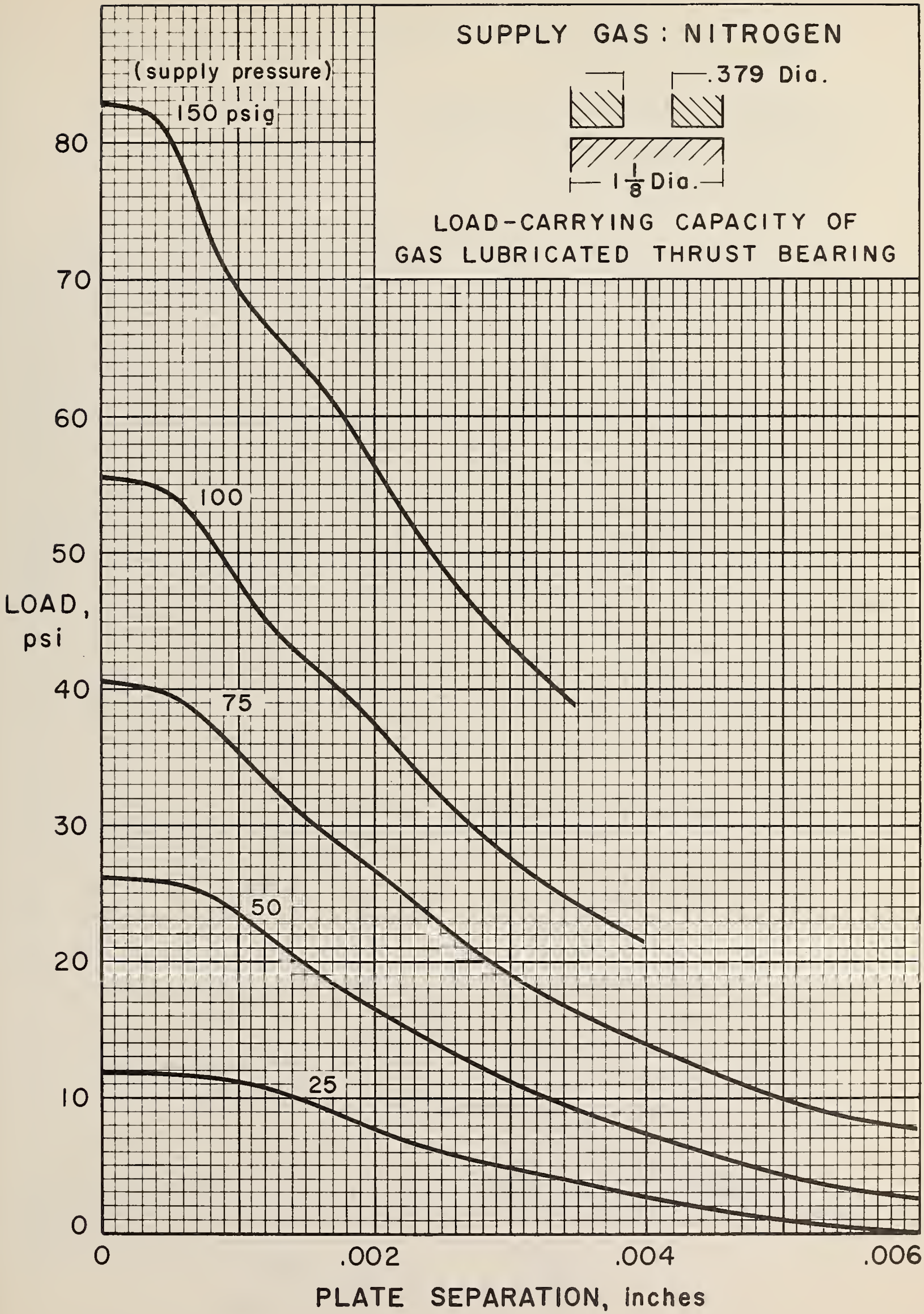


Figure 17 - Load vs. Plate Separation Curves

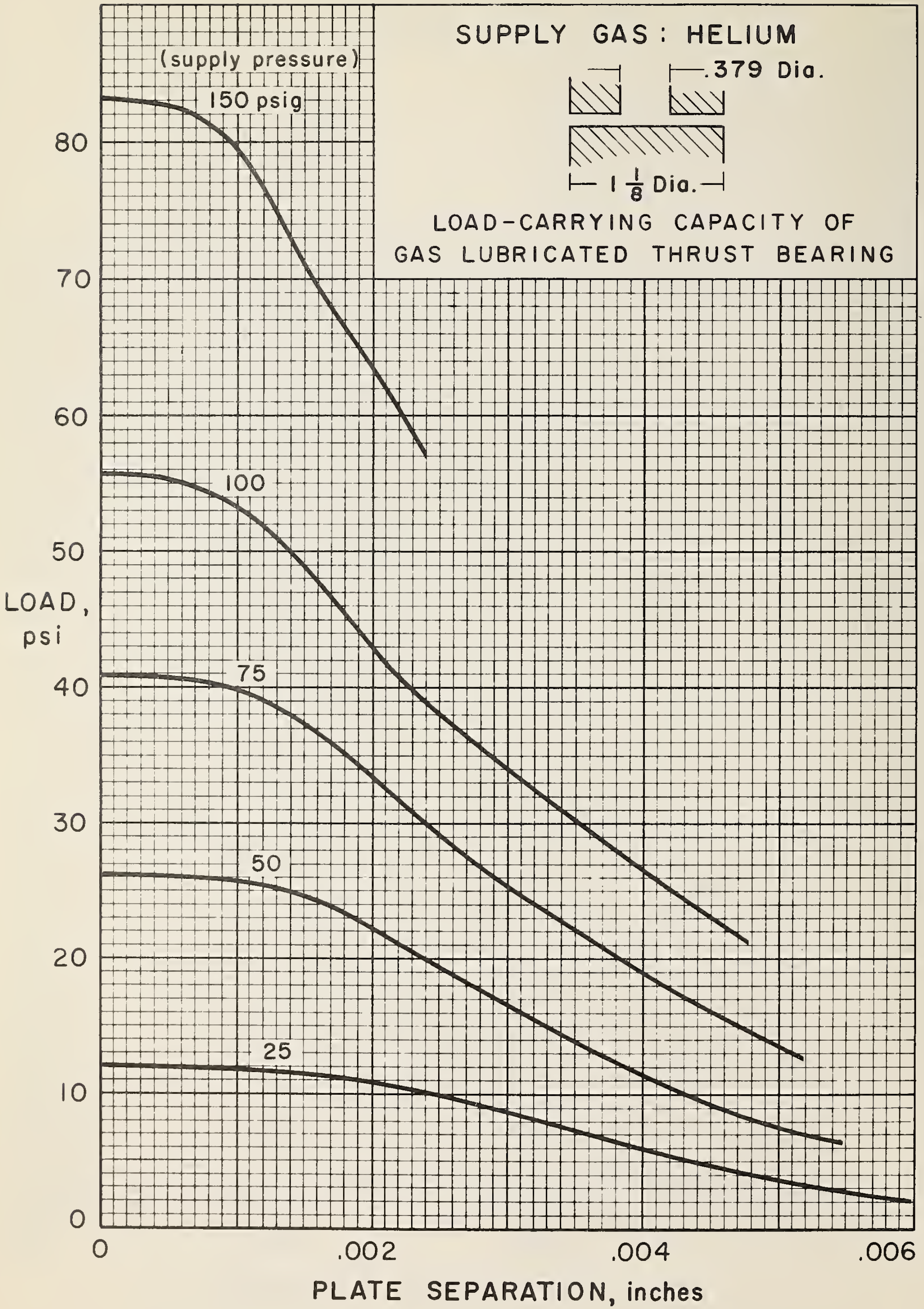


Figure 18 - Load vs. Plate Separation Curves

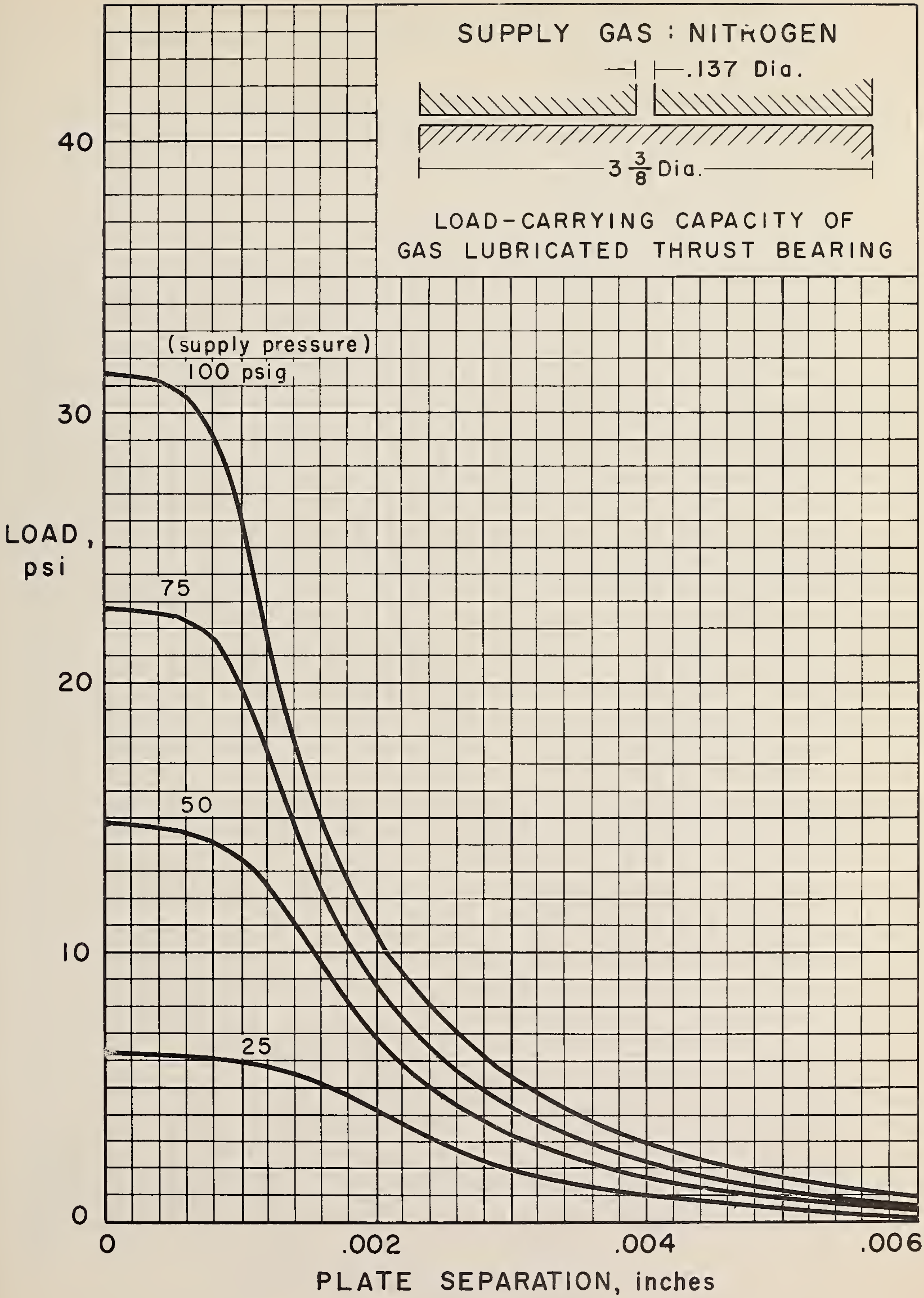


Figure 19 - Load vs. Plate Separation Curves

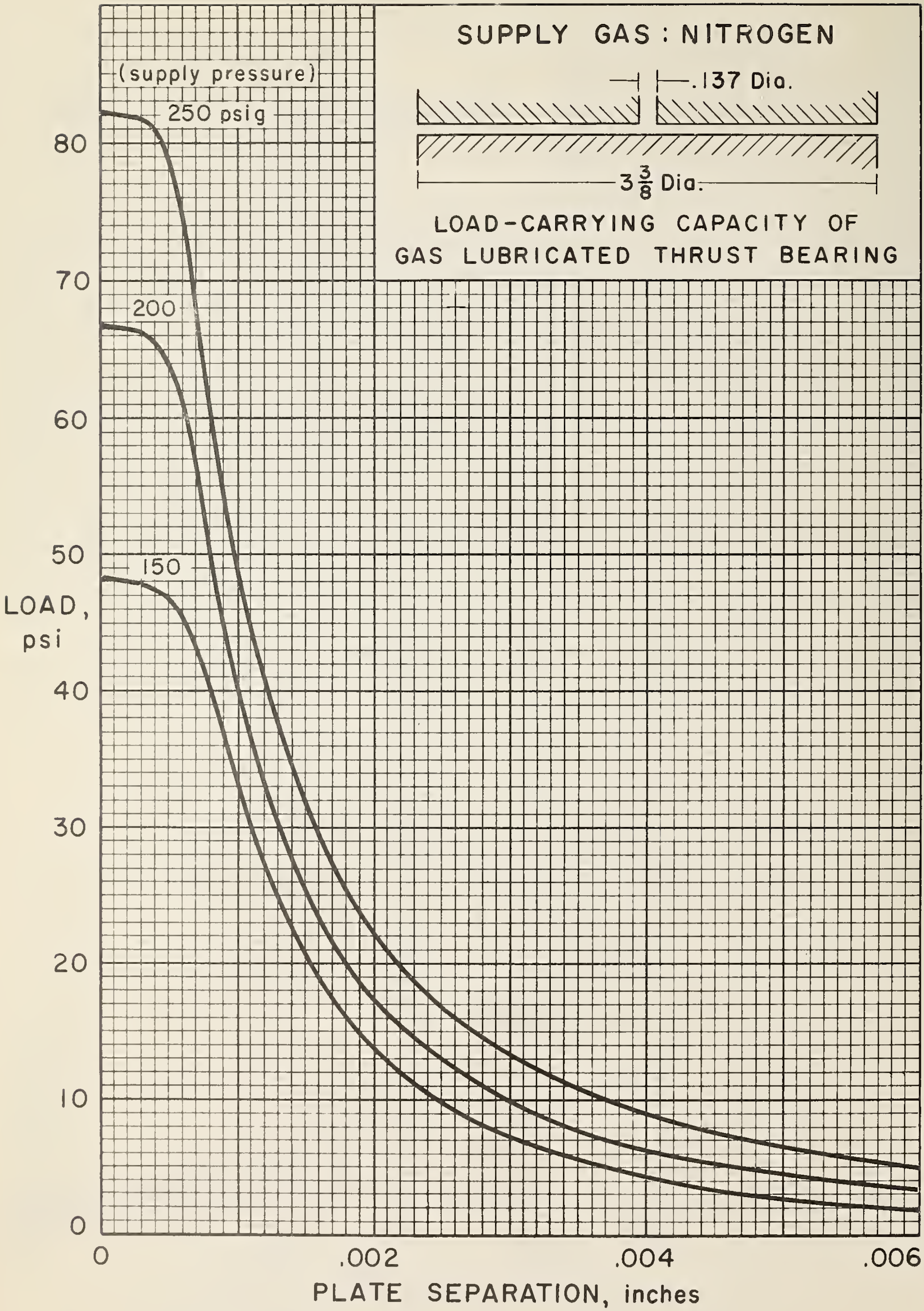


Figure 20 - Load vs. Plate Separation Curves

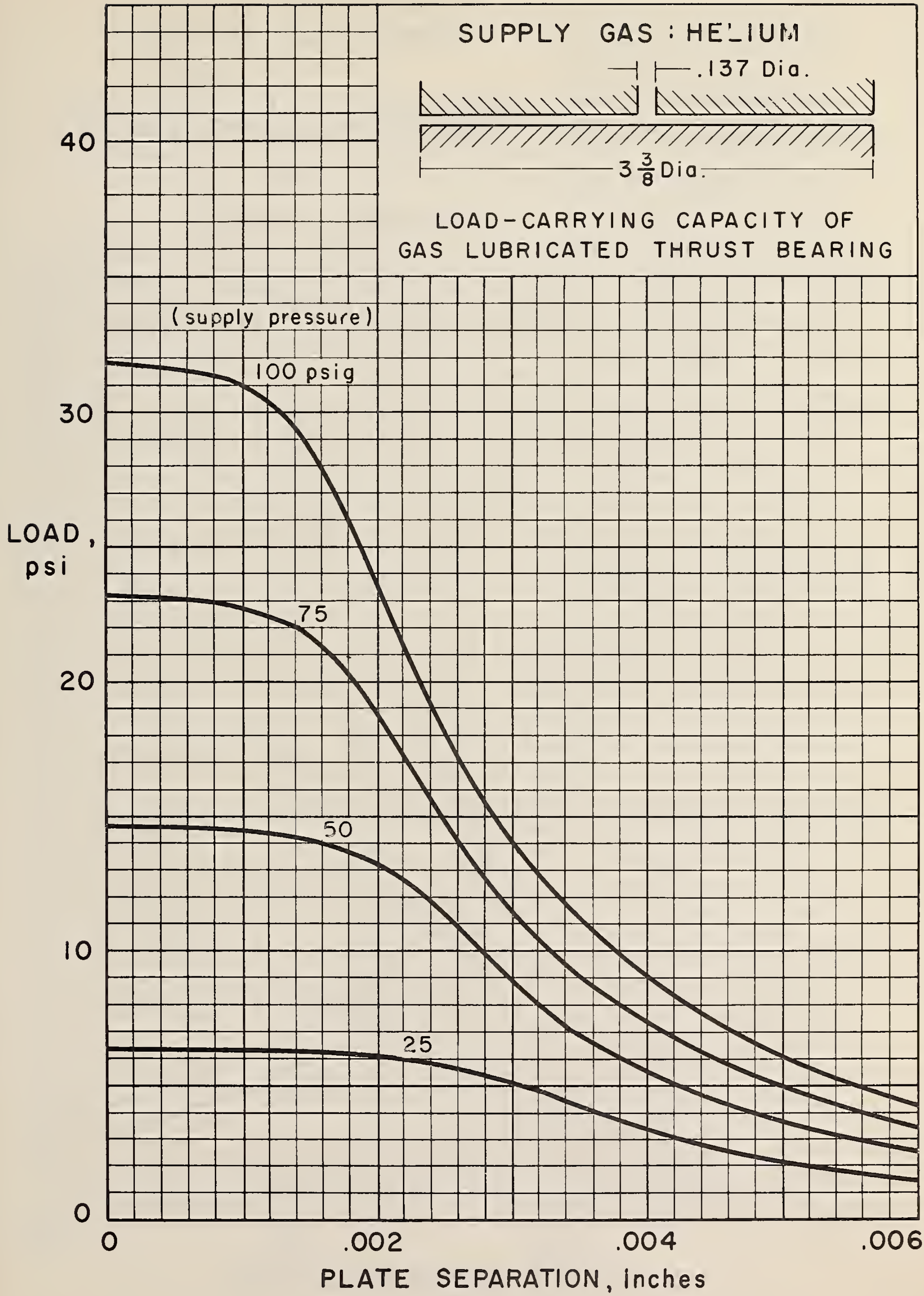


Figure 21 - Load vs. Plate Separation Curves

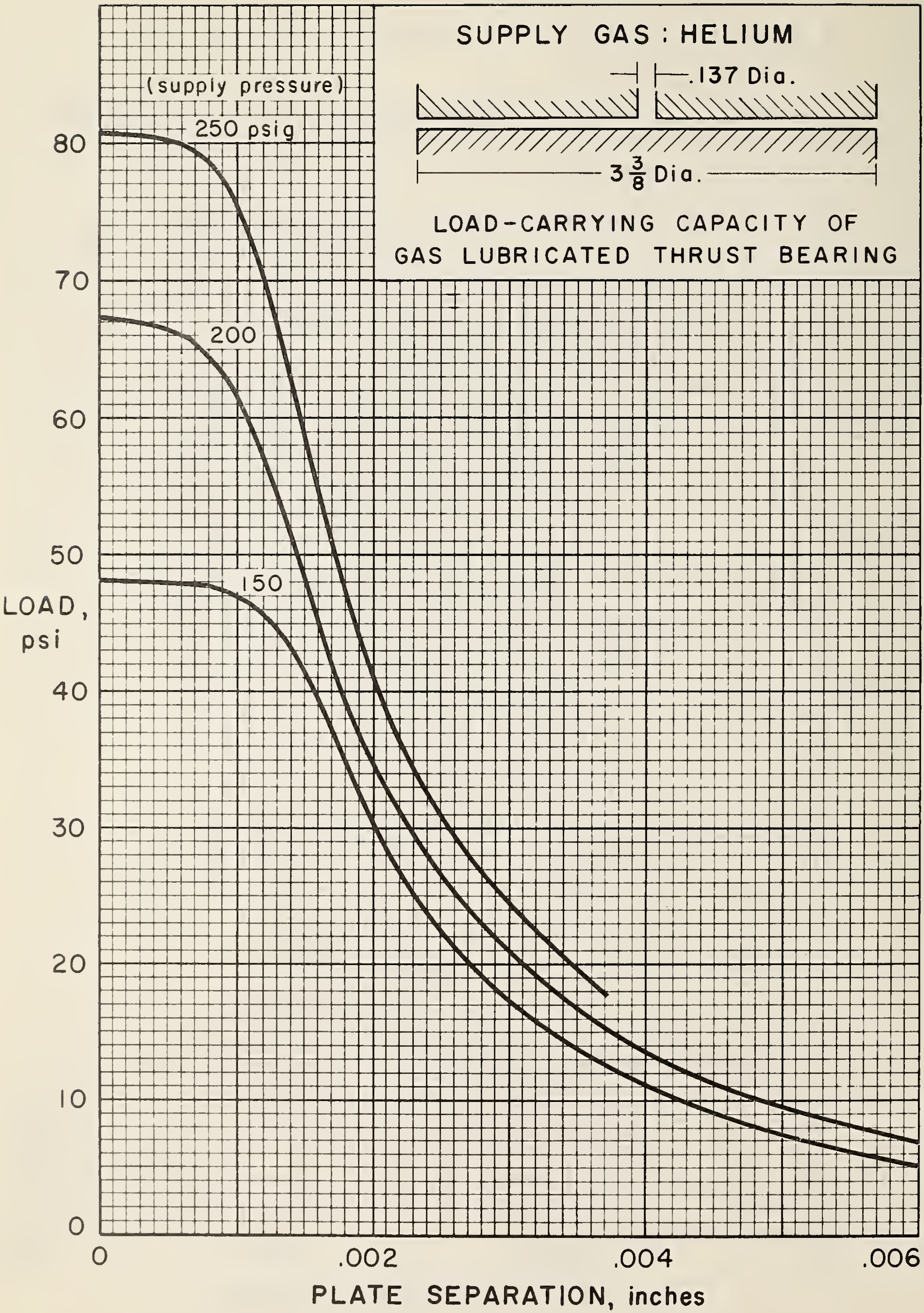


Figure 22 - Load vs. Plate Separation Curves

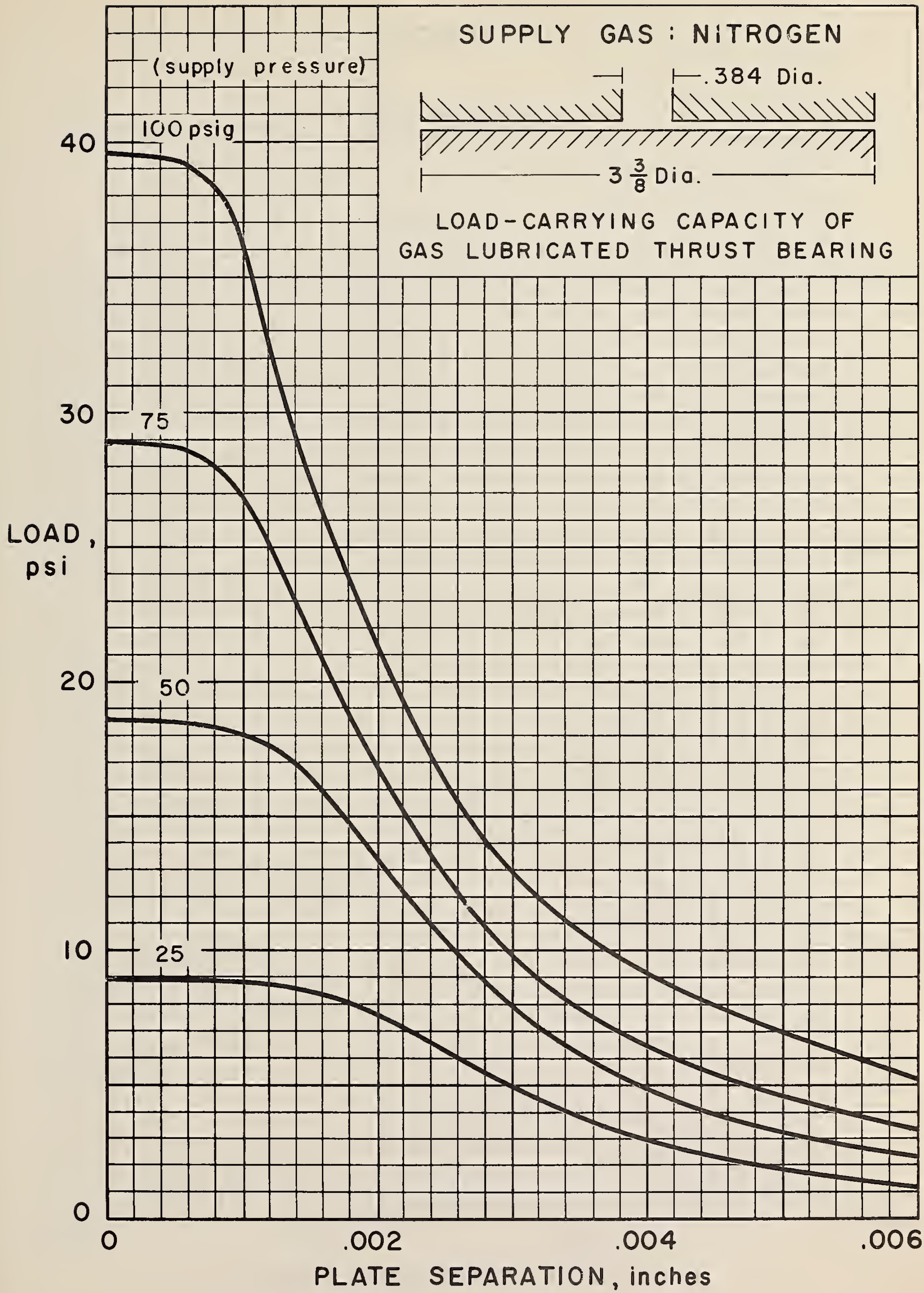


Figure 23 - Load vs. Plate Separation Curves

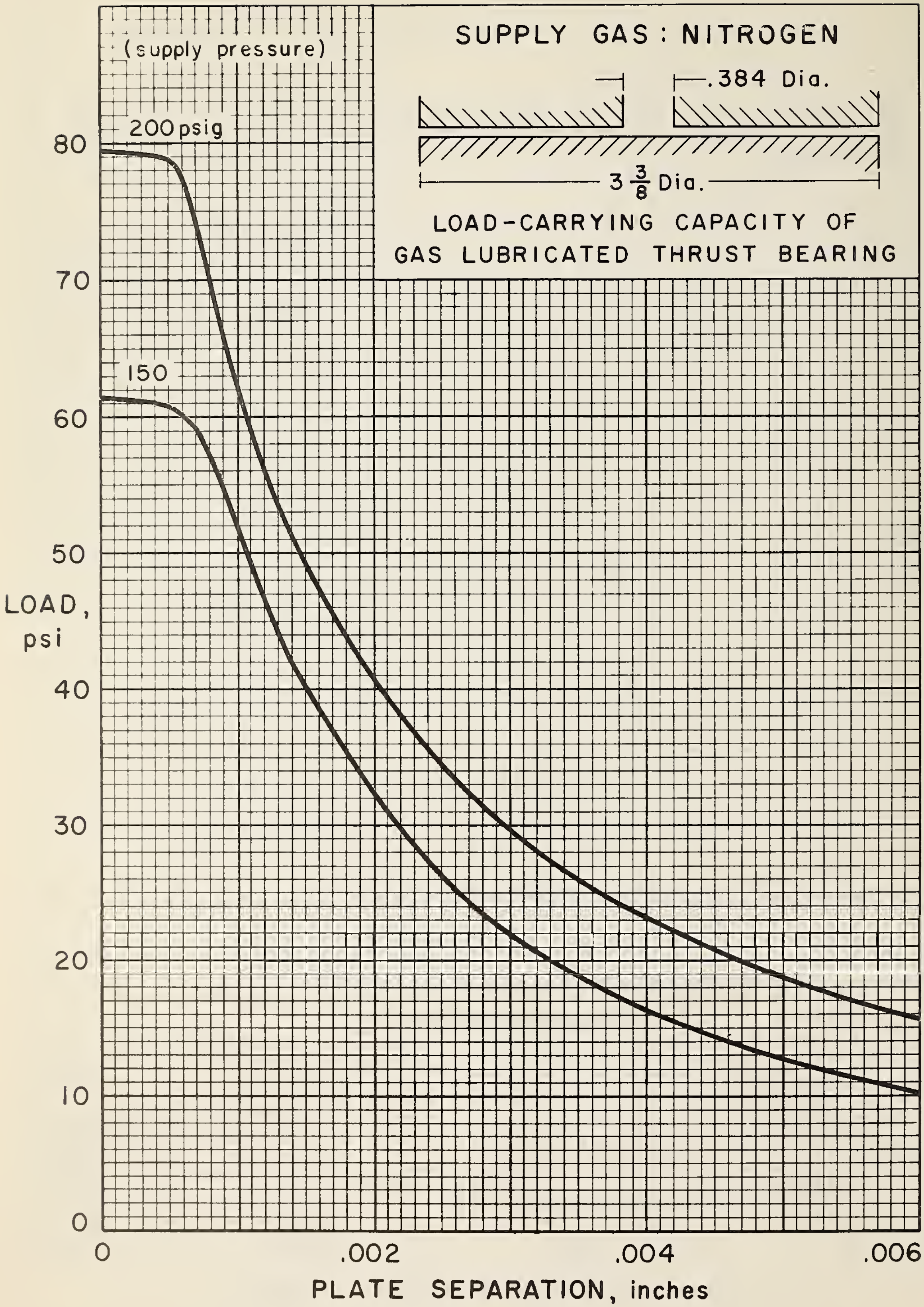


Figure 24 - Load vs. Plate Separation Curves

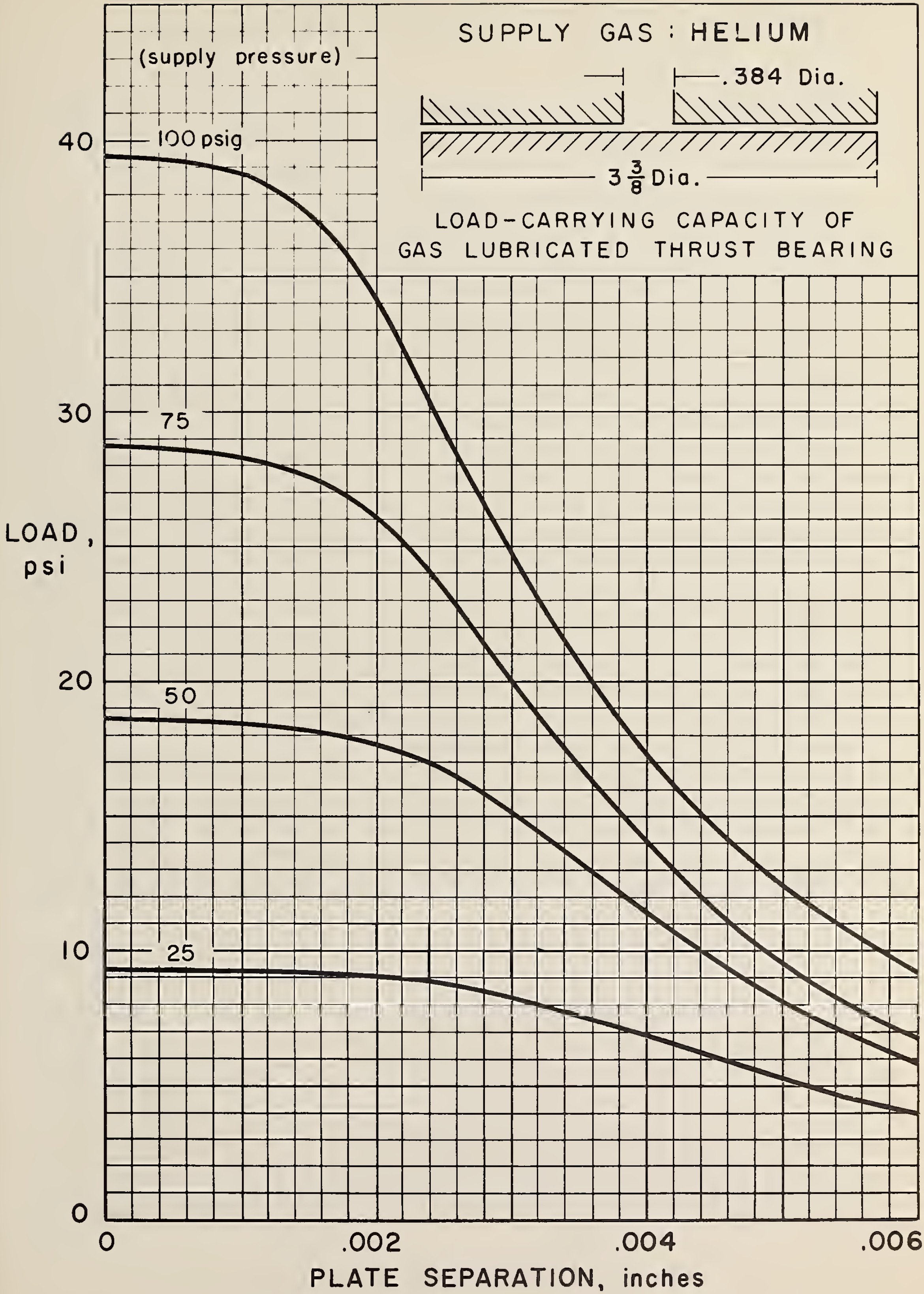
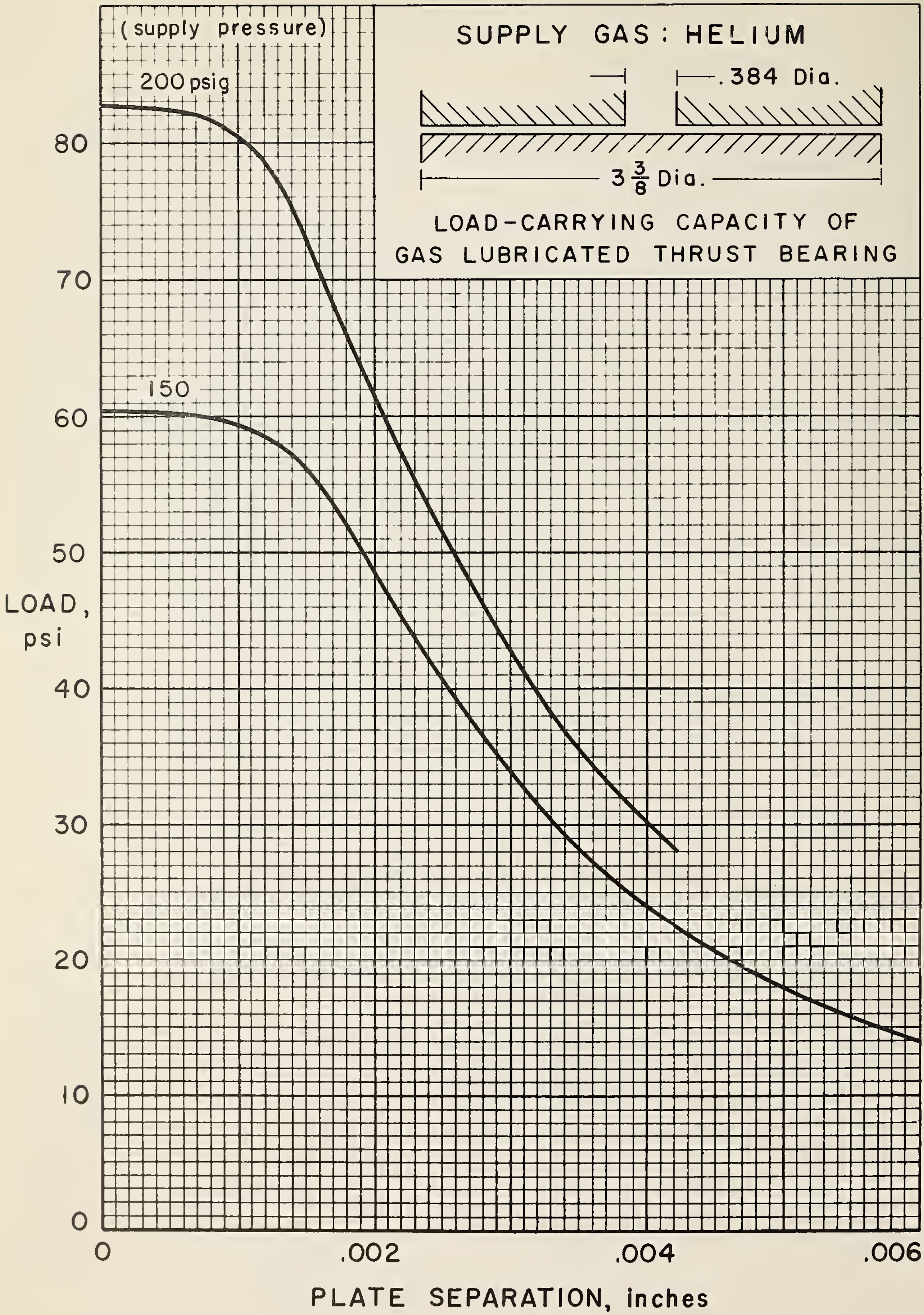


Figure 25 - Load vs. Plate Separation Curves



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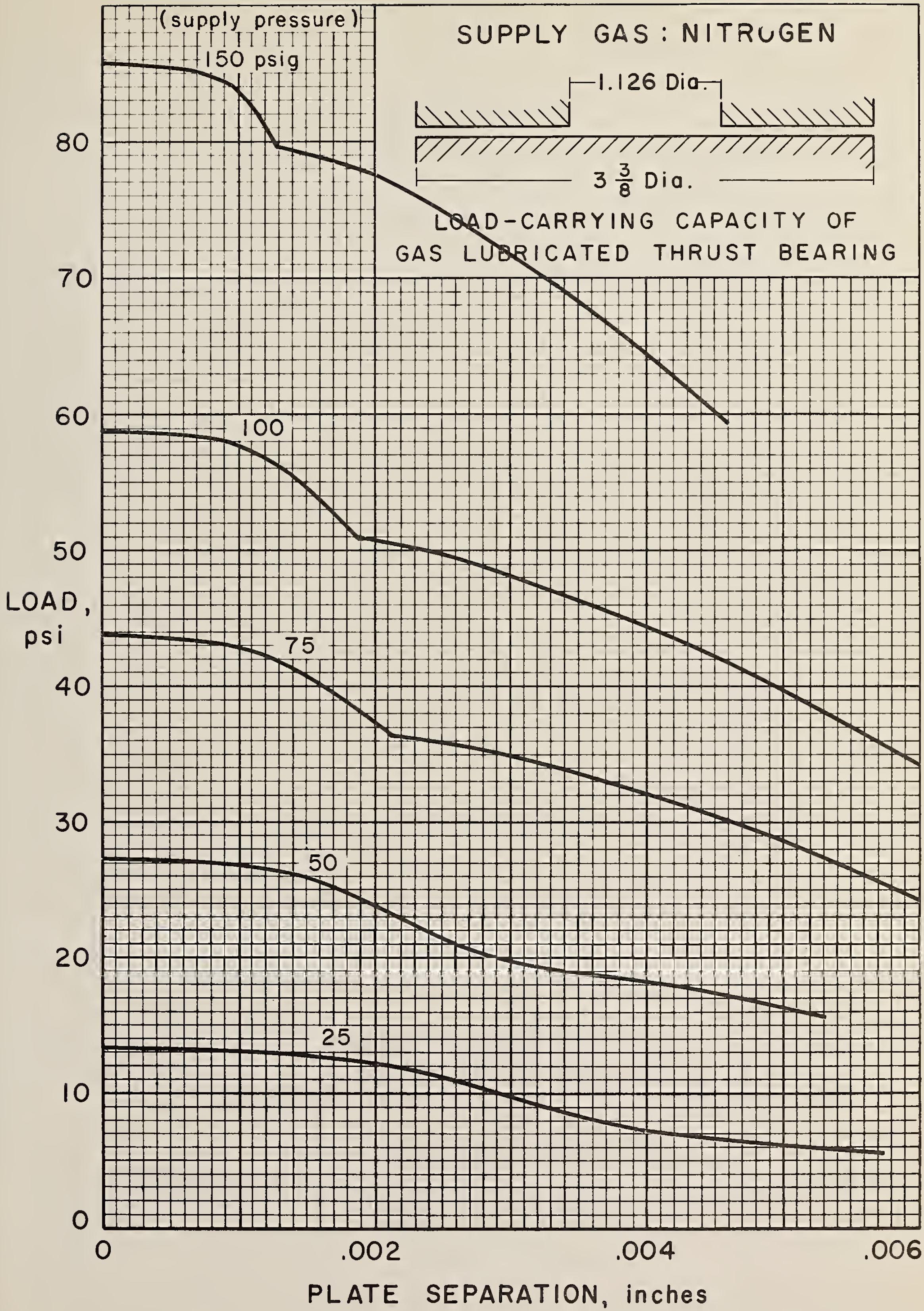

Figure 27 - Load vs. Plate Separation Curves

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