NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4274

MEASUREMENT OF THE EFFECT OF AN AXIAL MAGNETIC FIELD ON THE REYNOLDS NUMBER OF TRANSITION IN MERCURY FLOWING THROUGH A GLASS TUBE

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Washington
May, 1958

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SUMMARY

Experiments were conducted to determine the effect of a strong axial magnetic field on the flow of mercury through a circular channel. The magnetic induction was 15,000 gauss, and the channel was a pyrex tube 17-1/4 inches long and 0.027 inch inside diameter. Application of the magnetic field produced very little change in Reynolds number of transition when large initial disturbances were introduced at the entrance to the flow tube. However, the magnetic field increased the Reynolds number of transition by as much as 10 percent at Reynolds numbers between 5,000 and 8,000 when only slight instabilities were present; at lower Reynolds numbers this increase was not observed.

INTRODUCTION

The possibility of stabilizing the flow of a conducting fluid by means of a magnetic field has been the subject of considerable speculation. In particular, it has been suggested that a parallel field (lines of magnetic flux along lines of flow) could be used to damp out small oscillations from which turbulence develops, thus increasing the Reynolds numbers of transition on airframes.

It was first demonstrated experimentally by Hartman and Lazarus (ref. 1) and again by Shercliff (ref. 2) that a transverse magnetic field has the effect of raising the Reynolds number at which transition from laminar to turbulent flow occurs. The stability of flow between parallel plates has been investigated theoretically for a coplanar field by Stuart (ref. 3) and for a transverse field by Lock (ref. 4). Much larger effects are predicted for transverse than for parallel fields. Theoretical calculations for two-dimensional flow predict easily detectable effects when the magnetic parameter $Q = \sigma B^2 d/\rho u$ reaches the value 10^{-4} for transverse fields (ref. 4) and 3×10^{-2} for parallel fields (ref. 3).

The present experiment was undertaken to provide experimental data on the effect of a parallel magnetic field on the Reynolds number of transition. Mercury flow through a circular pipe was chosen because of the relative simplicity of the experiment. It should be recognized, however, that pipe flow is of a fundamentally different character from flow over airframes, so that no direct quantitative inference can be made concerning the latter.

SYMBOLS

Q	magnetic parameter, $\frac{\sigma B^2 d}{\rho u}$, dimensionless
Re	Reynolds number, $\frac{\rho u d}{\eta}$, dimensionless
σ	electrical conductivity of the fluid
B	applied magnetic induction
d	characteristic dimension (diameter in case of circular flow tube)
ρ	density of the fluid
u	velocity of the flow
η	viscosity of the fluid

APPARATUS AND PROCEDURE

A mercury reservoir (see fig. 1) 4 inches in diameter and 52 inches high was made from Lucite tubing with provisions near the bottom for attaching the flow tube and for draining the reservoir. The flow tube used had an internal diameter of 0.027 inch and was 17-1/4 inches long; its entrance was flared in order to allow high Reynolds numbers with laminar flow. The pressure drop across the flow tube was adjusted by changing the height of the mercury in the reservoir. The flow rates for a given pressure were determined by weighing samples of mercury collected over timed intervals. The Reynolds numbers were computed from the average flow rates thus obtained.

The electromagnet consisted of 14 layers of copper tubing wound on a 3/4-inch core of laminated mica tube 16 inches long. The inner six layers were 1/4-inch O.D. tubing and the outer eight layers were 5/16-inch O.D. tubing. The layers were separately water cooled and were connected in series electrically. A direct current of 750 amperes was used in all tests. The coils were encased in iron with a pole piece opposite the exit end in an attempt to make the magnetic induction along the axis as nearly constant as possible. A plot of the magnetic induction along the axis of the magnet is given in figure 2.

Additional cooling along the flow tube was provided by a stream of air gently blown down the center of the electromagnet. The mercury temperature was thus stabilized near 70° F, the exact temperature being recorded for each test. The flow rate was determined alternately with and without magnetic field in rapid succession. The air and cooling water flows were continued during the tests without current in the magnet in order to duplicate conditions as closely as possible. Cross hairs were installed at the entrance end of the flow tube in order to introduce the slight amount of disturbance necessary to induce turbulent bursts. The flow tube was cleaned with concentrated nitric acid after approximately every 20 minutes of running time. Cleanliness was found to be very essential for reproducibility. Vibration of the apparatus, on the other hand, did not seem to affect the flow. A qualitative estimate of the amount of turbulence could be made visually by observing the jet of mercury at the exit end of the flow tube. The jet was steady and uniform when the flow was laminar but showed considerable irregularity during increasingly frequent turbulent bursts as the flow became more turbulent.

EXPERIMENTAL RESULTS

The results of the test are shown in figure 3. The ordinate indicates the pressure difference required between the ends of the tube to obtain a given flow rate which is represented by the Reynolds number, $\rho ud/\eta$. As noted in the figure, the open and solid symbols are test results obtained with no magnetic field and with a field of 15,000 gauss, respectively. The data on the right of the figure show that at high Reynolds numbers (where the flow consisted of turbulent bursts in otherwise laminar flow) the magnetic field was able to shift the flow to fully laminar. This effect was observed at Reynolds numbers from approximately 5,000 up to 8,000, the limit obtainable with the apparatus. The resulting increases in average flow velocity increased the Reynolds numbers up to 10 percent. At lower Reynolds numbers, and for the more turbulent flow conditions at higher Reynolds numbers, the effect of the magnetic field was observed to decrease rapidly. The shift dropped to approximately 2 percent almost immediately when the flow could no longer be shifted to laminar, and eventually to approximately zero when the flow was fully turbulent.

The bounding lines drawn in figure 3 for laminar flow and fully turbulent flow were determined experimentally. The laminar plot agrees approximately with the predicted theoretical value and is an extension of the curve for Reynolds numbers under 1,800 where only laminar flow is possible. The laminar conditions were characterized by a steadiness of flow which could be visually observed. The fully turbulent flow was obtained by means of a sharp entrance end to the flow tube. The resulting pressure-drop curve departs from the laminar flow relation near Re = 1,800. With a sharp entrance to the tube, the magnetic field did not stabilize the flow a noticeable amount (see the symbols near the fully turbulent curve). The entrance to the tube was then smoothed, and separate tests were made for different tripping conditions and are shown plotted in figure 3. The tripping conditions for only slight turbulence were extremely critical and were not reproducible. It was found that a slight amount of contamination was more effective in inducing turbulence than the cross hairs which were installed.

As can be seen from figure 2, a certain amount of transverse component of the field was present at the ends of the magnet. This cross field was small and is believed to have had a negligible effect; indeed, with a magnetic parameter Q as small as 0.01, laminar flow is detectably slowed down by a transverse field. No such slowing down was observed here. A further test was made by placing the entrance of the flow tube in a transverse field of the same order of magnitude as that present in the main magnet. This field had no observable effect on the flow.

CONCLUDING REMARKS

The magnetic parameter Q, in this experiment, ranged from 0.09 at $Re = 8{,}000$ to 0.4 at $Re = 1{,}800$, as is indicated in figure 3. These were the highest values of Q and Re obtainable with the apparatus. The results indicate that the stabilizing effect occurred only at Reynolds number above about 5,000, so that the region of practical applicability seems to be at fairly high Reynolds numbers and when there are only slight disturbances in the flow. The parallel magnetic field was ineffective in stabilizing highly turbulent tube flow. Unfortunately, no quantitative inference can be made from pipe flow to flow over airframes; however, it would be of interest to perform similar experiments on the flow of ionized gases around bodies in a magnetic field nearly parallel to the lines of flow.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Feb. 19, 1958

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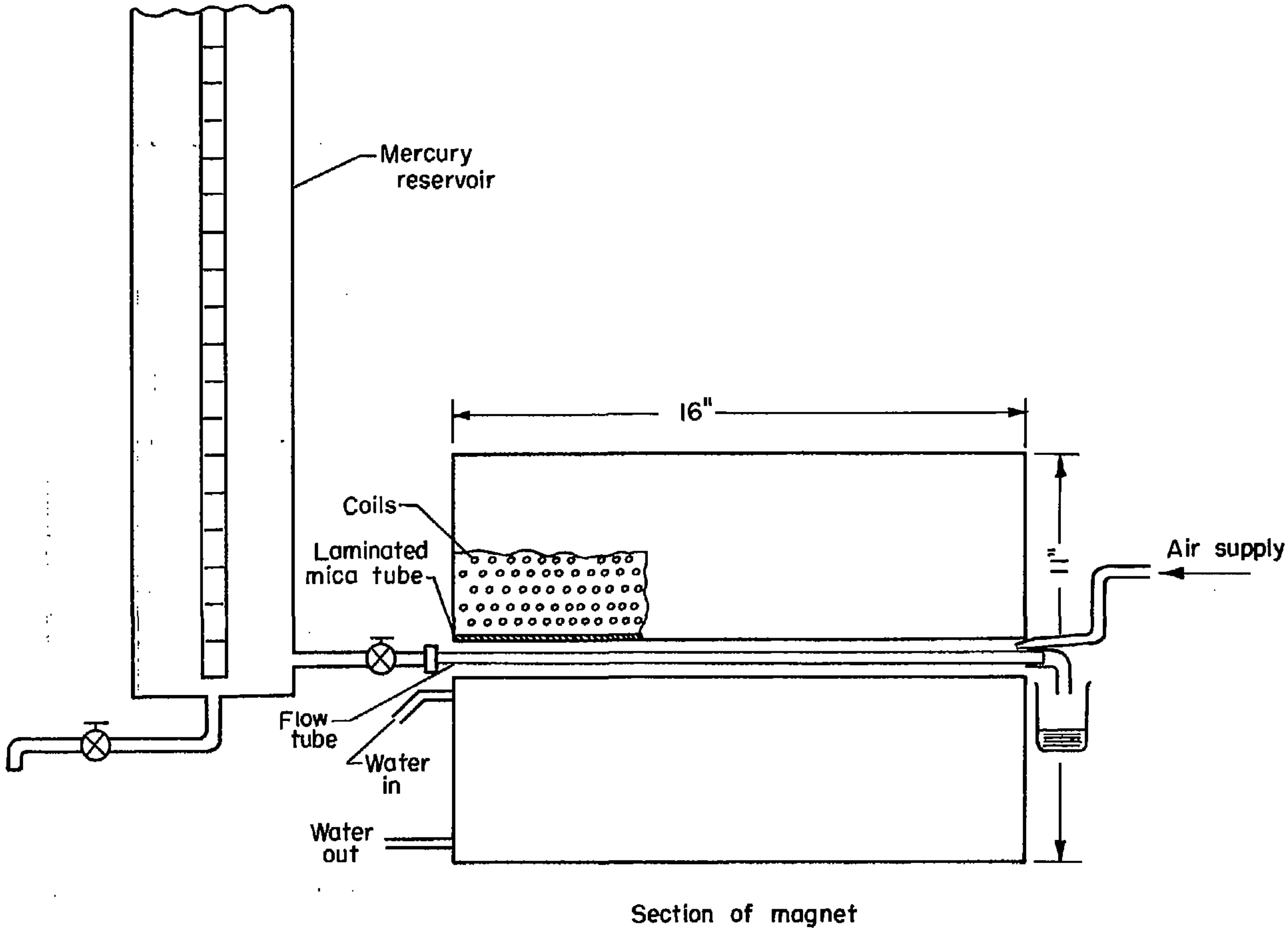

Figure 1.- Schematic diagram of the apparatus.

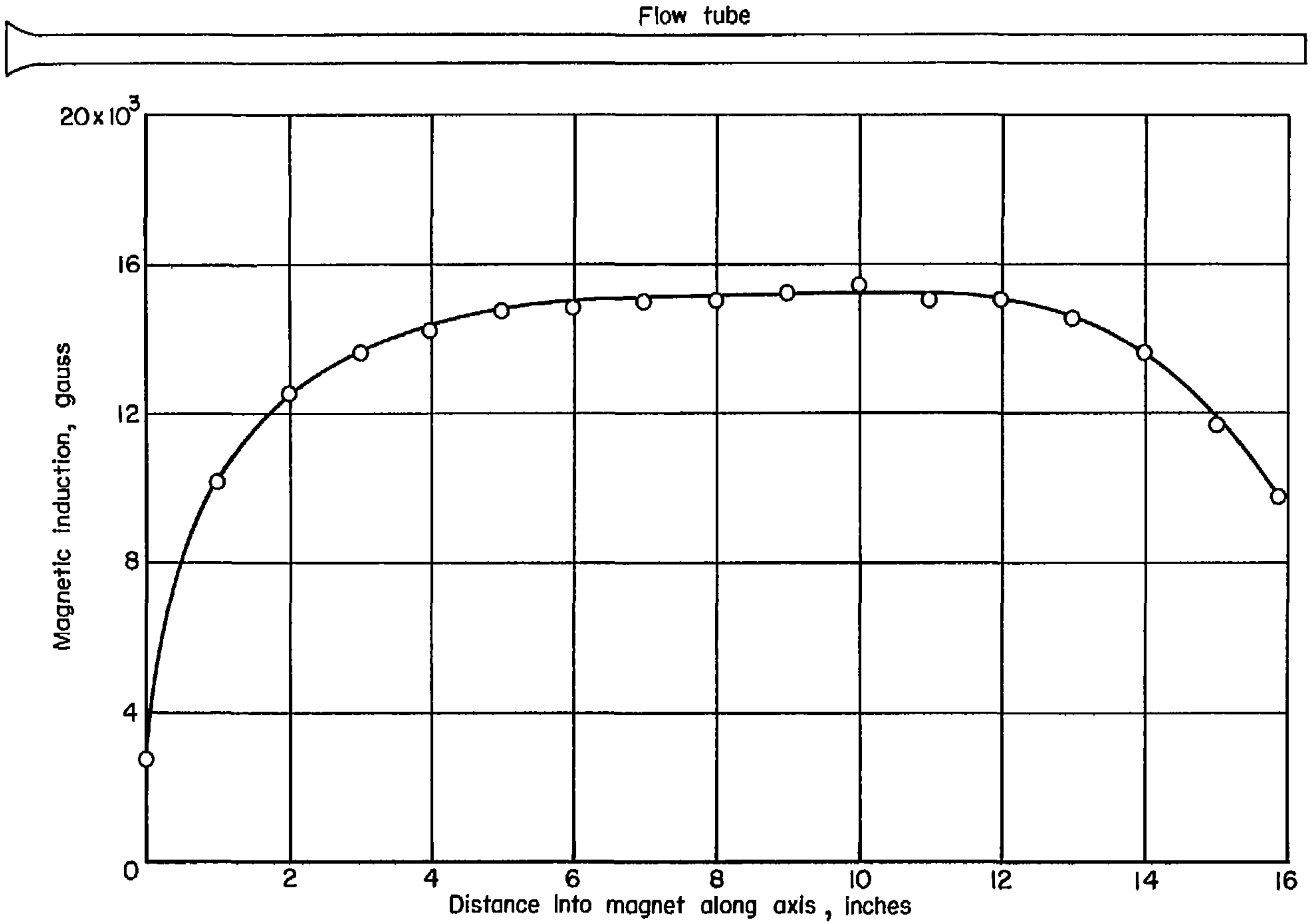

Figure 2.- Value of the magnetic induction along the axis of the electromagnet and relative position of the flow tube.

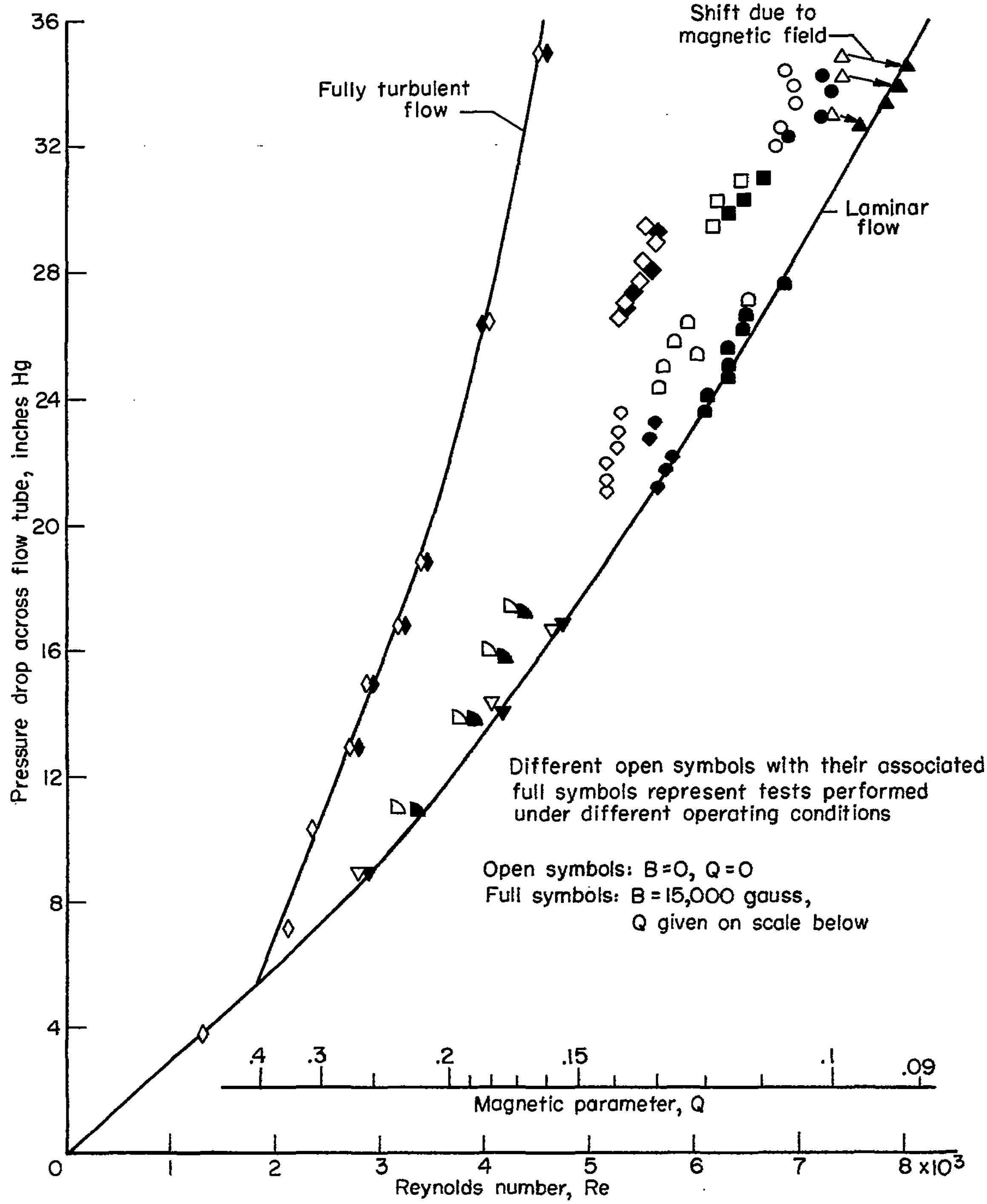

Figure 3.- Effect of an axial magnetic field on the Reynolds number at various values of pressure drops across the flow tube.