# NASA TECHNICAL MEMORANDUM

NASA TM X-64892

# THE MAXOMETER—DYNAMIC AND STATIC TESTS

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October 1974

**NASA**

*George C. Marshall Space Flight Center*
*Marshall Space Flight Center, Alabama*

| 1. REPORT NO. NASA TM X-64892 | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO. |
|---|---|---|
| 4. TITLE AND SUBTITLE <br><br> The Maxometer — Dynamic and Static Tests | | 5. REPORT DATE <br> October 1974 |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) <br> Dennis W. Camp and Robert E. Turner | | 8. PERFORMING ORGANIZATION REPORT # |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS <br><br> George C. Marshall Space Flight Center <br> Marshall Space Flight Center, Alabama 35812 | | 10. WORK UNIT NO. |
| | | 11. CONTRACT OR GRANT NO. |
| | | 13. TYPE OF REPORT & PERIOD COVERED |
| 12. SPONSORING AGENCY NAME AND ADDRESS <br><br> National Aeronautics and Space Administration <br> Washington, D. C. 20546 | | Technical Memorandum |
| | | 14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES   This report was prepared and published to make available information on a unique peak wind speed instrument for research and operational use by the scientific community. The work was conducted under the operational direction of the Aerospace Environment Division, Space Sciences Laboratory.

16. ABSTRACT

Prior to the development of the maxometer, no anemometer existed which could withstand the extreme environmental conditions, such as high flow velocities and extreme temperatures, associated with the launch of aerospace vehicles. Two models of the maxometer were developed which are capable of measuring extremely high wind speeds (130 m/sec) and retaining a record of the peak speed over any given time period. This report covers the dynamic and static tests of these models and the results obtained.

| 17 KEY WORDS <br><br> Meteorology <br> Wind Speed <br> Peak Speed <br> Anemometer | 18. DISTRIBUTION STATEMENT <br><br> Unclassified - Unlimited <br><br> Robert E. Turner |
|---|---|

| 19 SECURITY CLASSIF. (of this report) | 20 SECURITY CLASSIF. (of this page) | 21. NO. OF PAGES | 22 PRICE |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | 17 | NTIS |

## ACKNOWLEDGMENTS

Many people contributed directly or indirectly to the preparation of this report. The list is too long to acknowledge everyone. No less than approximately 15 people made substantial contributions in the field measurements, static tests, and wind tunnel tests. Although names are not given, the authors are grateful to every person who worked diligently behind the scenes to accomplish the test results.

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# THE MAXOMETER — DYNAMIC AND STATIC TESTS

## I. INTRODUCTION

The maxometer is an instrument capable of measuring extremely high wind speeds (approximately 130 m/sec) and retaining a record of the peak wind speed over any given time period. Prior to the development of this instrument, no anemometer existed which could withstand the extreme environmental conditions, such as high flow velocities and extreme temperatures, associated with the launch of aerospace vehicles. Two models of the maxometer were developed: (1) Model E for use in measuring extreme winds in the ambient atmospheric environment and (2) Model S for use in obtaining measurements in a severe environment such as that found in the launch of space vehicles. The Model E has been field tested at the Hurricane Research Center, Miami, Florida; Weather Station, Bootheville, Louisiana; and the Naval Air Station, Corpus Christi, Texas. The Model S was tested on the launch umbilical tower (LUT) at the Kennedy Space Center, Florida, during Apollo and Skylab launches. Both models of the maxometer have been extensively tested in wind tunnels. The speed range covered in these tunnel tests was approximately 20 m sec$^{-1}$ to 130 m sec$^{-1}$. The agreement between the maxometer measured speed and the independently obtained tunnel speed was quite good.

## II. DESCRIPTION AND BACKGROUND

During static tests and launch of space vehicles, extremely large induced flows are generated. If conventional anemometers are used in an attempt to measure these flows, the anemometers are usually destroyed. Prior to the development of the maxometer, attempts to obtain values for extremely high flows, whether induced or natural, were by theoretical means, i.e., by use of potential flow theory. Thus, the development of the maxometer meets a need of the atmospheric scientist and meteorologist in their investigations of extreme flow conditions.

At the onset of the program for the development of a peak wind sensor, the only thought was to obtain a sensor for measuring the induced flow from the exhaust of a large space vehicle during both static testing and launch. However, shortly after the onset of the program it was realized that by making some minor modifications the maxometer could be used to measure the extreme flow of a natural wind. Thus, the severe environment model (Model S) was modified, and an ambient environment model (Model E) resulted. Model S was designed to withstand high temperatures (approximately 2000 °F for at least 1 ) seconds), high noise levels, and excessive shock associated with the launch and static testing of space vehicle engines. This model was also designed to be used to measure flow from fixed predetermined directions.

Unlike Model S, the Model E does r ,t have to withstand such a harsh environment. Thus, the materials used in Model E were less expensive than those used in Model S. The Model E was designed to align the sensing element into the wind regardless of wind direction. The sensing element of both models is a 10. 2 centimeter diameter disc. Pressure from the fluid flow acting on the disc will cause a compression of the linear springs inside the maxometer. A clutch system will lock the spring system at its most compressed point until a stronger flow is encountered or until it has been manually released. The maxometer and its parts are shown in Figure 1.

At various times during the development of the maxometer, several modifications were considered. Only one has or is being implemented at present. That is the elimination of one of the springs (smaller one) in the maxometer. The smaller spring was only useful for measuring low flow rates; and since conventional anemometers could be used for measuring these values, it was considered that the elimination of this spring would simplify the sensor and maintain the capability of its primary function, measuring peak flow. Two other modifications which were considered and subsequently dropped were the addition of a deicing or anti-icing unit and the addition of some form of protective device over the sensing disc so that flying debris would not interfere with the flow being measured. These last two possible modifications have been suggested to the authors; however, no reasonable method has been found for accomplishing them.
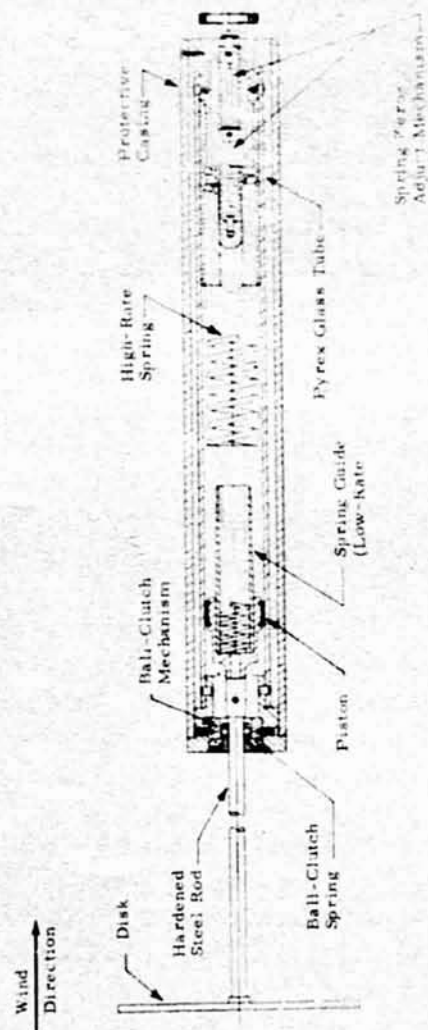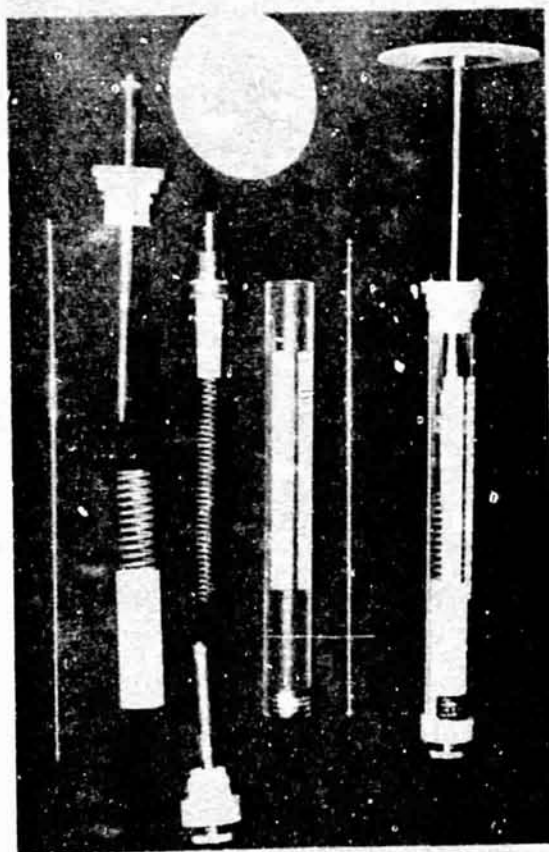
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Figure 1. Maxometer.

Wind Direction

Disk
Hardened Steel Rod
Ball-Clutch Spring
Ball-Clutch Mechanism
Piston
Spring Guide (Low-Rate)
High-Rate Spring
Pyrex Glass Tube
Protective Casing
Spring Force Adjust Mechanism

## III. FIELD MEASUREMENTS

The maxometer has been used to measure extreme induced flow caused by the exhaust from launch vehicles. The vehicles, which were launched from Cape Kennedy, Florida, were the launch vehicles for two of the Apollo missions and three of the Skylab flights. Specifically, flow data were obtained for Apollo 15 and 16 and for Skylab I, II, and III. The peak flow values obtained for Apollo 15 and 16 were reported [1] to be approximately 100 and 55 m sec$^{-1}$, respectively. For the Skylab launches, peak flow speeds of 95, 90 and 105 m/sec were found for Skylab I, II, and III, respectively.

Attempts were made to obtain peak flow values from three locations on the face of the LUT (two at the 67-m level and one at the 110-m level) for the Apollo and Skylab flights. Table 1 gives the peak flow values obtained during these launches. It should be noted that some of the maxometers were broken during these tests. The broken sensors appeared to have had a large lateral force acting on them. As a result of this lateral force, the maxometer at the 110-m level was tilted at a 30-degree angle in the last few tests. It can be noted that the largest value obtained came from the last Skylab launch at the 110-m level (maxometer tilted at a 30-degree angle).

It was hoped that a sufficient number of maxometers could be placed on the LUT so that the induced flow could be mapped. However, for various reasons this was not possible; thus, we were only able to state what the possible extreme flow was down the face of the LUT (see Table 1).

The maxometers have also been tested in the natural environment. A brief discussion of these environmental tests is given in Reference 1. These environmental tests were inconclusive because the wind speeds encountered in most cases were below the threshold value of the maxometer, which is approximately 15 m/sec. The maxometer was tested at the following sites: the Hurricane Research Center, Miami, Florida; the National Weather Service, Bootheville, Louisiana; and the Naval Air Station, Corpus Christi, Texas. Plans are presently under way to have the maxometers installed at various locations along the Gulf Coast of the U. S. in the hope of possibly obtaining wind measurements associated with a hurricane.

TABLE 1. MAXOMETER INDUCED FLOW MEASUREMENTS

| STATION | APOLLO 15 | APOLLO 16 | APOLLO 17 |
|---|---|---|---|
| A. 67 m. (NORTHEAST CORNER) | 99 m/SEC | 55 m/SEC | *** |
| B. 67 m. (NORTHWEST CORNER) | * | 25 m/SEC | *** |
| C. 110 m. (TOP CENTER) | 27 ** m/SEC | 41 m/SEC | *** |

| STATION | SKYLAB I | SKYLAB II | SKYLAB III |
|---|---|---|---|
| A. 67 m. (NORTHEAST CORNER) | 95 m/SEC | 90 m/ SEC | 72 m/SEC |
| B. 67 m. (NORTHWEST CORNER) | **** | **** | 90 m/SEC |
| C. 110 m. (TOP CENTER) | DESTROYED | **** | 105 m/SEC |

\* DATA BELOW THRESHOLD OF ~20 m/SEC
\*\* NOT CONSIDERED TO BE ACCURATE DUE TO INSTRUMENT DAMAGE
\*\*\* NO DATA RECEIVED
\*\*\*\* DATA QUALITY TOO POOR TO USE

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## IV. STATIC TESTS

The maxometers were static tested in July 1973 on a Dillon Universal Testing Machine (Model M-1). These tests consisted applying a force to the sensing element (disc) of the maxometer and measuring the force necessary to displace the disc given distances. A typical plot from one of these tests is illustrated in Figure 2. In this figure the scale has been doubled; i.e., 20 millimeters on the figure is equal to 10 millimeters of displacement.

The major fact illustrated in Figure 2 is the apparent linearity of the springs used in the maxometers. In the figure, the curve from zero to approximately 63 millimeters is for the small spring only (Fig. 1). The remainder of the curve illustrates the linearity relationship for the small and large spring together. The small perturbations on the curve are believed to be almost entirely caused by internal friction.

As a result of these static tests and the wind tunnel tests, to be discussed in the next section, serious consideration is being given to eliminating the small spring. In fact, one instrument for the tunnel tests had only one spring. The only apparent effect was the change in the threshold of the maxometer, which was to be expected.

## V. WIND TUNNEL TESTS

During January 1974, wind tunnel tests of the maxometers were conducted in the high-speed 2 by 3 meter (7 by 10 foot) wind tunnel at the Langley Research Center, Virginia. A discussion of this tunnel is given in Reference 2. These tunnel tests were for calibrating the maxometers. A total of 37 maxometers were tested in 71 individual tests for a speed range of 20 to 130 m/sec. Up to three instruments were tested at a time (Fig. 1).

Figures 3 and 4 are graphs of the results of the wind tunnel tests. A scatter plot of maxometer measured speed versus displacement of the sensing disc is presented in Figure 3 for three maxometers. The solid line in this figure is a plot of

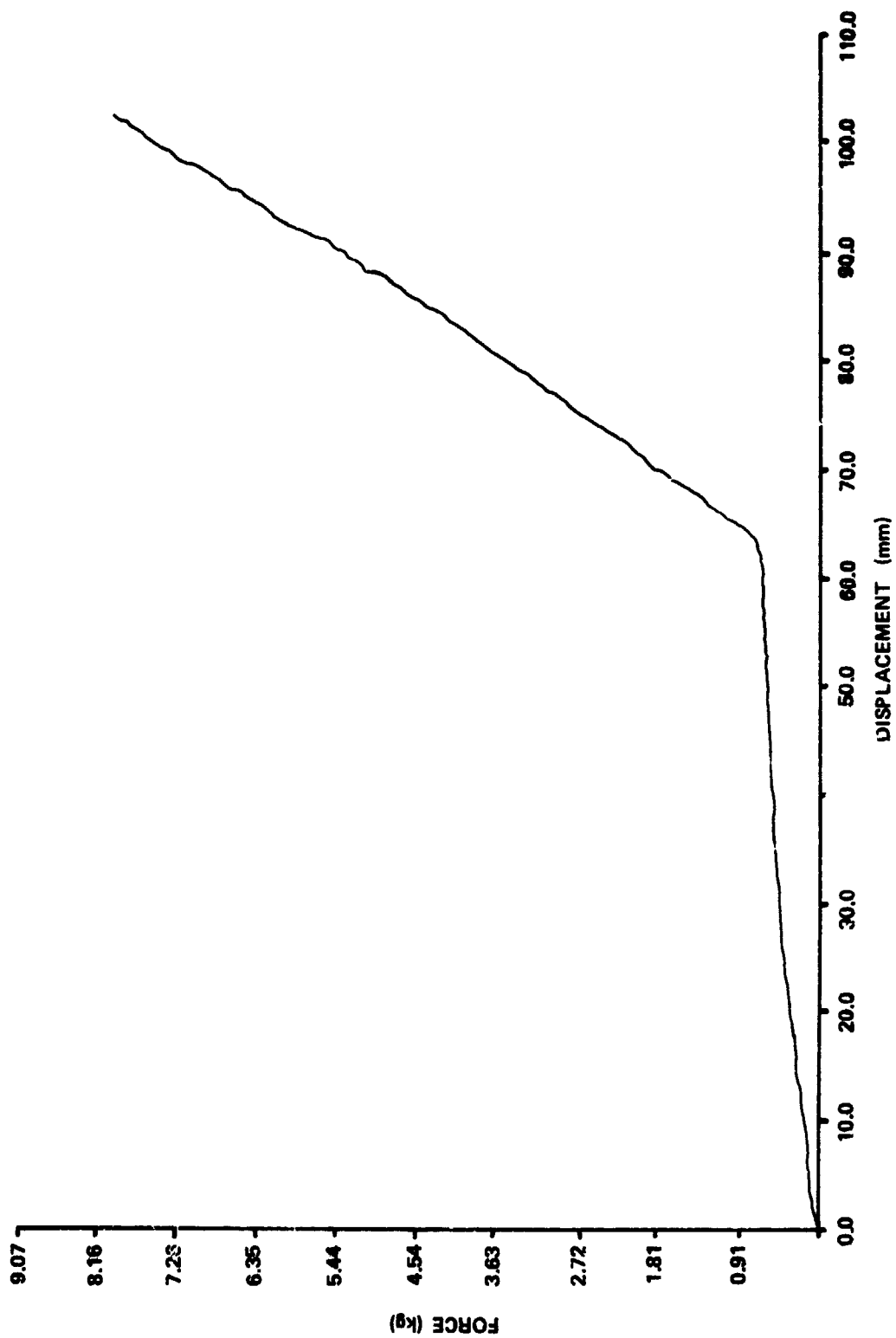$$u = 23.20 \left[ (1 + 0.0363D) A \right]^{\frac{1}{2}} \tag{1}$$
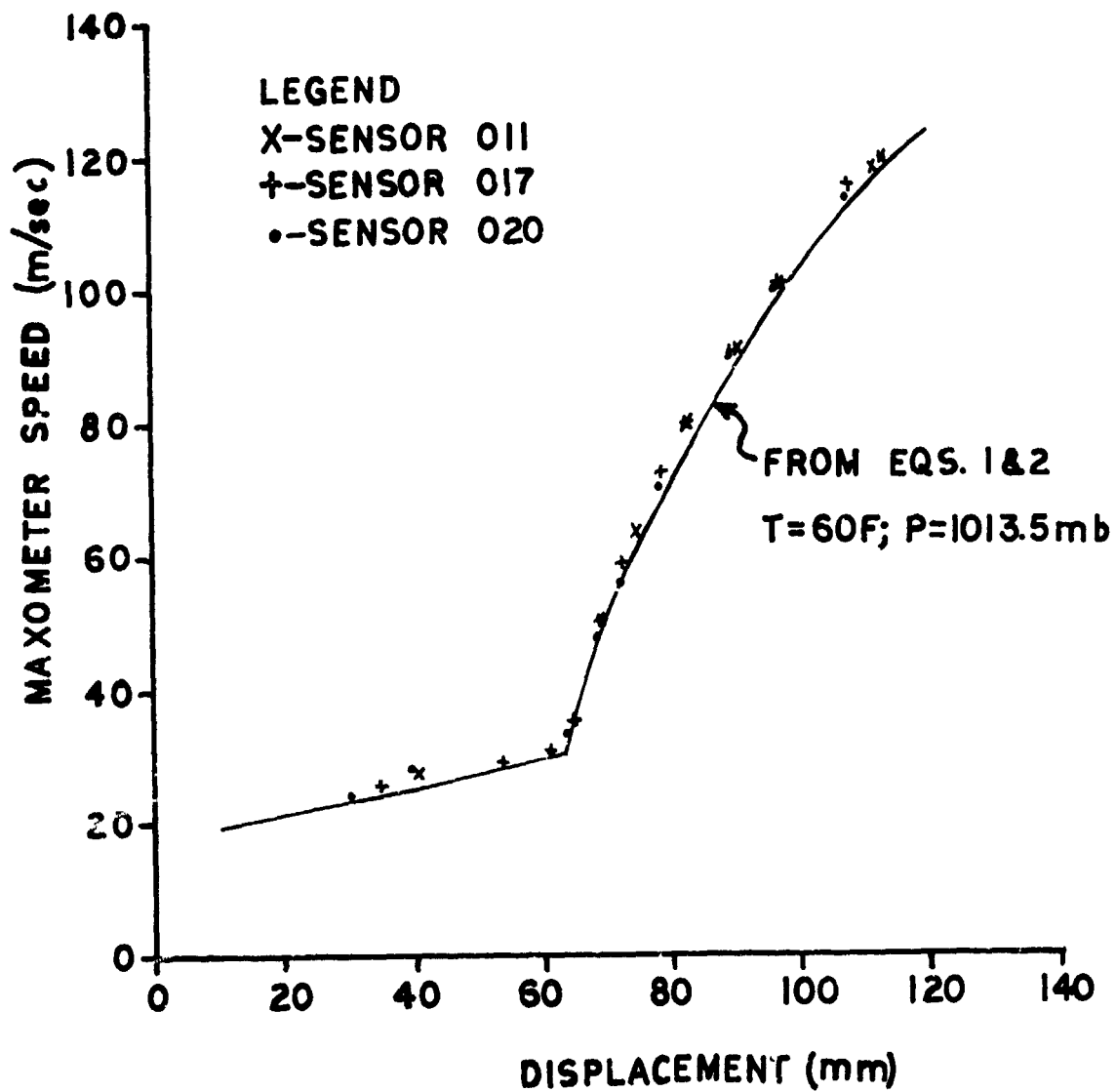
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Figure 2.  Static test curve.

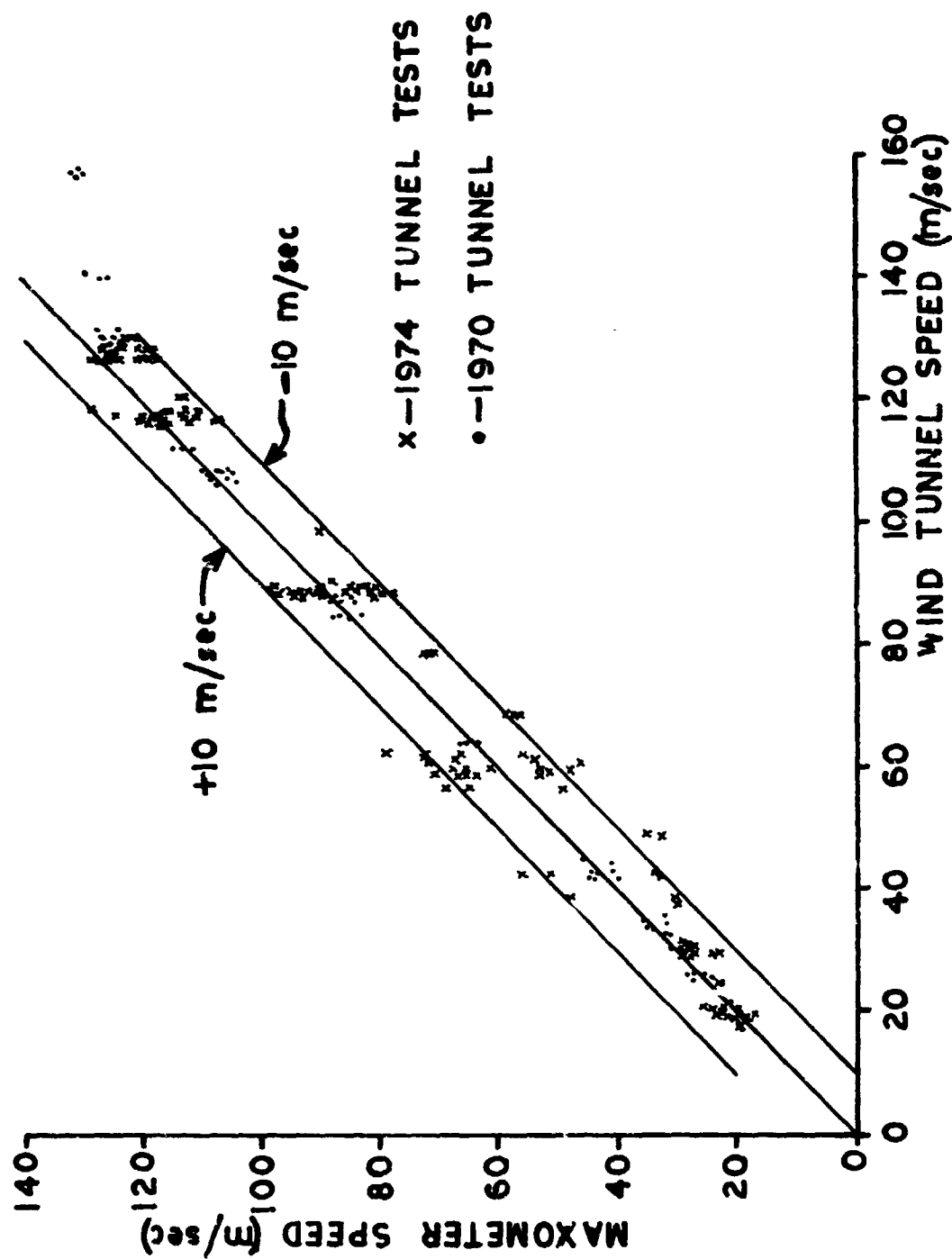Figure 3. Maxometer speed versus displacement.

FIGURE 4. COMPARISON FLOW MEASUREMENTS

Figure 4. Comparison flow measurements.

for $D \leq 63.5$ mm and

$$u = 23.20 \left[ (D - 60.20) A \right]^{\frac{1}{2}} \tag{2}$$

for $D \geq 63.5$ mm, where

$$A = (T + 459.67)/P \tag{3}$$

and A is held constant [3], T is ambient temperature (°F), and P is ambient pressure (mb). Also, in this figure values are given for three instruments tested under tunnel ambient temperature and pressure. Equations 1 through 3 are the equations to be used to determine the flow sensed by the maxometers. From these equations, it is readily seen that three inputs are necessary; namely, displacement of sensing element, ambient pressure, and ambient temperature.

Figure 4 is a comparison of the maxometer measured flow and a conventional wind tunnel measurement of the tunnel flow. The maxometer values were determined by use of Equations 1 through 3. This figure shows that while the results obtained from the January 1974 (x's in figure) tests were not as desirable as the earlier tests (o's in figure), they are fairly good. The root-mean-square error (RMSE) of the maxometer data used in the figure was determined by use of

$$RMSE = \left[ \Sigma (u - u_c)^2 / N \right]^{\frac{1}{2}} \tag{4}$$

where $u$ is the speed value for the maxometer, $u_c$ is the speed of the wind tunnel instrument, and N is the number of data points used. For the earlier tests $N = 123$, and a RMSE of $\pm 2.0$ m/sec was obtained. In the 1974 tests $N = 209$, and the RMSE was found to be $\pm 7.0$ m/sec.

The average absolute error ($\bar{e}$) was determined by

$$\bar{e} = (\Sigma |u - u_c|)/N \tag{5}$$

and was found to be 1.6 m/sec and 5.8 m/sec for the 1970 and 1974 tests, respectively.

From Figure 4 it can be seen that the error is approximately constant over the range measured. For errorless measurements, all the data would be on the line where $u = u_c$. The $\pm 10$ m/sec lines basically envelope the data with the exception of the speed values in the 60 m/sec range. As a matter of note, the RMSE and the average absolute error for the range 50 to 80 m/sec were found to be 9.0 and 8.3 m/sec, respectively. No reason could be found for the large error in this range. The lowest RMSE and lowest average absolute error were for the speed range of 100 to 125 m/sec. For this range they were 5.9 and 4.5 m/sec, respectively.

# VI. REFERENCES

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3.  Johnson, P. T., and Krause, M. C.: A Maxometer for Peak Wind Speed Anemometry. NASA CR-61337, 1971.
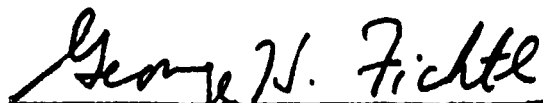
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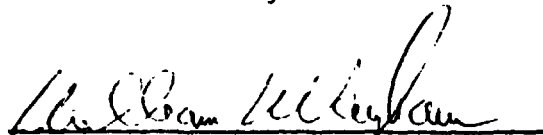# APPROVAL

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by

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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