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A SIMPLE TOTAL ENERGY SENSOR

By

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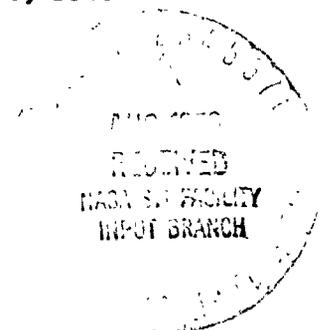(NASA-TM-X-73928) A SIMPLE TOTAL ENERGY   N76-27226
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16. Abstract

A sailplane owes its performance to the utilization of energy supplied from external sources. Sensitive rate of climb instruments (variometers) connected to static pressure sources are commonly used to indicate rising or sinking of the sailplane. Several methods have been used to provide dynamic pressure compensation for rate of climb when zooming or diving, so that the variometer indicates rate of change in total energy instead of rate of change in potential energy. The most widely used compensators have been of two types; diaphragm-volume systems and venturi systems.

This research concerns a study of a simple technique for total energy compensation having the primary requirement of good compensation with a low cost, easy to make sensor. A comprehensive library search and a small wind tunnel were used to explore fundamentals and to develop a number of probes which were flight tested with satisfactory results.

Simple probe configurations were tested using the characteristics of laminar flow separation around a small cylinder to produce a sensor pressure having the desired relationship between static and dynamic pressures. Wind tunnel and flight tests confirmed the concepts for a wide range of speeds, altitudes, and flow directions encountered in soaring. Data and findings are presented, along with a discussion of factors important to total energy compensation.

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SUMMARY

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Simple probe configurations were tested using the characteristics of laminar flow separation around a small cylinder to produce a sensor pressure having the desired relationship between static and dynamic pressures. Wind tunnel and flight tests confirmed the concepts for a wide range of speeds, altitudes, and flow directions encountered in soaring. Data and findings are presented, along with a discussion of factors important to total energy compensation.

INTRODUCTION

The ability of a sailplane to remain aloft for long periods of time, or to cover significant cross-country distances, is dependent upon its effective use of energy supplied by external sources. For this reason, clear and accurate information concerning the total energy situation and its rate of change are extremely significant to successful soaring. While there are many factors involved in a rigorous treatment of total energy, it is possible for a pilot to interpret his total energy situation with simple modifications to a variometer system. The important addition to a sensitive variometer is a device which integrates the effects of concurrent changes in potential energy and kinetic energy, thereby providing a good indication of what is happening to useful total energy.

Simplified Energy Considerations

The total energy of a sailplane at a given time is the sum of its potential and kinetic energies. A pilot customarily determines his total energy situation by a glance at the altimeter and the air speed indicator. In addition to sensing the absolute value of total energy, it is most important to "energy management" that the pilot also be able to sense the rate of change in total energy at all times.

The rate of change in total energy is principally affected by two factors:

1. The drag of the sailplane which is constantly reducing the useful energy, and

2. The air mass energy effects on the sailplane.

The drag is dependent on the aerodynamic characteristics of the sailplane, its velocity, altitude, and the load factor. There is little a pilot can do about the aerodynamic characteristics of his sailplane in flight, however, he can control the velocity and the load factor affected by maneuvers. The air mass will be producing sink, climb, or velocity increments to the sailplane which are dependent on its characteristics and the pilot's skill in positioning the sailplane with respect to local air currents.

In summary, the useful total energy from a pilot's viewpoint may be thought of as the instantaneous total energy associated with his given altitude and velocity, less the energy being dissipated by the drag of the sailplane moving along its flight path, plus the energy being added to the sailplane by the air mass.

Variometers as Total Energy Indicators

Several forms of variometers exist which give accurate rate of climb information. Most of these instruments work on a principle of pressure drop across an orifice or mass flow measurements to and from a reference volume. When connected to a static pressure source, they

offer a good indication of rate of change in altitude or rate of
potential energy change. If an altitude change occurs at a constant
velocity, this reading also represents the rate of change in total
energy.

If the same variometer could be connected to a pressure source
which not only varies with the static pressure, but also inversely
with the dynamic pressure, it would be possible to use the same
instrument for indicating rates of change in total energy. This is
the basis for the total energy research presented in this report.

PRESSURE AND ENERGY RELATIONSHIPS

In still air, a sailplane flying at high speeds could exchange
most of its kinetic energy for potential energy by zooming. If the
sailplane had no drag, the energy exchange would be complete, and a
perfect total energy instrument would indicate no change in total energy
for such a transfer. As mentioned, a sensitive variometer can be
converted to function as a total energy instrument if the ambient
static pressure source is replaced by a pressure source appropriately
combining pressures related to the altitude and velocity. For the
imaginary sailplane with no drag, a perfect total energy pressure source
would simply provide constant pressure to the instrument throughout the
zoom, with the decreasing pressure due to increase in altitude exactly
compensated by a pressure increase inversely proportional to the change

in the square of the velccity. In other words, since the variometer detects rate of change of pressure, a pressure proportional to the difference between the static pressure and the dynamic pressure would provide the desired total energy indication.

It is customary to refer to pressures in a non-dimensional form called pressure coefficients, defined by

$$C_p = \frac{P_{Local} - P_{Ambient}}{q}$$

where:

P_{Local} = local or sensor pressure source

$P_{Ambient}$ = static pressure

q = dynamic pressure

Since P_{Local} for a total energy sensor should use the difference of the ambient and dynamic pressures, the required pressure coefficient $C_p = -1.0$, i.e.,

for $P_{Sensor} = P_{Ambient} - q$

$$C_{p_{Sensor}} = \frac{(P_A - q) - P_A}{q} = -1.0$$

For the actual case of the sailplane with drag gliding in still air, the variometer sink rate reading with such a source would simply be the sailplane polar value associated with the speed being flown. Such a polar, obtained from Reference 1, is shown in Figure 1, indicating an increasing sink rate with increasing speeds because of a higher drag. Thus, the use of a variometer with total energy compensation depends on a pilot knowing his polar relationships so that he can easily judge whether rising or sinking air is modifying his sink rate for the known flight speed. This is commonly done by accomplished pilots, although there have been recent developments of so-called "netto" variometers which factor the sailplane polar into the variometer reading (Ref. 2). It is important to recognize that the total energy compensation is also the essential first step for a netto variometer, so the research described here is applicable to either form of total energy compensation.

TOTAL ENERGY SENSORS

Several forms of total energy sensors have been developed. In 1940, Kantrowitz described the principles of such a technique (Ref. 3). The Irving venturi was a well known approach to this matter (Ref. 4), and more recently, the Althaus venturi (Ref. 5) has been widely used. Along with these probe techniques, many diaphragm systems have been successfully used, one of the most recent being the Schuemann compensator (Ref. 6). A recent probe compensator, known as the

Braunschweig tube, described in Ref. 7, uses the same principles applied in developing the probes discussed in this report. However, they are more difficult to make, and were found to be more sensitive to manufacturing tolerances.

The most significant aspects of the probes developed in this report are:

(1)   Good compensation over a wide speed and altitude range,

(2)   Insensitivity to flow direction,

(3)   Simplicity of construction, and

(4)   Relatively low drag.

Possibilities for Simple Total Energy Sensors

There are many aerodynamic shapes that produce pressure distributions with local pressure coefficients of -1.0, but they are often very sensitive to flow conditions or variations in angle of attack, Reynolds number, etc. For instance, there may be several locations on an airfoil where C_p = -1.0, but the locations are likely to vary sensitively with angle of attack.

A literature search of pressure distributions over various shapes (Refs. 8-15) indicated the possibility of using a cylinder, because the typical two-dimensional pressure distribution around a cylinder shows pressure coefficient values of -1.0 at about 55° to 60° from the stagnation point (Fig. 2). However, the gradient is very steep at this position and it would be necessary to locate pressure orifices quite

precisely. In addition, this location would be very sensitive to variations in flow angle. What is more interesting about the pressure distributions for cylinders at relatively low Reynolds numbers is the fact that the pressure coefficients are nearly constant around the aft side of cylinders from about 100° to 180°, and for a wide range of Reynolds number are well within 10 percent of the desired $C_p = -1.0$ value.

The best data found dated back to the period from 1916 to 1932, when there was a research emphasis on theoretical determinations of air flow around simple shapes for purposes of developing lift and drag prediction techniques. The limitations of early experimenter's wind-tunnel sizes, plus their interest in the low-speed range, resulted in experimental data for conditions very similar to those encountered by sailplanes. Thus, it was possible to gain insight concerning Reynolds number effects and other flow phenomena of direct interest from early efforts. Based on these data, enough encouragement was obtained to proceed, and an experimental activity was initiated to explore the practicality of using a cylinder to obtain a suitable reference pressure for total energy compensation.

Range of Conditions for Sailplanes

Before determining the application of existing data and developing a test program, it was essential to understand the range of conditions and basic aerodynamic relationships for typical sailplane operations.

Having found that cylinders might offer appropriate sensor pressures, Reynolds numbers as a function of cylinder diameter were calculated using Ref. 16, for a range of velocities and altitudes (Fig. 3). It is customary to base Reynolds number for cylinders on cylinder diameter. Practical cylinder diameters for sailplane sensors, considering structural as well as aerodynamic factors, range from 3/16-inch to 1/4-inch. This fact allowed the easy addition of scales to Figure 3 for three specific diameters, so that Reynolds numbers may be obtained at a glance for various test or flight conditions.

It can be seen that for the spectrum of speeds from about 40 miles per hour to 150 miles per hour, and for altitudes from sea level to 20,000 feet, ratios of Reynolds number to diameter, R/d , (usually referred to as unit Reynolds number) fall within values of 2.5 x 10^5/ft. and 16 x 10^5/ft. In actual practice, the most important region for compensation ranges between R/d values of 5 x 10^5/ft. to 10 x 10^5/ft. For 3/16-inch diameter sensors, this results in Reynolds numbers ranging from about 8,000 to 16,000.

APPARATUS AND SENSORS

Wind Tunnel

Early experiments were performed with a simple free-jet wind tunnel
assembled from a shop vacuum cleaner. A water manometer was made with
rulers and glass tubing purchased at a Hobby Shop. Data obtained with
this facility provided some verification for the two-dimensional pressure
distributions around cylinders, helped provide a feel for the effects of
hole size, and indicated the promise of obtaining coefficients suitable
for total energy compensation.

Shortly thereafter, a small wind tunnel that had been made as an
Explorer Scout Project with the help of some NASA Langley researchers
became available, Fig. 4. The facility was powered by a 1/4-horsepower
motor, had an 8- by 10- by 10-inch test section, and had been designed
to produce uniform flow at speeds up to about 60 mph.

By using stepped pulleys on the fan and motor drives, it was
possible to select various velocities simulating flight conditions over
a range of Reynolds numbers. Velocities corresponding to sea level,
full-scale conditions of 32, 43, and 54 mph were used. R/d values of
3.0×10^5/ft., 4.0×10^5/ft. and 5.0×10^5/ft. provided test conditions
within the range of interest. Velocity profiles indicated less than
1 percent flow velocity variations across the test section.

The motor could run continuously at the two low settings but tended to overheat at the maximum velocity, especially when the humidity was high. For this reason, most of the baseline data were obtained at the mid-range velocity settings.

Probe Mounting and Instrumentation

Probe mounting provisions were simple; an adapter was fitted to the bottom of the test section so that probes extended through a hole into the test section as shown in Figure 4. Angle of yaw variations were made by rotating the probe, using an indicator pointer attached to the probe mount and directly reading angles scribed on the bottom of the plexiglas test section. Angle of sweep data were obtained by inserting sections of carefully bent tubing into the probe holder. These adapters allowed angle of sweep variations over $\pm 25^{O}$ in 5° increments.

Instrumentation consisted of simple inclined manometers using distilled water. Three wall statics permanently positioned in the test section were manifolded together and used at all times for reference. A removable total pressure probe was used to determine the stream pitot pressure and to calibrate velocities.

## Typical Sensor Configurations

Brass tubing having various diameters was used for all sensors. Solder was used for plugging the ends in most instances, although brass screws or small brass scraps sometimes were soldered into place and filed to shape. For the large tubes, a small ball of steel wool inserted

into the end helped to provide a means of closing tube ends with solder. Although some tube ends were rounded off during early tests, it was determined that the additional variable of end-shape was hard to control. Consequently, all tests reported here were made with tube ends filed off normal to the tube, and beveled very slightly.

Holes were drilled with high-speed drills ranging in size from 1/32-inch to 1/8-inch, and deburred. All measurements to hole positions were from the ends of the tubes to the centers of the holes. Most tests were made with tubes having 1/32-inch diameter holes, although several checks were made with larger holes.

For most tests, tube lengths were six inches total, with about five inches extending into the free stream. This placed the tube ends near the center line of the tunnel where the flow was very uniform. For two-dimensional tests, 12-inch tubes were used to span the test section, with holes placed midway on tubes such that the holes were at midstream of the test section.

For identification of various sensors, all dimensions were given in thirty-seconds of an inch. The dimensions applied to probe configurations were as follows:
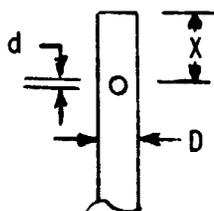
D-d-x for a 3/16-inch diameter tube, with a 1/32-inch diameter hole located 5/16-inch from the end, would be identified as configuration 6-1-10.

METHOD OF CONDUCTING TESTS

After a number of initial tests of random hole configurations and positions, a matrix of test configurations was selected to provide systematic data trends. For the 3/16-, 7/32-, and 1/4-inch tube sizes, 1/32-inch diameter holes were drilled at various X/D positions to obtain the basic trends in coefficient with respect to X/D. Three wind-tunnel speed settings were used and the probes rotated through a series of angles to obtain pressure distributions around the tubes. The tubes were mounted normal to the airstream in a simple holder with an angle indicator and rotated to selected angles by hand. Pressures were allowed to stabilize and data readings taken from the water manometer. The same process was repeated for the different tube sizes and velocities, thus also providing some variation in Reynolds number values.

After the systematic set of baseline data was obtained, experiments were conducted with multiple holes in the same manner.

WIND TUNNEL TEST RESULTS

Basic Data and Trends

In Figure 5, typical pressure distribution data obtained on sensor configurations are shown for a set of 3/16-inch diameter probes. The similarity of these data to simple two-dimensional data obtained by earlier experimenters is obvious. A significant aspect of these data is the nearly constant coefficient for hole positions from 100^0 to 180^0.

This indicates that a probe with an aft facing hole should be extremely insensitive to angles of sideslip over a wide range. Also seen are the differences in coefficient for $\theta = 120^O - 180^O$ when X/D varies, indicating the three-dimensional effects on pressure coefficients that result from having holes located near the end of the tube. It was this discovery that suggested that the three-dimensional relationship with coefficient could be used to select a hole location that would give the desired coefficient.

After some flight test experiments, a series of tests with varying sweep angles was conducted to determine sensitivity to pitch or down-wash angles. The results, Figure 6, showed a marked gradient of coefficients for variations in probe sweep from -10° to $+25^O$, but an insensitivity to sweep over the range from -10° to -25°. Downwash calculations showed that a probe installed near the top of the vertical tail would see only a maximum of 3° downwash change over the range of lift coefficients expected to result from a high-speed zoom.

In Figure 7, a summary of many test points is presented. The trend of coefficients as a function of X/D for a range of hole locations can be seen. The significant finding is the linearity of this trend through a range of coefficient values around $C_p = -1.0$, because this clearly indicates the potential for making a simple probe. Also shown are data for probes having forward sweep of 20° exhibiting the linear trend with respect to X/D, at a different reference level. It should be noted that the X/D = 2.0, $\gamma = -20^O$ gives the desired pressure coefficient, $C_p = -1.0$.

Effect of Hole Size

During the course of the experiments, several different hole sizes
were tested. All of the expe ience obtained with various hole sizes
supported the findings from Reference 8, (Figure 8), that a range of
hole sizes produce the same coefficients at a Reynolds number of 8,500.
During flight tests with 3/16-inch diameter probes, it was found that a
sensitive variometer with audio indicated a slight resonance with the
1/32-inch diameter hole. Doubling the hole diameter to 1/16-inch
eliminated the burbling sound noted with the smaller hole. The average
pressure readings did not appear to be affected by hole size in the wind
tunnel or in flight tests, as long as the center of the openings were
the same distance from the end of the probes.

Reynolds Number Effects

Although two-dimensional data in Figure 2 showed effects of Reynolds
number to be small for the probe sizes and range of flight conditions of
interest, a simple experiment was performed in the wind tunnel to see
whether Reynolds number effects could be noted. Figure 9 shows the
results of doubling the Reynolds number, well into the range of greatest
interest. Any variations for the aft facing hole appear to be within
the scatter of wind-tunnel results and there was no consistent difference
observed which could be attributed to Reynolds number.

Description of Best Configurations

For the range of velocities from 40 to 150 miles per hour, and for altitudes from sea level to 20,000 feet, a probe diameter of 3/16-inch is satisfactory. For the diameter, an aft facing hole 1/16-inch in diameter should be located 3/8-inch from the end of the probe. The probe should be swept forward 20 degrees. Sketches of two successful probe configurations tested in the wind tunnel and in flight are illustrated in Figure 10. Probes having diameters of 7/32-inch and 1/4-inch with the same geometric ratios were also tested. Although they provide the desired total energy compensation, it is obvious they also produce proportionately higher drag values than the 3/16-inch diameters.

FLIGHT TESTS

Throughout the period of wind tunnel experiments, flight tests were performed on various configurations. Most of the tests were conducted with a Schweizer 1-26B with a Ball Electric Variometer Model 101-D. Several flights were also successfully made with Winter and PZL variometers. Tests were conducted with probes mounted aft of the removable portion of the turtle deck and on the upper tip of the fin spar. No quantitative measurements were made in flight; however, a standard procedure was used to indicate the response of the variometer with different probe configurations. The most meaningful tests were made on calm days by establishing glides at steady speeds ranging from 50 to 100 mph and zooming to thermalling speeds of about 40 mph.

In addition to tests by the author with a Schweizer 1-26B, replacement probes were made for the Althaus probe that is mounted on the forward fin of the Standard Libelle. Flight tests similar to those described for the 1-26 were made with the Libelle by an experienced competition pilot. Exactly the same basic probe dimensions proved best for both sailplanes.

Probe Mounting Configurations

Because of easy installation, several tests were made with probes mounted just aft of the removable turtle deck on a 1-26B. This location gave fairly good results but was never as good over a range of conditions as a fin location. The fin location for the 1-26B placed the probe in free stream air, not affected by the changes in pressure over the wing and body. The probe made for mounting on the forward fin of the Standard Libelle was also operating in free stream conditions. While these tests and other experiences suggest the free stream locations as the most suitable, fuselage locations may be acceptable, although some tailoring of the probe hole position may be necessary to favor compensation during zooms at the expense of compensation during dives.

Adjustments During Flight Tests

As shown by wind tunnel results, the position of the orifice with respect to the end of the tube was very important. For final adjustment to a given installation, it was found that drilling the hole slightly farther from the end of the tube (approximately 1/32-inch) than twice the diameter, allowed easy adjustment after initial flight

test by filing off the end of the tube in small increments and retesting until achieving good compensation. One or two iterations usually sufficed. As mentioned earlier, the shape of the end of the tube affected compensation and care had to be exercised to bevel the edges very slightly. It was also imperative that a good seal exist after filing; it was found very worthwhile to check for leaks after any such filing adjustments because a tiny hole in the soldered end produced drastic effects on compensation.

Sealing of Removable Probe Joints

Extreme difficulty was experienced in sealing, when using tape to secure removable probes inserted into metal holders. As a result, a series of tests was run on various tapes and taping procedures. No taping technique was found that provided dependable results and the only sure sealing method for a probe connection was to use a small sleeve of plastic tubing in lieu of taped connections. Since the total energy indication is extremely sensitive to leaks, all connections should be checked carefully to insure proper results.

Flight Test Conclusions

For the configurations illustrated in Figure 10, smoothly executed zooms resulted in a steady change in rate of sink readings between the correct values for speeds at beginning of zooms to the proper sink rates for thermalling speeds. No excessive overshoots in climb or sudden

increases in sink rate were exhibited during zooms. Similar results
were obtained for pushovers from thermalling speeds to various cruise
speeds. Checks were also made during rapid transients with elevator
movement, rudder movement, and sideslip. Loops, lazy eights, and other
coordinated maneuvers involving changing speeds and altitudes gave good
qualitative checks during transient conditions. While flight tests
were not made above 10,000 feet, no variations were noticed as a result
of altitude.

DRAG ESTIMATES FOR TYPICAL INSTALLATIONS

Considerable data exist from classical theory and experiments on
the two-dimensional drag of cylinders in the desired Reynolds number
range. From Ref. 14, a two-dimensional cylinder drag coeffi ıt of
1.15 was obtained for the Reynolds number range of 10,000 to 20,000.
For finite cylinders of given length/diameter ratio, a form factor to
modify two-dimensional coefficients was available from Ref. 10. For a
3/16-inch diameter cylinder 5 inches long (length/diameter ratio
approximately 27) this form factor, to be multiplied times the two-
dimensional coefficient, is 0.78. There is also a reduction in drag
due to sweep that is proportional to the $(cosine)^3$ of sweep angle,
(Ref. 15). For a 20^0 sweep angle, an additional multiplying factor of
0.85 is appropriate.

In summary, the drag coefficient based on frontal area for a swept probe installation is approximately

$$C_D = 1.15 \times 0.78 \times 0.85$$

$$C_D = 0.76$$

For a 3/16-inch diameter probe 5 inches long, the drag at 100 mph, 5,000 ft. altitude, is about one-tenth of a pound.

FINDINGS AND CONCLUSIONS

Meaningful information on rates of change of useful total energy can be provided during flight by a sensitive variometer coupled with a pressure sensor having a coefficient $C_p = -1.0$. Wind tunnel experiments conducted with a small facility developed simple probes and determined their characteristics under various flow conditions. Flight tests were conducted to verify wind tunnel results.

The best probe configurations tested had the following characteristics:

1. Cylindrical tube, diameter of 3/16- to 1/4-inch.
2. Tube end squared off with very slight bevel of sharp edge.
3. Aft facing pressure orifice, a drilled hole about 1/3 the tube diameter (1/16- to 3/32-inch).
4. Center of hole located at a distance two times the tube diameter from the end of the tube (3/8- to 1/2-inch).

5. Probe swept forward about 20° with respect to flow direction.

6. Probe mounted in free-stream air, extending a minimum of 5 to 6 inches from the aircraft.

7. Vertical tail location good; aft fuselage acceptable.

Such a probe, coupled with a good variometer in a leak-free system, should provide the following:

1. Good total energy rate information over a flight range from 40 to at least 150 mph, altitudes from sea level to at least 20,000 feet.

2. Insensitivities to normal yaw, pitch, and roll attitude variations.

3. Drag of a typical installation at 100 mph is about one-tenth of a pound.

REFERENCES

1. "Polars of Eight." By Paul Bikle. Soaring Magazine, June 1970,
    Vol. 34, No. 6.

    An experimental treatment of sailplane performance for
    several sailplanes, including the Schweizer 1-26.

2. "The Netto System." By Tom Brandes. Competition Workshop Soaring,
    March 1975, Vol. 39, No. 3.

    Discussion of a concept for approximating a sailplane polar
    in a total energy variometer system so that only vertical
    air mass movements are indicated.

3. "Letter to the Editor." By Arthur Kantrowitz. Journal of the
    Aeronautical Sciences, October 1940, p. 523.

    A brief description of principles for a venturi to provide
    a variometer pressure that would allow it to read rate of
    change of total energy in altitude units.

4. "Total Energy Variometers." By F. G. Irving, M. Eng. D.I.C.
    Presented at Vth OSTIV Congress, Buxton, England, 22 July - 4 August
    1954.

    A description of a venturi design to provide a reference pressure
    capable of converting a variometer to a total energy indicator.

5. "A New Venturi for Total Energy Compensation." By D. Althaus,
    DIPL. PHYS. XII OSTIV Contress, 1970.

    A description of a low drag venturi using principles of laminar
    flow separation to provide a total energy reference pressure
    for variometers.

6. "An Improved Diaphragm Based Total Energy Compensation System."
    By W. C. Scheumann. AIAA Paper No. 74-1014, September 1974.

    A description of an improved diaphragm total energy system with
    matched filters in the pitot and static circuits to damp gusts.

7. "The Braunschweig Tube." By Tom Brandes. Soaring, January 1975,
    Vol. 39, No. 1.

    A description of a total energy probe using laminar separated
    flow around a cylinder to achieve a total energy pressure
    source for use with conventional variometers.

8. Abstract - Flow Past Circular Cylinders at Low Speeds. By A. Thom,
    D. Sc, Ph.D. Reports and Memoranda No. 1539 (T.3275) June 1932.
    London: Printed and Published by His Majesty's Stationery Office.

    Extended data on effect of hole size on pressure measurements
    on cylinders at R = 8500.

9. "Pressure Distribution Round a Cylinder." A blueprint copy of a
    paper by G. I. Taylor, M.A. presented by the Superintendent, Royal
    Aircraft Factory. Reports and Memoranda, No. 191, March 1916.

    A discussion of pressure distributions at wind speeds of 20,
    30, 40, and 50 feet per second for a 6" diameter cylinder.
    Notes sudden change with particular V/ν , (velocity/kinematic
    viscosity or Reynolds function), about the same as for results
    . · on cylinder reported in 1913.

10. "An Investigation of Fluid Flow in Two Dimensions." By A. Thom,
    D.Sc, Ph.D, ARTC. Communicated by Professor J. D. Cormack, C.M.G.,
    C.B.E., D.Sc., M. Inst. C.E. Reports and Memoranda No. 1194 (AE 356)
    November, 1928. London: Printed and Published by His Majesty's
    Stationery Office.

    An excellent presentation of theory and experimental results
    of flow around cylinders. Data includes pressures, drag, flow
    fields for R = 28 to R = 17,000, and effects of hole size on
    measurement accuracy for holes up to about 0.275 times tube
    diameter.

11. "Further Experiments on the Flow Around a Circular Cylinder."
    By A. Fage, A.R.C.Sc and V. M. Falknew, B.Sc. Reports and Memoranda
    No. 1369 (AE 496-T.3062) February 1931. London: Printed and
    Published by His Majesty's Stationery Office.

    Further study at higher Rs = 60,000 to 212,000 with emphasis
    on effects of turbulence and roughness measurements of friction
    drag.

12. "On the Effect of Air Compression on Drag and Pressure Distribution
    in Cylinders of Infinite Aspect Ratio." By T. E. Stanton. Reports
    and Memoranda No. 1210 (AE-370) November 1928. London: Printed and
    Published by His Majesty's Stationery Office.

    Data on pressures and drag at Mach Numbers from 0.25 to
    M = 2.0 for cylinders at $R \approx$ 20,000. Excellent presentations
    of pressures around cylinder.

13. "The Flow Past Circular Cylinders at Low Speeds." By A. Thom, D.Sc., Ph.D., Carnegie Teaching Fellow, University of Glascow (Communicated by G. I. Taylor, F.R.S., Rec'vd. April 24, 1933). Proceedings of The Royal Society of London, Series A, containing papers of a mathematical and physical character, September 1933.

> A theoretical treatment of pressures, drags, and flow fields compared with experimental data.

14. "Modern Developments in Fluid Dynamics." An account of theory and experiment relating to boundary layers, turbulent motion and wakes Composed by the Fluid Motion Panel of The Aeronautical Research Committee and others and edited by S. Goldstein. Vols. I and II, Oxford at the Clarendon Press, 1938.

15. "Aerodynamic Drag." Practical data on aerodynamic drag evaluated and presented by Sighard F. Hoerner, Dr. Ing. Habil published by the author, 1951.

> A thorough treatment of drag data from all sources.

16. "Standard Atmosphere - Tables and Data for Altitudes to 65,000 Feet. NACA Report 1235.

> A collection of tables and plots of standard atmosphere data, aerodynamic relationships, and formulae useful in wind tunnel testing.
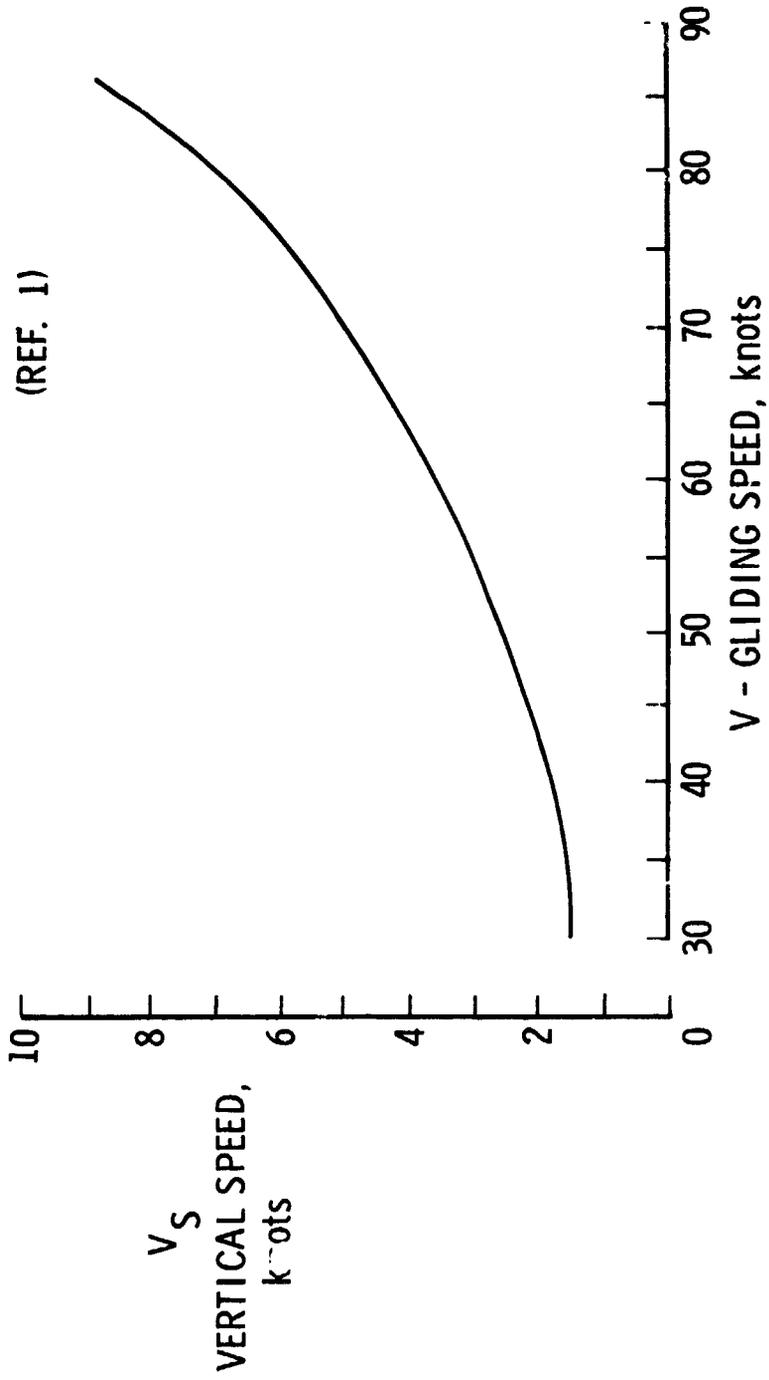
TYPICAL POLAR
SGS – 1-26

(REF. 1)

V_S VERTICAL SPEED, knots

V – GLIDING SPEED, knots

FIGURE 1

TYPICAL PRESSURE DISTRIBUTIONS
TWO-DIMENSIONAL CYLINDERS
(REFS. 10 AND 14)

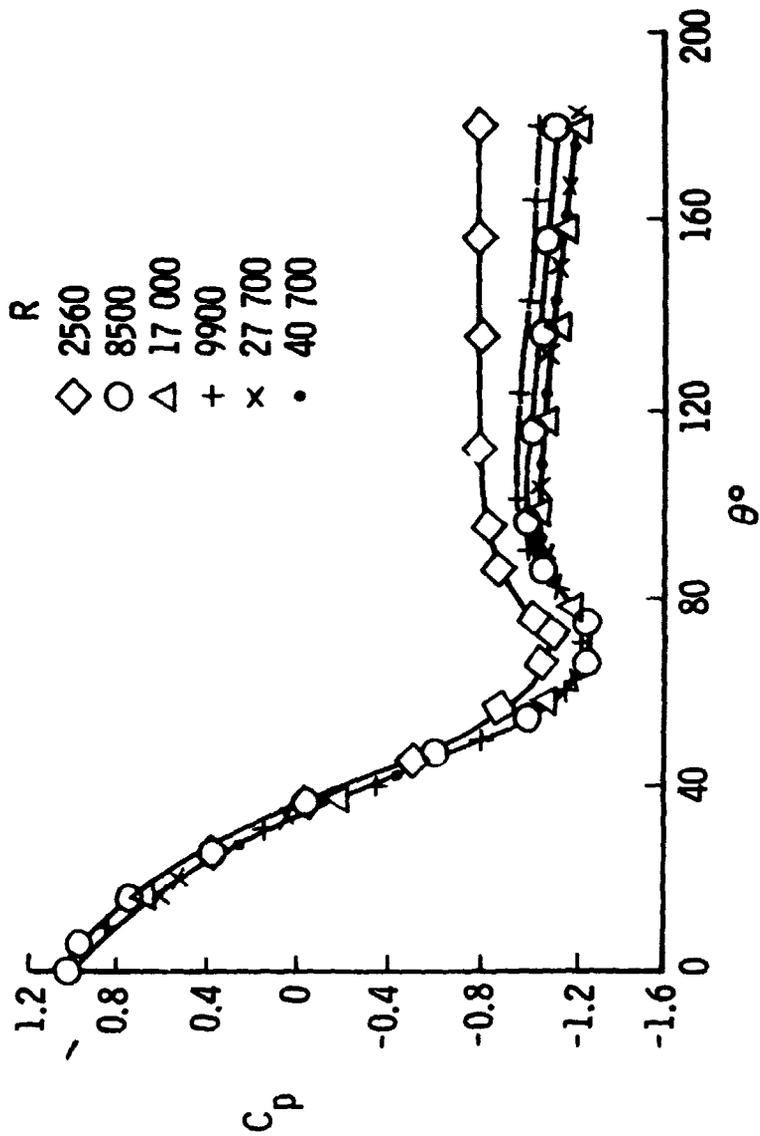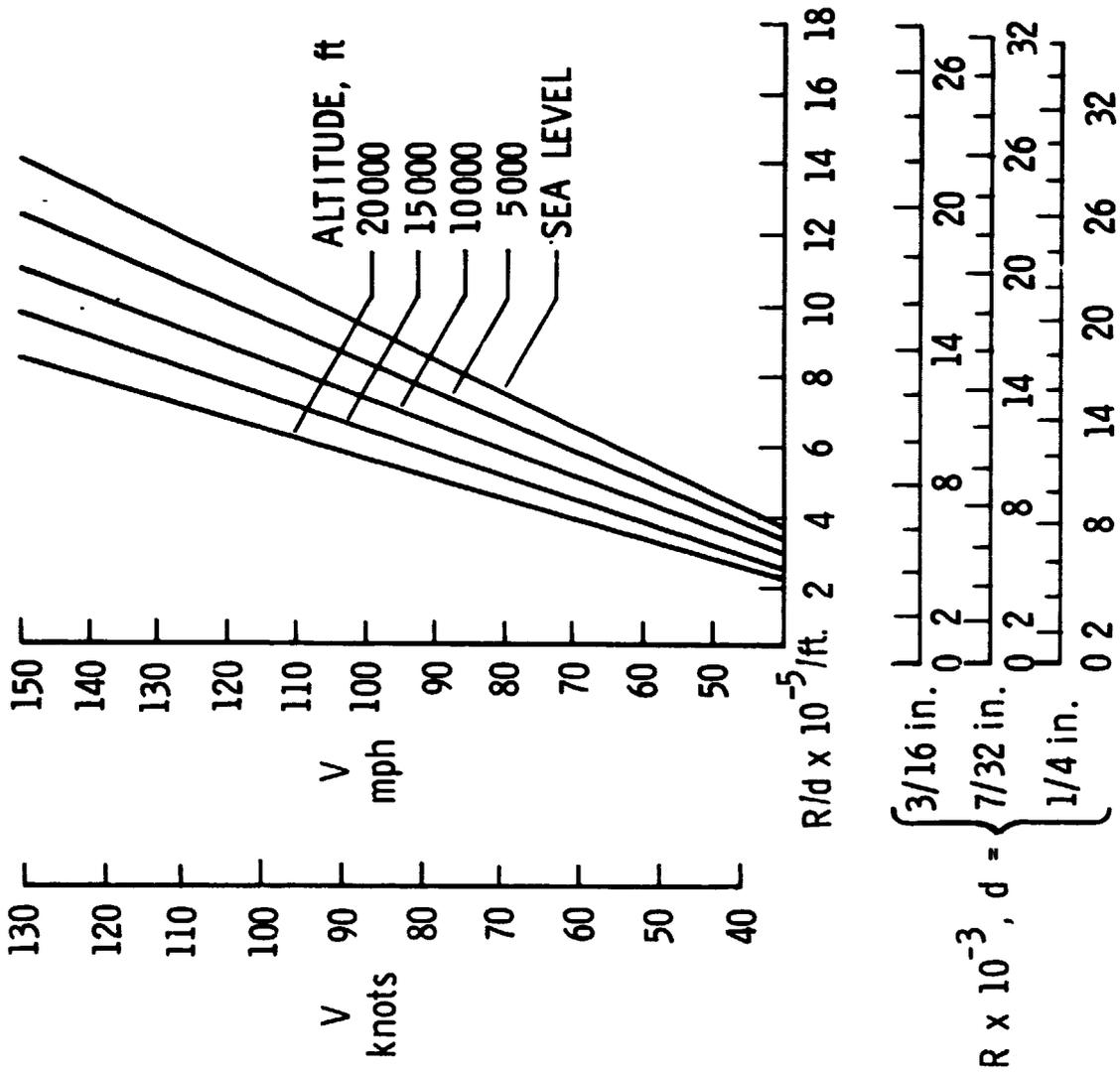| R	
◇	2560
○	8500
△	17 000
+	9900
×	27 700
•	40 700

FIGURE 2

REYNOLDS NUMBERS FOR VARIOUS CYLINDER DIAMETERS

FIGURE 3

8- × 10-INCH WIND TUNNEL

FIGURE 4

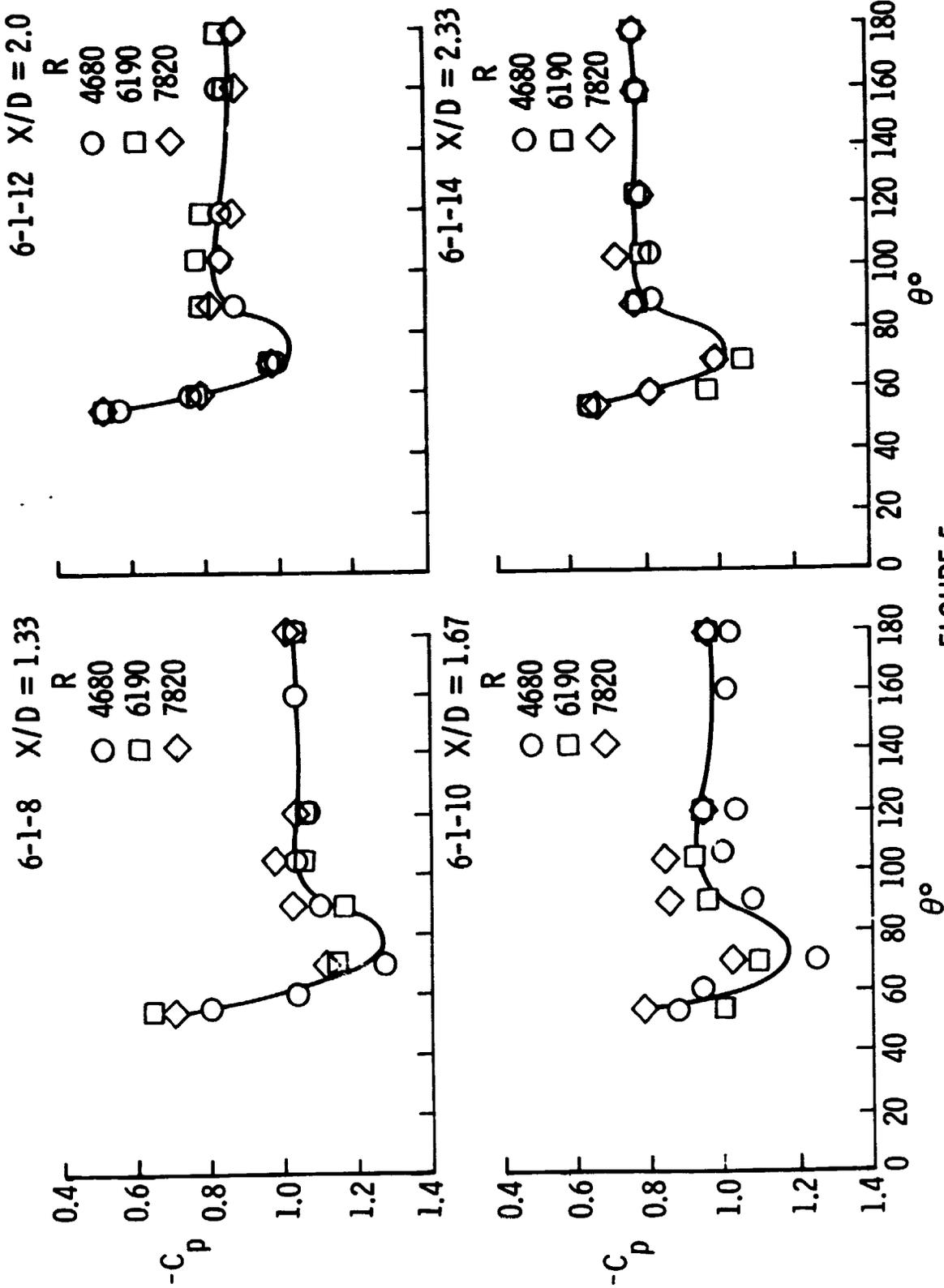# TYPICAL PRESSURE DISTRIBUTIONS
THREE-DIMENSIONAL CYLINDERS

FIGURE 5

VARIATION OF CP WITH SWEEP
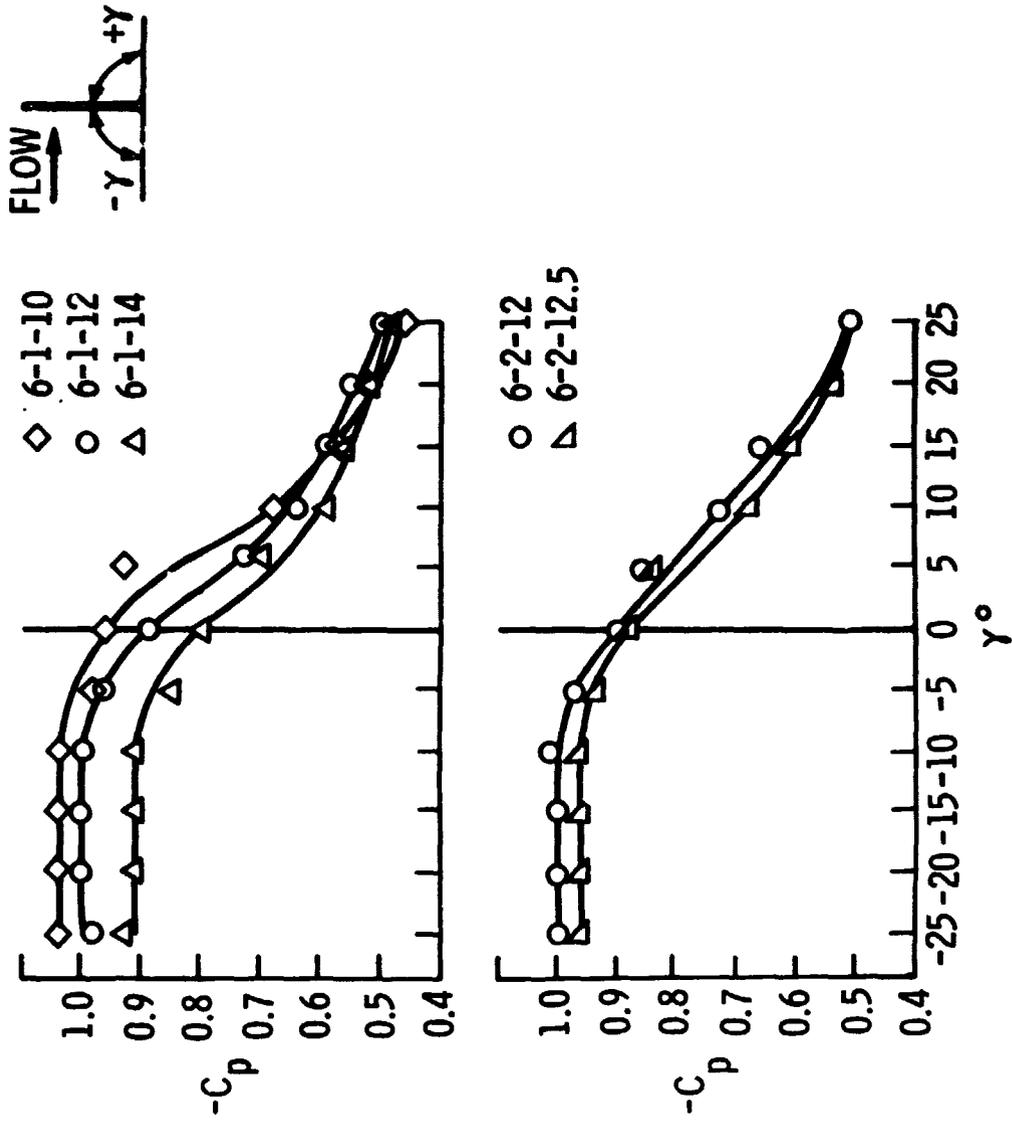
FIGURE 6

PRESSURE COEFFICIENTS AS FUNCTION OF HOLE POSITION

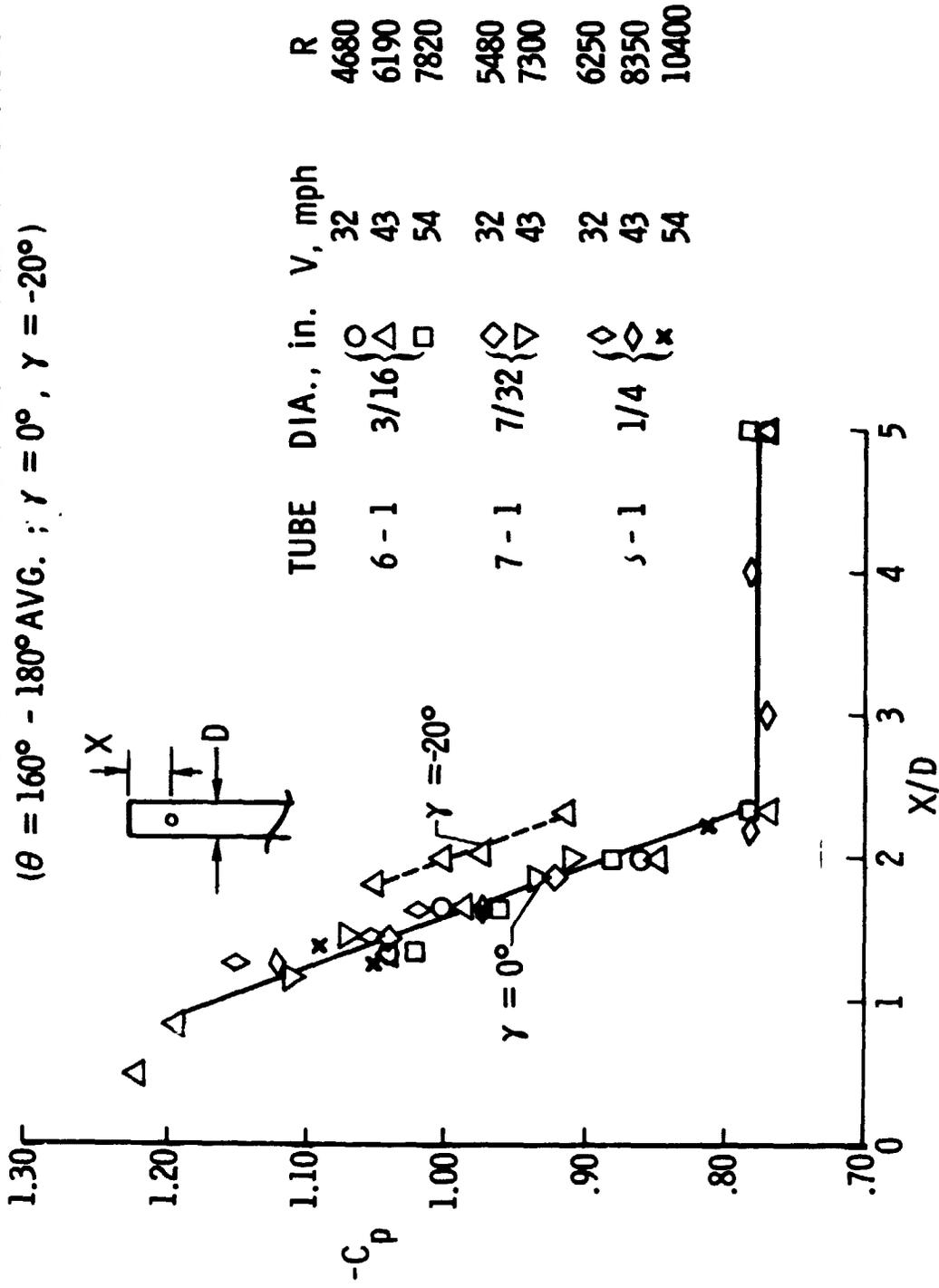$(\theta = 160° - 180° \text{AVG.} ; \gamma = 0° , \gamma = -20°)$

FIGURE 7

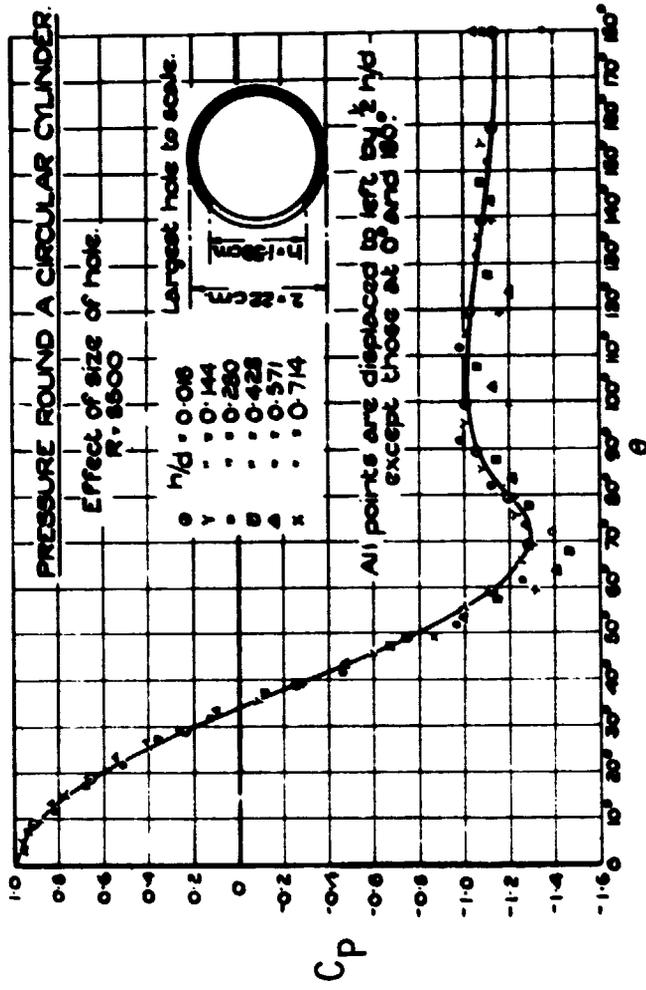# EFFECT OF HOLE SIZE ON PRESSURE COEFFICIENTS

(REF. 8)

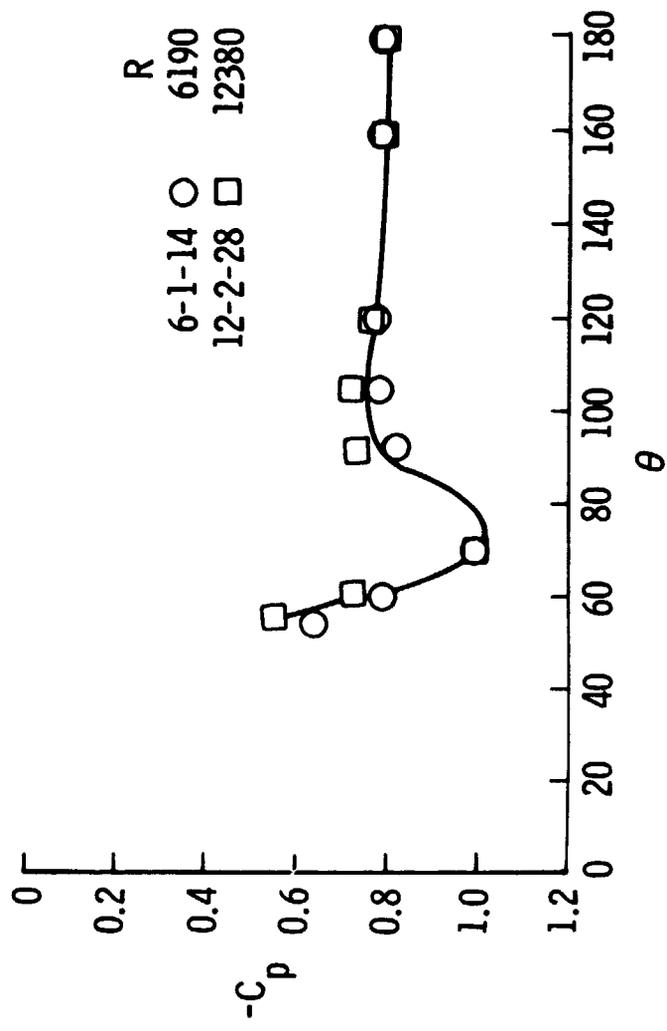FIGURE 8

EFFECT OF REYNOLDS NUMBER ON PRESSURE COEFFICIENT

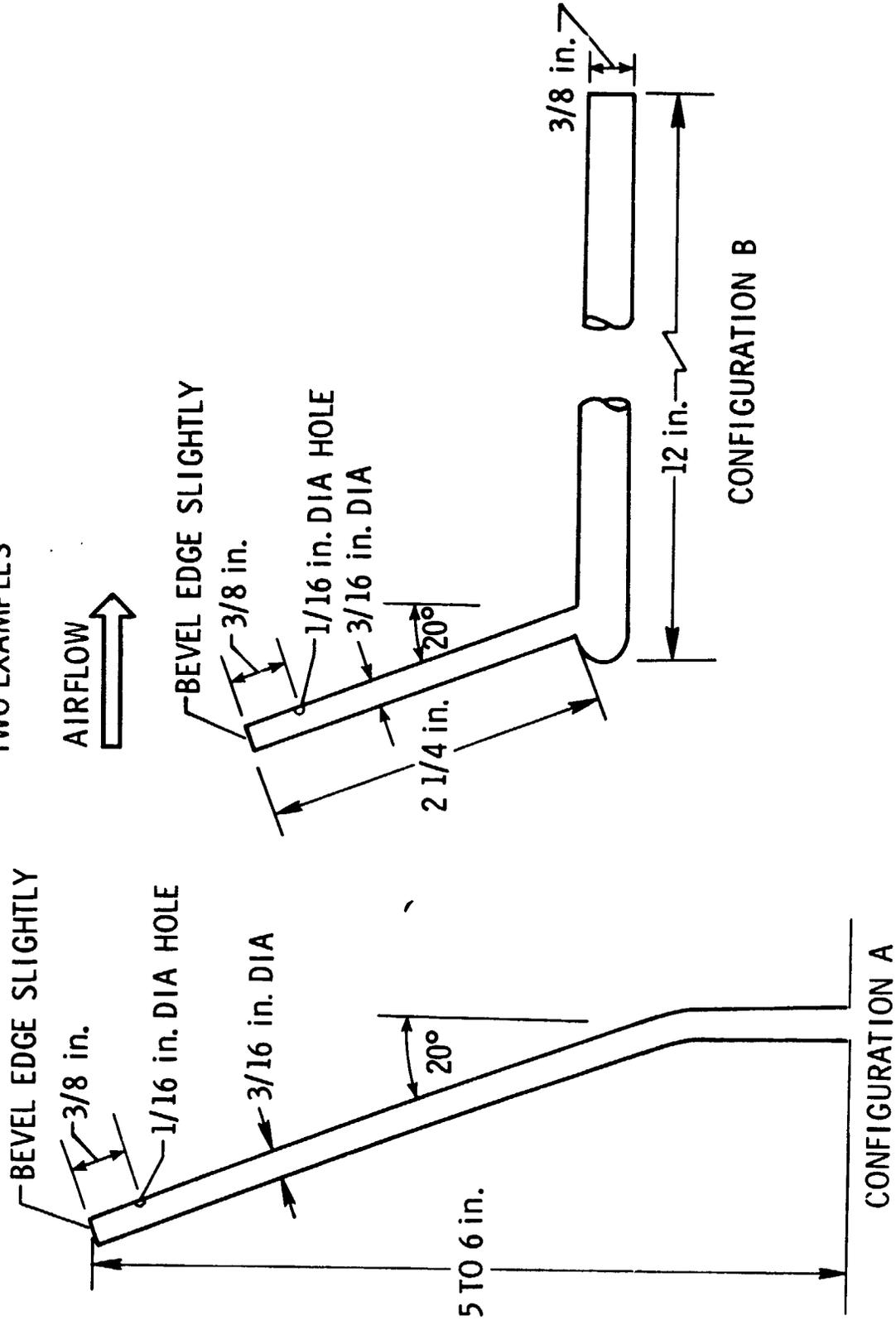FIGURE 9

TOTAL ENERGY SENSORS TESTED
TWO EXAMPLES

AIRFLOW →

BEVEL EDGE SLIGHTLY
3/8 in.
1/16 in. DIA HOLE
3/16 in. DIA
20°
5 TO 6 in.

CONFIGURATION A

BEVEL EDGE SLIGHTLY
3/8 in.
1/16 in. DIA HOLE
3/16 in. DIA
20°
2 1/4 in.
12 in.
3/8 in.

CONFIGURATION B

FIGURE 10