PIBAL-141

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CONTRACT No. N6ORI-98
TASK ORDER II
NR 220-039

TECHNICAL MEMORANDUM No. PIB-11

PROJECT SQUID

FINAL REPORT OF PHASE I

by

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POLYTECHNIC INSTITUTE OF BROOKLYN

DEPARTMENT OF

AERONAUTICAL ENGINEERING AND APPLIED MECHANICS

15 SEPTEMBER 1948

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Phase I. Problem No. PIB-1R1

Experiments with Sleeve Valve Pulse Jets without Combustion.

Air intake through automatically working reed valves, as used on pulse jet engines, is restricted and inefficient. Operating life of the reeds is short because of fatigue failure. These two disadvantages of the conventional valve mechanisms prompted the idea of developing rotating sleeve valves, which would work either automatically or by some driving device. The valve openings were placed on the circumference of the combustion chamber wall, where, with proper design of the air intake ducting, any percentage of the combustion chamber frontal area could be opened for air intake. Furthermore, in order to approximate constant volume combustion, it was intended to place rotating sleeve valves also at the down-stream end of the combustion chamber. It was, however, recognized that the development of the "exit" valves was especially difficult, since the operating temperatures would necessarily be much higher than those at the entrance. Hence it was decided to concentrate first on the intake valve development.

In order to find the necessary operating tolerances and the optimum slot sizes for such a valve mechanism it was decided to have the first model, which was to be tested in our wind tunnel, machined and to prepare the second model for the hot tests up to a semi-final machined state. Extensive investigations and especially Mr. F. Parker's recommendation pointed to the ITE Circuit Breaker Co., in Philadelphia, Pa. as the most suitable contractors for the machining of the model. This organization had great experience in the design and machining of high speed stainless steel compressors and turbine parts. Another decisive factor was the very low cost estimate given by this firm. A visit to this company convinced us that it was well equipped and eager to undertake the work.

Extensive delays in delivery and very unsatisfactory machining and assembly of the cold model necessitated dis-assembly, redesigning, and remachining of the model. Thus our test program was retarded and a high additional cost of the model resulted.

Whipple & Co. of New York, the second lowest bidders, have done the remachining and reassembly of the cold model in a very satisfactory manner.

The delays mentioned above and the early termination of the contract on the part of Squid did not allow time for carrying out the extensive testing program planned with the cold model; thus no conclusive results can be reported, although every effort was made to determine the pressure and velocity distributions for at least two intake slot sizes.

The installation of the cold model in the wind tunnel is shown in Fig. 1. This figure does not show the valve driving mechanism, a variable speed motor driven flexible shaft, which together with the apparatus and the electrical equipment, is shown in Fig. 2.

The engine drag was measured at various tunnel speeds with the valves in two stationary positions, i.e. valves open and valves closed, as well as with rotating valves. The results of these measurements are shown in Fig. 3.

Fig. 4. shows a schematic drawing of the test model with the points where pressure and velocity measurements were planned. Statham strain gage-type pressure detectors were to be used for the pressure distribution at various points of the engine, while the hot wire equipment was to be used for the determination of the velocity distribution at the indicated cross sections.

The above named tests were planned to be carried out with various air intake slot sizes and various intake duct configurations. Variation of tail pipe length was also contemplated in order to find the correct length corresponding to cold resonation. Only the minimum and the maximum slot sizes could be tested in a preliminary fashion, and no other intake duct configuration but the one designed for high speed air flow could be tested because of lack of time.

Phase I. Problem No. PIB-1R2

Experiments with Sleeve Valve Pulse Jets with Combustion.

The first model was designed with rotating sleeve valves for air intake only. The reason for this decision was explained in PIB-1R1, i.e. in the previous chapter.

After successful elimination of any difficulties with this first model it was contemplated to design and to build a second model which would employ exhaust valves as well as entrance valves for the purpose of producing constant volume combustion.

A test model, similar to the one used for the cold tests, had also been ordered at I.T.E. Circuit Breaker Co., Philadelphia, Pa. The latter model was not completely machined on the outside surface of the combustion chamber and on the inner surface of the rotating sleeve valve since it was thought necessary to await experience gained from the cold test model before determining the necessary clearance between these two surfaces.

After the decision of the Policy Committee to discontinue work on the hot-test model, work on this model has been suspended, and the engine is being stored at present in its half-machined condition at PIBAL.

In order to be able to measure the actual developed thrust of a pulse jet engine, which would be needed for comparison with any theoretical results, a new type of pulse jet suspension, together with instrumentation and equipment had to be developed. A small-scale test stand incorporating all the features of a full-scale thrust measuring stand has been designed and built. Calibration of the equipment and thrust measurements on a Dyna-jet have been made with very promising results. The suspension, the thrust measuring equipment, and the results of calibrating and thrust measurements are described in Technical Memorandum PIB-9 "Application of Dynamic Strain Gages to the Measurement of Continuous and Average Thrust of Pulse Jet Engines", by Paul Torda, Walter Ira Weiss, E. Schatzki and J. Lovingham.

Phase I. Problem No. PIB-1R3
Development of a Pressure Gage for Measurement of Continuous Fluctuations with Minimum Time Lag.

Intensive investigations of available dynamic pressure detectors (gages or transducers) have shown that the strain gage type would be well suited for measuring continuously varying pressures in a chamber. The strain gage type pressure detectors, manufactured by the Statham Laboratories in California seem to be particularly promising for such applications. Preliminary investigations of such gages have shown that unless the parts of the gage are correctly assembled, the gage is vibration-sensitive. [Through the cooperation of the Statham Laboratories the vibration sensitivity of the gages was reduced and the development of a high temperature pressure detector was started.]

A detailed critical survey of available pressure detectors and the mechanical and electric equipment used in connection with the Statham pressure gages at this Institute is presented in Technical Memorandum PIB-6 "Application of Statham Pressure Transducers to the Continuous Recording of Instantaneous Pressures", by W. I. Weiss.

A detailed survey of calibration methods of dynamic pressure detectors has shown that no standardized procedure has been used by various research groups in the pulse jet-field. To satisfy this need, calibrating procedure and calabrating equipment have been developed at this Institute. This method and a description of the apparatus used have been reported in Technical Memorandum PIB-8 "Calibration Method and Equipment for Dynamic Pressure Dectectors", by Paul Torda and Walter Ira Weiss.

Phase I. Problem No. PIB-1R4

Investigation of Inflow Through Periodically Opening Valves.

A detailed analysis has been made of a compressible air inflow through automatically operating reed valves as used in pulse jet engines. An exact, and, as well, an approximate theory, both of which are applicable to reed valve design, have been worked out at this Institute. It has been found that much more time would have to be spent on laborious computations in working out numerical examples before the exact theory could be applied for design. Therefore the approximate theory has been developed, and its results compared with those obtained by the exact theory. The results compare sufficiently well, and hence it is thought that the approximate theory can be used by designers without undue difficulty. Three technical reports have been published covering this work. They are:

Technical Report No. 9, "Compressible Flow Through Reed Valves for Pulse Jet Engines. I - Hinged Reed Valves". By Paul Torda and I. P. Villalba, and J. H. Brick.

Technical Report No. 10, "Compressible Flow Through Reed Valves for Pulse Jet Engines. II - Clamped Reed Valves", by Paul Torda.

Technical Report No. 12, "Approximate Theory of Compressible Flow Through Reed Valves for Pulse Jet Engines", by Paul Torda.

Phase 1. Problem No. PIB-1R5

Measurement of Rapidly Varying Temperatures by Ultrasonic Pressure Waves.

The knowledge of instantaneous gas temperatures in the combustion chamber and in the tail pipe is of great importance in the investigation of pulse jet engines. Conventional temperature measuring methods do not lend themselves to the above named investigation because of their large time lag and their relatively large size. Professor I. Fankuchen suggested the use of an ultrasonic beam of rays to measure the instantaneous temperatures in the combustion chamber of the jet engine. This method involves a negligible time lag and does not interfere with the gas flow.

The investigations were carried out as follows:

1. Development of an experimental supersonic vibrator to facilitate final design of the transducer.
2. Investigation of energy transmission in turbulent flow.
3. Construction of the final transducer.
4. Measurement of instantaneous temperatures in the combustion chamber.

After the completion of the development of an experimental supersonic vibrator to facilitate final design of the transducer the investigation of energy transmission in turbulent flow was negative, which therefore eliminated the construction of the final transducer. Further consideration of the measurement of instantaneous temperatures in the combustion chamber indicated that the variables involved in the measurements would not be separable, and hence, that even if it were possible to transmit appreciable energy through the combustion chamber, the results would still be a function not only of the temperature but also of an inseparable function of the velocity and density of the combustion gases.

Phase I. Problem No. PIB-1R6

Unified Pulse Jet Theory

This work was undertaken in February 1948 in an effort to satisfy the request of the Office of Naval Research to develop an approximate but still essentially reliable method of predicting the performance of pulse jets of different design.

Besides this purpose, it was expected that a basis might be provided for coordinating the numerous and often disconnected experimental data on flame propagation and the travel of discontinuity surfaces in the combustion chamber with an overall theory for pulse jet engines.

A special procedure of a semi-inverse method assuming a one-dimensional turbulent flow through the duct was found for the analysis of the effect of combustion, conduction, and convection on the waves in the combustion chamber and tailpipe both of constant or varying cross section.

Different types of mass waves, i.e. mass flow multiplied by area, $\rho \mathbf{A} = f(x,t)$ were chosen for this method, partly based on data of experimental publications and partly based on appropriate reciprocating mass flow functions.

In this way:

The velocity wave function follows from the mass wave function by the quadrature integration of the continuity equation.

The pressure wave function follows from the quadrature-integration of the dynamic equation of flow.

The temperature wave function is given by the quotient of pressure wave and density wave.

The total heat input is derived from the energy equation, which contains the functions, determined above, of pressure temperature and density.

The net heat input of fuel combustion and eventually of leakage (negative) is derived by the subtraction of the contributions of convection and conduction of heat.

Until now, three wave patterns (ρA) have been assumed, namely:

(1) A wave merely outflowing, such as to describe the first start of the pulse jet.

(2) A starting mass wave.

(3) A reciprocating mass wave as has been observed through the window of an operating pulse jet model.

The method of starting on the basis of an expected mass wave, in order to derive from it step by step velocity, temperature, pressure, heat input, and thrust function, has the great advantage of integrating exactly by quadratures, without the necessity of linearization.

A Technical Report on case 1 was finished, but is not yet finally edited.

A Technical Report No. 13 on case 2 was submitted in July 1948, under the title "On Time and Space Functions of Heat Input necessary to Produce, in a Tube, Waves of Density, Velocity, Pressure, Temperature, Momentum and Periodic Thrust of Required Character", by H. J. Reissner. It gives the explicit analysis and numerical examples in dimensionless form, so that each of the 6 variables indicated above are represented as functions of time and space by sets of curves.

A Technical Report on case 3 has been started, but its completion depends on a final decision of the Office of Naval Research. It might be added that the above procedure described in several progress reports and in Technical Report No. 13 does not in any way overlap the investigations undertaken at the other places concerning shockwaves and flame propagation, but must, as mentioned above, rather be judged as a substratum in which the many scattered phenomena might be correlated.

Phase I. Problem No. PIB-1R7

Measurement of the Temperature of Inner Walls by X-Ray Diffraction.

This Problem will be continued under Phase 3.

Phase I. Problem No. PIB-1R8

Development of Improved Techniques for the Measurement of Gas Densities by X-Ray Absorption.

This Problem will be continued under Phase 3.

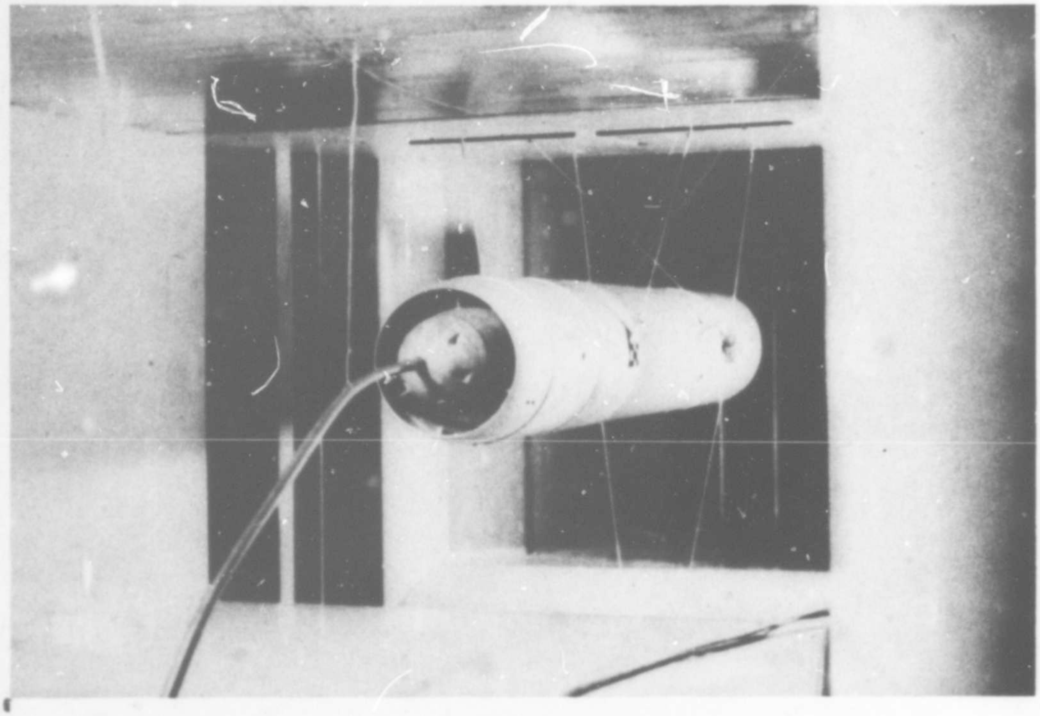


FIG. 1a

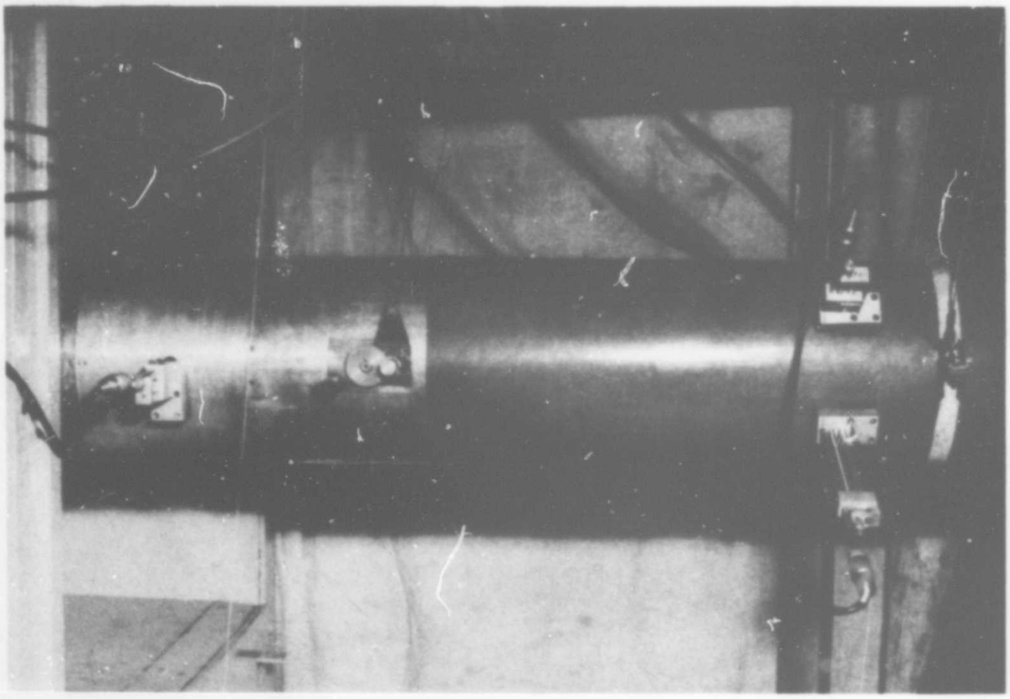


FIG. 1b

COLD MODEL INSTALLATION
IN THE WIND TUNNEL

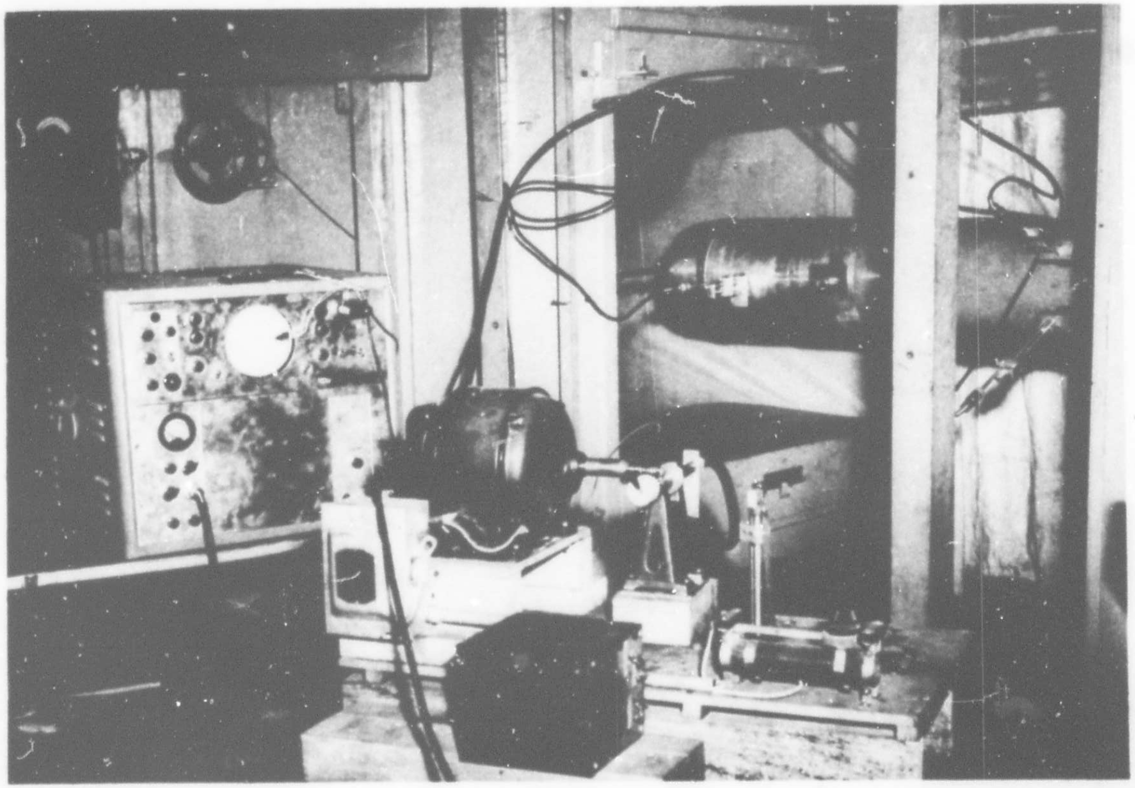
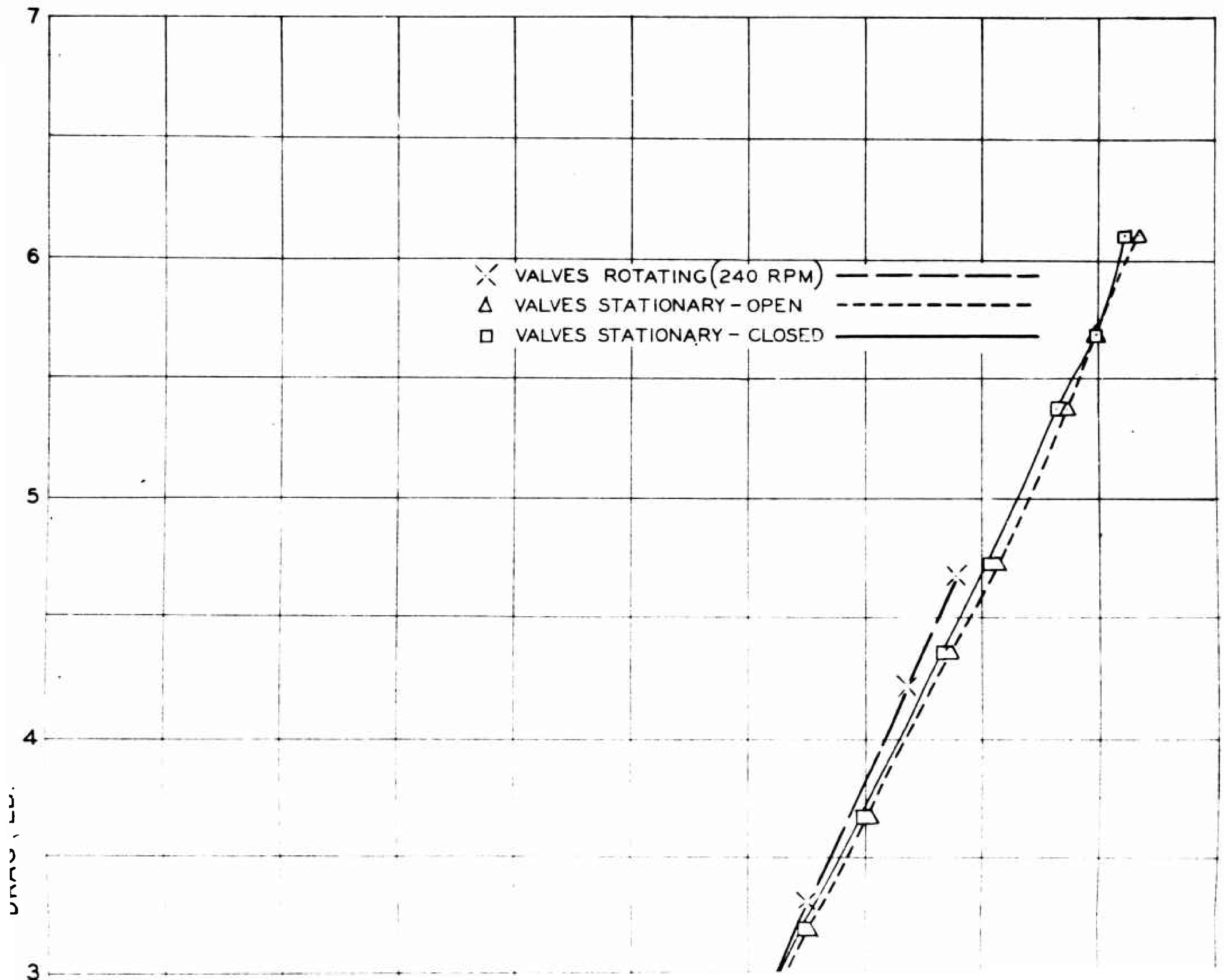


FIG. 2

COLD MODEL MOUNTED IN THE WIND TUNNEL, SHOWING DRIVING MECHANISM, INSTRUMENTATION, AND ELECTRICAL APPARATUS.



7
6
5
4
3
DRAG, LB.
VALVES ROTATING (240 RPM)
VALVES STATIONARY - OPEN
VALVES STATIONARY - CLOSED

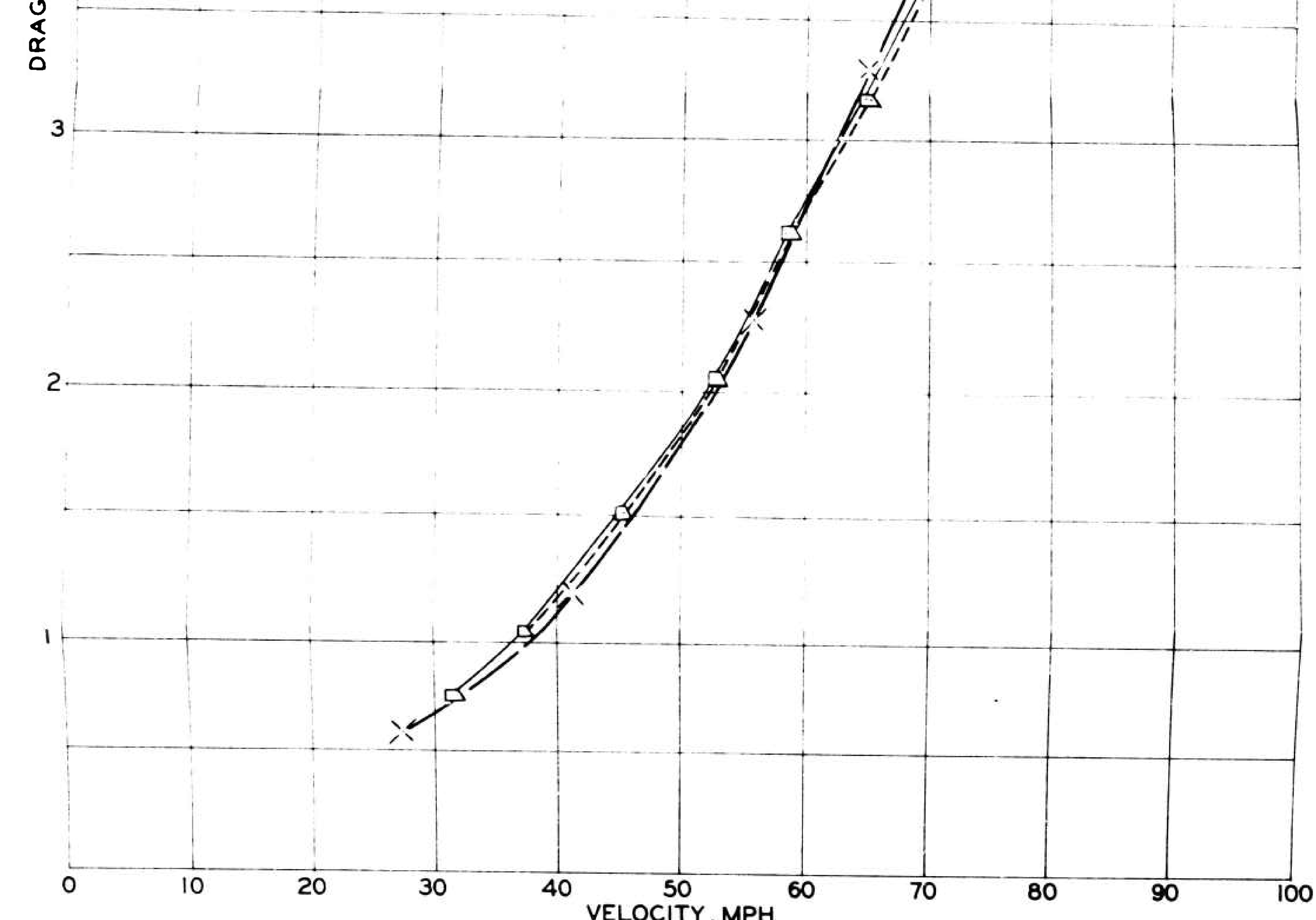
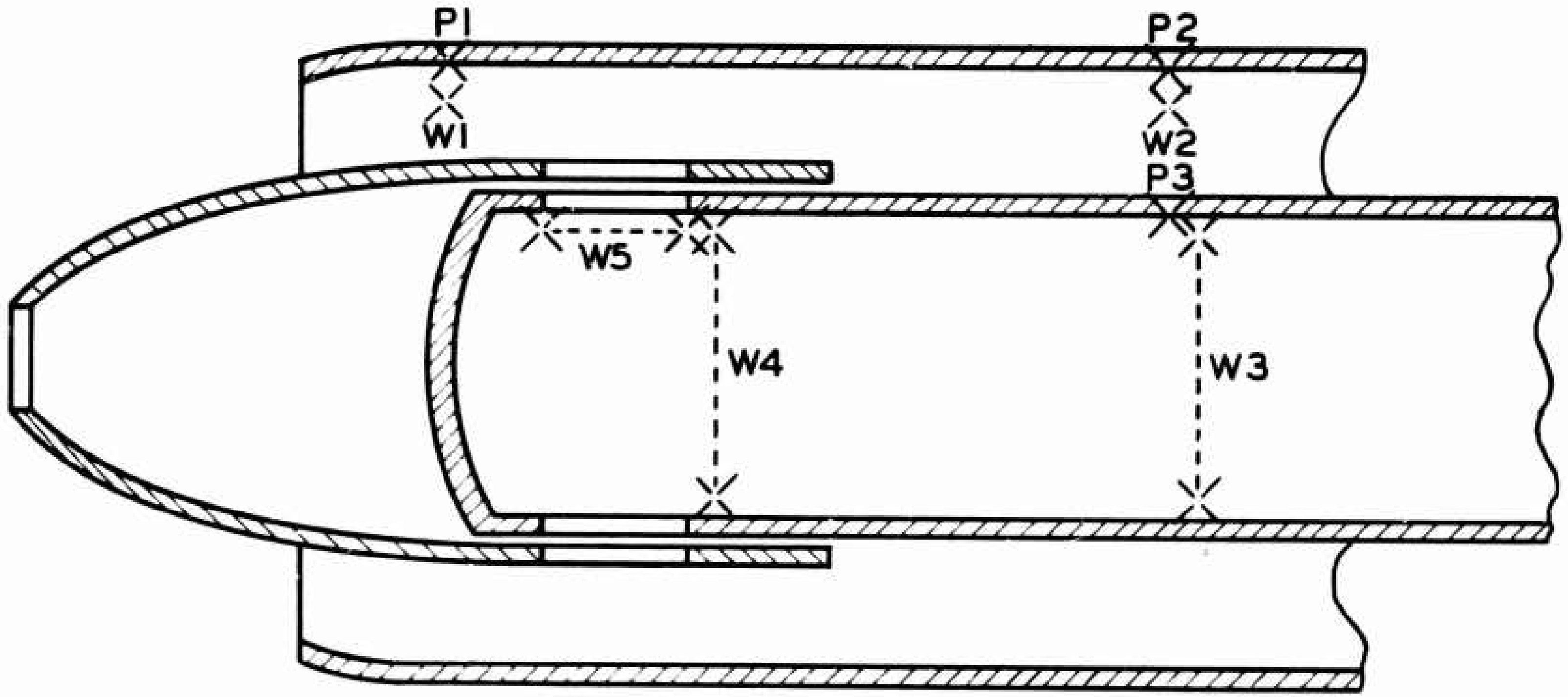


FIG. 3. DRAG OF ROTATING SLEEVE VALVE ENGINE
(SMALLEST SLOT OPENINGS)



W - HOT WIRE		P - PRESSURE DETECTOR	
W1	INTAKE VELOCITY	W2	COOLING VELOCITY
W3	VELOCITY ACROSS COMBUSTION CHAMBER	W4	VELOCITY ACROSS COMBUSTION CHAMBER
W5	VELOCITY ALONG COMBUSTION CHAMBER PORT	P1	WALL PRESSURE AT INTAKE
P2	WALL PRESSURE IN COOLING JACKET	P3	WALL PRESSURE IN TAIL PIPE

FIG. 4 SCHEMATIC DRAWING OF TEST MODEL

TYPE OF MEASUREMENTS CARRIED OUT AND THEIR LOCATION ON THE MODEL