INSTRUMENT RESEARCH

Temperature

Speakers: Isidore Warshawsky
Clarence C. Gettelman
Marvin C. Scadron

On your tour through the laboratory, you will have noticed that the words "pressure," "temperature," "flow," "speed," "thrust," occur over and over again in our discussions. These quantities are the fundamental variables that ultimately determine the range, the speed, the economy, and the efficiency of an airplane or an engine. They are the fundamental quantities that we actually measure in our research on engine performance and the accuracy of our research results can be no better than the accuracy of our measurements of these fundamental quantities.

Now, just as our research covers new fields, fields not previously explored, so must we be able to make measurements under conditions not previously encountered. And just as our research must be performed before the complete engine or the complete airplane can be designed and constructed, so must our instruments and our measurement techniques anticipate the requirements of our own research.

On your tour, you will see or have seen many completed instruments that we have already devised and that are now in routine use in our research. But now we would like to

show you some of the devices and techniques that are currently being worked on. We've selected only a few -- a representative sampling. I would like to present two developments in temperature measurement -- one fairly well completed, the other one just being started. Mr. Jaffe will then present a flow metering development, also fairly well completed. Mr. Sharp will present some new techniques in data reduction, with particular emphasis on pressure measurement, that are in the prototype stage.

Now, regarding temperature; more particularly, gas temperature. There are various methods of measuring gas temperature; the simpler ones use devices like thermocouples, that are inserted into the gas, are supposed to acquire its temperature, and that generate a voltage proportional to the temperature; more complex types are the optical methods, which measure the energy radiated by the gas, and the pneumatic types, that measure gas pressures as a means of deriving the gas temperature.

Although our temperature measurement research covers all of these methods, today I'd like to present just two phases of our progrm --- and both of these phases are concerned with thermocouples -- because the thermocouple has the advantage of being inexpensive, reproducible, compact, easily replaced; and because it provides the type of indication that we desire most from the standpoint of thermodynamic theory.

Now among the things we want in a thermocouple are that it shall be strong enough to stand mechanical handling, that it shall be light enough to respond quickly when the temperature changes, and that it shall not melt at high temperature.

Let us first discuss the problem of fast response. In order that we shall be able to observe or to control engine temperatures effectively, the temperature of the thermocouple must follow any fluctuations in the temperature of the gas, with minimum delay -- in other words, the thermocouple must have low lag. Consequently, it would ordinarily be made of fine wire so that it would have small mass and therefore be able to heat or to cool rapidly. Unfortunately, however, such a design would not allow the thermocouple to have the mechanical strength and the long life that we feel it should have. If we made it massive enough to be mechanically strong, its thermal lag would be excessive. Now the contribution we have been able to make on this problem consists of two parts: mechanical design, and electrical lag compensation.

A promising mechanical design is a simple butt-welded bare wire thermocouple in the form of a loop, as shown in figure 1. There is no excess mass here to cause high lag, as is found in some designs now in use. We have been able to acquire sufficient fundamental information regarding

the basic nature of the heat-transfer process between the thermocouple and the gas, to be able to predict fairly accurately the lag of a thermocouple of this design, and this lag is only moderate even if we make the wire quite massive in order to have it mechanically strong.

In addition to this mechanical design we have been able to devise some rather simple electrical lag-compensators, such as these over here, that effectively reduce the thermal lag of the thermocouple by factors that are sometimes as high as 40. Briefly, these compensators work in the following way.

If the gas temperature changes from one value to another, the thermocouple is unable to follow the temperature of the gas. But the compensator takes cognizance not only of the thermocouple temperature but also of the rate at which it is changing and of the direction in which it is heading - and in a manner of speaking, the compensator output gets there first, ahead of the thermocouple, and indicates the gas temperature, rather than the thermocouple temperature.

To illustrate the action of one of these compensators, we have in this flame a thermocouple whose electrical output is being fed to this recorder. Beside the flame is a jet of cold air issuing from this tube. If we suddently insert the thermocouple into the cold jet, you will see that without benefit of compensation, it takes an appreciable

time for the indication to reach its final value. Now let us repeat the experiment, but this time pass the thermocouple output through the compensator. You see that it takes considerably less time for the indication to reach its final value.

Another way we can demonstrate the effectiveness of electrical lag compensation is to subject the thermocouple alternately to these hot and cold jets. You will remember that the temperature of the hot jet corresponds to this point on the indicator; the temperature of the cold jet corresponds to this point on the indicator. First, let us try it without the compensator. If we oscillate the thermocouple between the two jets you will notice that the amplitude of oscillation of the pointer is very small. In other words, the faster the temperature changes, the less able is the thermocouple to follow these changes because of its thermal inertia or lag. Now let us insert the compensator. You see that the amplitude is restored to close to its original value and remains close to its original value as we reduce the frequency of oscillation.

Now the comination of this mechanical design, with moderate lag and fair mechanical strength, and this electrical compensation for whatever lag this design does possess, does give a good compromise between the rather contradictory demands of high strength and fast response.

So much for the problem of thermal lag. The second problem I would like to discuss is the measurement of high gas temperatures -- temperatures ordinarily considered beyond the range of thermocouples. For standard industrial thermocouples this upper limit is about 3000° F, which is close to the melting point of platinum and platinum is the thermocouple material ordinarily used to measure the highest temperatures. This 3000° F limit is being exceeded in much of our current research so that the problem is a rather important one. Now, for the solution of this problem, there seems to be some merit in the high-temperature thermocouple design whose basic principle is shown here. We take a butt-welded loop thermocouple, make its leads out of tubing, and run sufficient cooling air through these tubes so that, by conduction along the wire, the junction is kept at a constant temperature, well below the melting point of the wire. In other words, we deliberately introduce an appreciable temperature gradient along the wire, with the temperature being hottest at the junction, and tapering off toward the supports. We determine the magnitude of this gradient by auxiliary thermocouple wires welded at these points. At a given air pressure and velocity, this gradient is a direct function of the gas temperature because, as the gas temperature goes up, the gradient must be made steeper in order to keep this central junction at the same temperature. From the fundamental relations between heat transfer rates on the one hand and gas pressure

and velocity on the other hand -- the same information that we used in our lag work -- we appear to be in position to write down the relation between the true gas temperature and this temperature gradient for a given set of aerodynamic conditions.

And so, if we complete the design by providing an air-cooled shell as shown here (fig. 1) (and this shell can be of brass rather than of a critical high-temperature material like inconel) we have a thermocouple which appears able to measure temperature beyond the melting point of the thermocouple wire.

I have here a working model of a high-temperature thermocouple of this design. When I insert the thermocouple into this flame, this instrument, which is both an indicator and a controller, will indicate the temperature of this junction and will act to keep the junction at about 2700° F, well below the melting point of the wire.

At the same time, this instrument measures the temperature difference between these two points (this temperature gradient) and its scale has been marked off to indicate the corresponding gas temperature of this particular flame and you see that temperature is about 4000° F.

This concludes the portion of the demonstration concerned with temperature. I would like now to introduce Mr. Jaffe, who will discuss the electromagnetic flowmeter.

Flow Measurement

Speakers: Leonard Jaffe
Charles Michels

In the application of rocket engines, one of the serious problems is unsteady combustion -- in other words, instability. This instability may bring about more rapid burnout of the engine. Fuel lines may be broken. In all cases of instability we suffer a great loss in efficiency. To investigate this instability and determine its causes, it is necessary to measure the instantaneous rate of flow of the liquid propellants while the engine is under test. Even in steady rocket operation fuel flow is one of the important quantities which must be measured accurately. Heretofore, we have used orifices and weight tanks to measure flow but these methods do not meet all of the requirements of an unstable engine test. Therefore, the Instrument Research Section started to develop a new type of flowmeter.

The ability to measure accurately rapid variations in flow is not the only requirement of a suitable flowmeter. Propellants are generally hazardous. In most cases, these fluids are unstable, corrosive, and toxic. An ideal flowmeter should be capable of remote operation. It must be able to withstand corrosion and it must be structurally strong enough to withstand the high pressures and other

severe conditions to which it must be subjected. The electromagnetic flowmeter shown here is our answer to this problem.

The arrangement of basic components of the electromagnetic flowmeter is shown on this chart (fig. 2). If you have a magnet and move a slab of conductor through the magnetic field you will have a voltage generated between these two edges of the slab. This voltage will be proportional to the velocity with which the slab is being moved. Now let us consider a stream of liquid conductor to be composed of many of these slabs. As the slabs pass through the magnetic field consecutively a voltage is generated in each one proportional to the velocity with which it is moving. This generated voltage is picked up by these two electrodes as each successive slab comes in contact with them. If we now continuously read the voltage appearing at these electrodes we will have a comtinuous record of flow of liquid through the magnetic field. You can see from this simplified drawing that there are no moving parts or restrictions in the flowmeter to interrupt the flow. In the actual instrument we use a cylindrical flow path. The rectangular flow path is shown here merely to facilitate explanation.

I said that the liquid must be an electrical conductor for operation of this electromagnetic flowmeter. This is true, but the liquid must not necessarily be a good electrical conductor. Liquids such as water acids, alcohol, and acetone are sufficiently good conductor, but hydrocarbons, in general

are not. We have reason to believe, however, that we will be able to contaminate hydrocarbon fuels so as to make them sufficiently conductive without altering the other properties of the fuel.

We have here an electromagnetic flowmeter for demonstration. The basic components are the same as those shown on the previous chart. It appears considerably more complicated because of this superstructure which holds our connecting wires in such a manner as to eliminate extraneous electrical voltages. We have the flow path here. This is the inlet and this is the outlet. Above and below the flow path we have coils through which current is passed to produce the magnetic field. This is a core of magnetic steel which acts as a guide for the magnetic field. The electrodes are not visible here but are positioned as was shown on the chart. Associated with the meter but not shown here is the electronic equipment necessary to produce the magnetic field and to measure the voltage picked up at the electrodes. Here we have a dial which indicates average flow and on this oscilloscope we will display the voltage output of the meter.

We are now measuring the rate at which water is flowing through the meter. In this meter we are using an alternating magnetic field, therefore the output voltage as seen on the oscilloscope is an alternating voltage. The width of the pattern or distance from upper peak to lower peak is a measure of the velocity with which the water is now flowing.

If I decrease the flow the width of the pattern decreases. This is the kind of pattern we would observe for a smoothly running rocket engine. We will now vary the flow of water very rapidly to simulate the type of flow occurring the fuel line to an unstable rocket engine.

A permanent record of flow is made by photographing the screen of the oscilloscope. A small section of a flowmeter record taken on an actual rocket is shown here (fig. 3). This time is 0.2 second. On these same strips of film we have recorded the chamber pressure of the rocket. In this case the rocket performed smoothly. A very stable run. No variation in either the fuel flow or the chamber pressure. In the second case we see the same type of record but of a highly unstable rocket engine. Both the fuel flow and rocket chamber pressure here are pulsing violently. A study of time relationships between the fuel flow and chamber pressure can be made from these records.

In conclusion:

The electromagnetic flowmeter has been used successfully in rocket research

It responds rapidly to variations of flow rate

It is insensitive to inlet and outlet conditions

It is adaptable to rugged construction

There are no moving parts or restrictions in the flow passage.

These advantages which we can apply to water, acids, alcohol, acetone, and which we hope to be able to spply to gasolines and oils make the electromagnetic flowmeter a very promising and useful tool.

Automatic Data Reduction

Speakers: Elmer Sharp
Bert A. Coss

Testing full-scale jet engines involves tremendous quantities of data. In such testing we must measure pressure and temperature at hundreds of locations in the engine. Representative samples of the instrumentation to make these measurements are shown on the J-35 engine on your left. Pressure probes and thermocouples such as these are installed at various locations in the engine. We have shown examples of installations at the compressor outlet, compressor inlet and at the tail cone. Using the data obtained from these probes we can calculate air flow in the engine, compressor efficiency, and thrust. Fuel flow is measured by means of the pressure drop across a calibrated orifice in this instrument. In an actual test setup there will be up to 300 pressures and 70 temperatures measured on each engine.

The conventional method of recording pressures is to connect them to a manometer board such as this. The difference in height between two liquid columns is proportional to the difference in pressure applied to them. The pressures here are measured in inches of mercury. The pressures displayed here are characteristic of the pressures which would be observed in an engine of the J-35 type flying at sonic velocity at 30,000 feet altitude.

When test conditions have been established the manometer board is photographed. Film records such as this are obtained. A computing staff reads these films with a magnifying glass, crecords the readings and performs the necessary calculations on the data. This process is long and tedious; it is also costly. Frequently there are long delays after the taking of data before it is ready for analysis by the research staff. At the present time we average about 10,000 pressure and 3,000 temperature readings daily. This takes a staff of 100 computers to process the present daily output of data. The expansion of test facilities now under construction will about triple our present daily output. It is readily apparent that we have to streamline our data taking and reduction methods. The actual calculation can be greatly speeded up by using punched card computers. We are presently processing some of our data by this method; however, the major bottleneck in this process is getting the data onto the cards.

On your right are prototype instruments which have been developed at this laboratory for the purpose of reading pressure and temperature data automatically and recording it in a form suitable for direct and automatic insertion into punched card computing equipment. This equipment relieves operators of the monotonous and time-consuming task of manually transcribing and calculating the thousands of readings daily.

In the automatic pressure recorder, pressures are measured by comparing them to an accurately measured variable reference pressure. In this simplified chart (fig. 4) we see how this is done. This is the primary pressure-sensing element. It is a very sensitive pressure switch. The test pressure is applied to one side of a flex diaphragm and a variable reference pressure is applied to the other side.

Initially we evacuate this tank containing the variable reference pressure. Since the pressure we wish to measure is greater than a vacuum it forces the diaphragm over, completing an electrical circuit. Also attached to this tank is the instrument which measures the pressure in the tank very accurately and sends out electrical pulses when the tank pressure is increasing. It send out one pulse for each 0.01 of mercury in rise of tank pressure. To record data we allow air to enter the tank and the pressure within it to rise. The pressure-measuring pulse generator continuously measures the tank pressure and sends out electrical pulses indicating how far the pressure in the tank has risen. These pulses are transmitted through the contacts in this capsule and counted. This continues until the tank pressure equals the pressure to be measured. At this instant the pressures balance in the capsule and the contacts open. The number of pulses which have been received at the counter is then a direct measure of the pressure in .0. of mercury. The pressure continues to rise and the

pressure-measuring pulse generator still sends out pulses, but they are no longer counted. The tank pressure is allowed to rise until it exceeds the highest pressure we expect to measure. At this point the cycle is automatically stopped and the tank is evacuated.

I have explained the operation for one pressure being measured. Actually there is nothing to prevent us from putting many of these capsules on the reference pressure tank and attaching a counter to each one. In fact, we have one capsule on the tank for each tube in this manometer board.

In the next chart (fig. 5) we see a schematic diagram of the entire system. Pressures from the engine are connected to the capsules by means of tubing. The electrical pulses from the capsules are temporarily recorded in a magnetic recorder which records the pulses from all of these capsules simultaneously. This magnetic recorder is similar in principle to the wire and tape recorders presently in common use, except that this recorder has 60 input channels. After the pressure scanning operation is complete, this takes about 10 seconds, that is when the pressure in the tank has risen to a value higher than the highest pressure to be measured, all the data are recorded, the recorded signals are played back, one pressure reading at a time, and counted. Information is sent from the counter to the coder where a tube number and a probe classification

code is added to the pressure reading. From the coder, information goes to two places. In the typewriter it is tabulated in a printed page so the actual pressure readings are available for examination almost immediately. Exactly the same information is also punched into a paper tape. This tape is used to automatically punch the cards for the calculators used to compute the data. These are the capsules which are connected to the pressure to be measured. They are attached to the variable reference tank. On top of the tank is the instrument which weighs the tank pressure and sends out electrical pulses. The magnetic recorder is located in the bottom of this rack. The pulses are counted in this counter as they are played back. The rest of the rack contains the coder, supervisory equipment, and power supplies.

This automatic pressure recorder will be installed within a few weeks at the 8- by 6-foot Supersonic Tunnel. Here it will record pressures from the ram jet engine you will see demonstrated there.

Temperature data are recorded on a punched tape in a form similar to the pressure data. The automatic temperature recorder reads thermocouple voltages. This machine punches its readings in the paper tape before stepping to the next thermocouple. You will notice flashing in the electron tubes as it steps from one reading to the next.

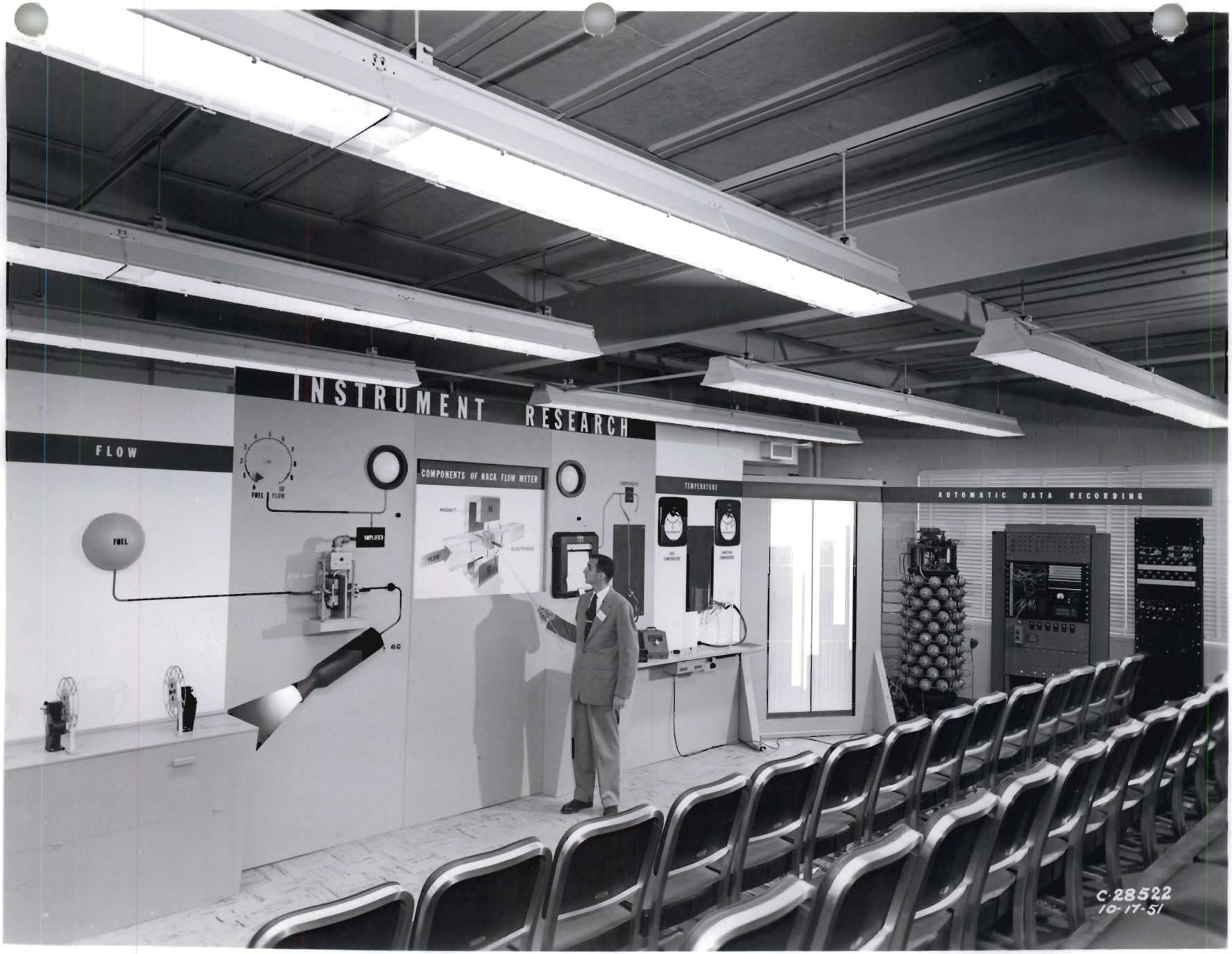
When the pressures have been recorded I will start the automatic temperature recorder. (Press button - 15 seconds.)

We have recorded 24 thermocuple voltages in about 15 seconds. We are tabulating pressure readings at the rate of one every 1.4 seconds.

Across the hall you will see punched cards being made from this tape and the calculating machines are computing air flow in the engine, thrust, specific fuel consumption, and compressor efficiency for a previous test. In about 15 minutes the data from this test will be computed and ready for analysis by the research staff.

The results of a previous test have been calculated and I have the results here. They are: thrust (_____), specific fuel consumption (_____), compressor efficiency, (_____), air flow in engine (_____).

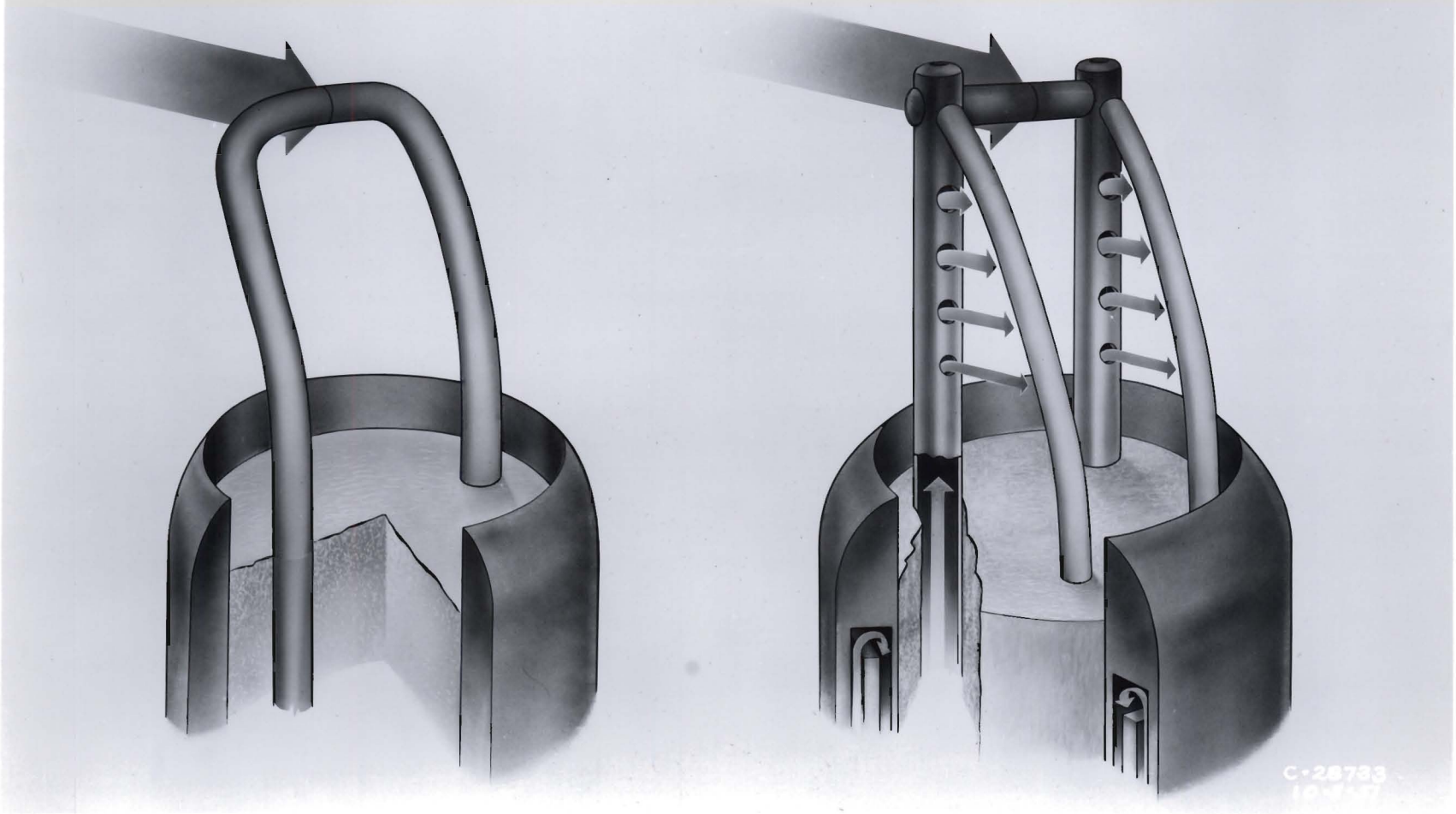
You are invited to examine the computing process and tabulated pressure data as you leave.


INSTRUMENT RESEARCH
FLOW
FUEL
AMPLIFIER
COMPONENTS OF NACA FLOW METER
MAGNET
FLOW
ELECTRODES
TEMPERATURE
AUTOMATIC DATA RECORDING
C-28522
10-17-51

NACA

FAST RESPONSE THERMOCOUPLE

HIGH TEMPERATURE THERMOCOUPLE



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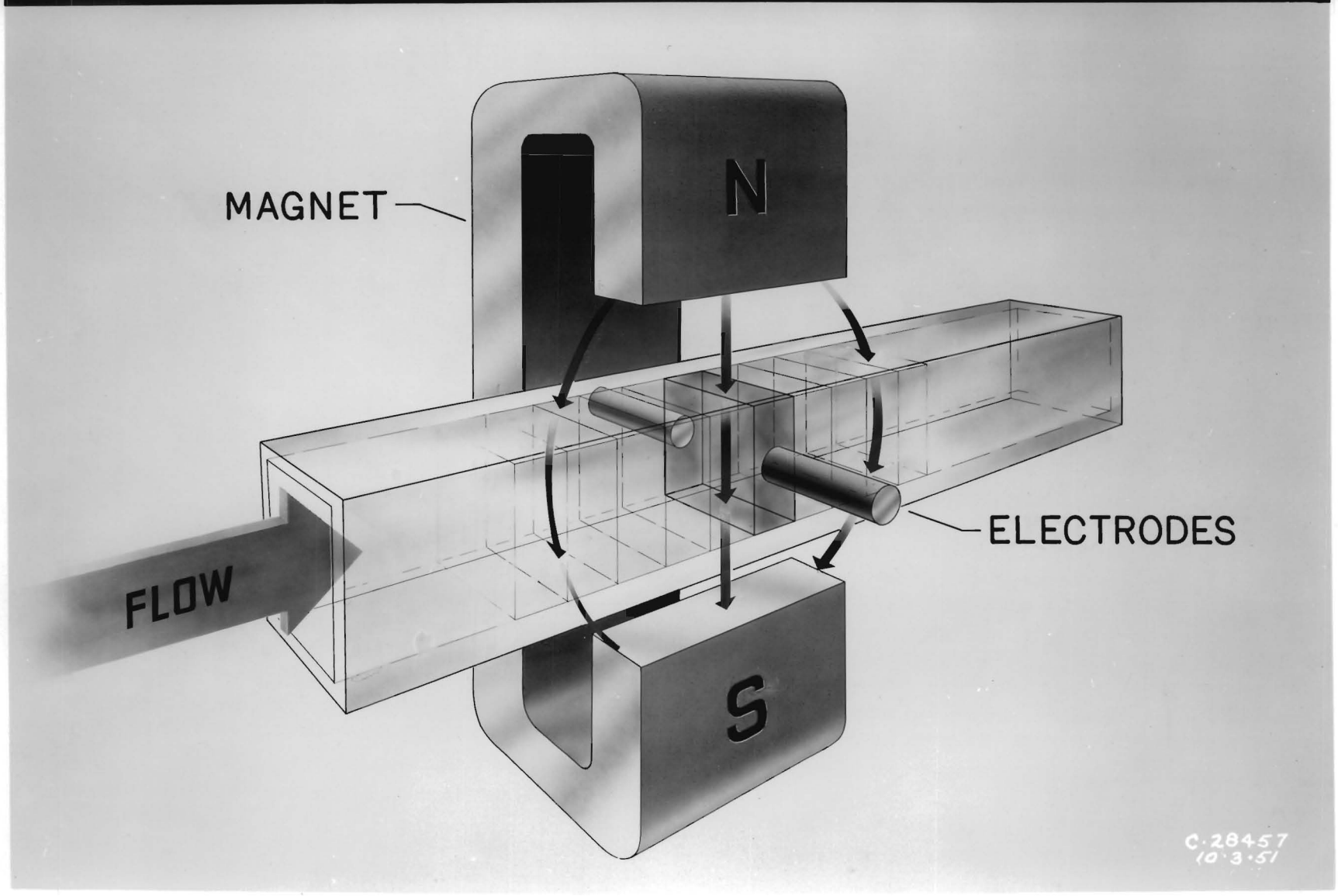
COMPONENTS OF NACA FLOW METER



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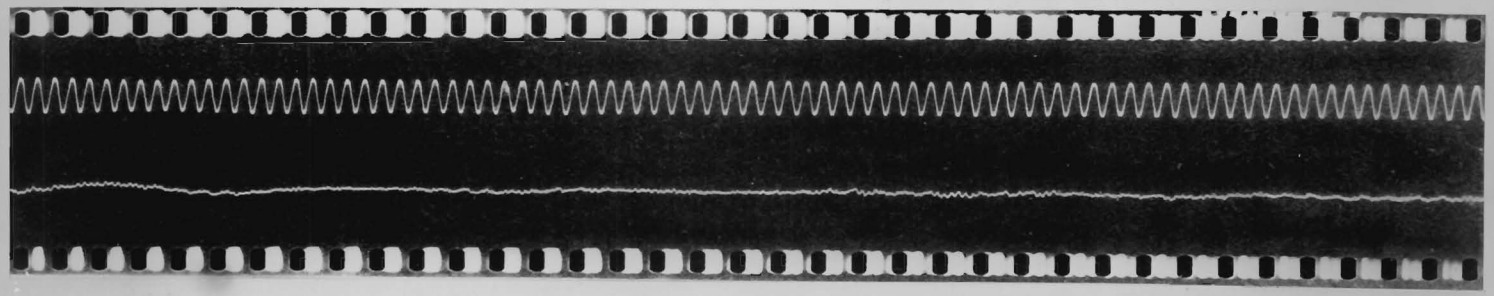
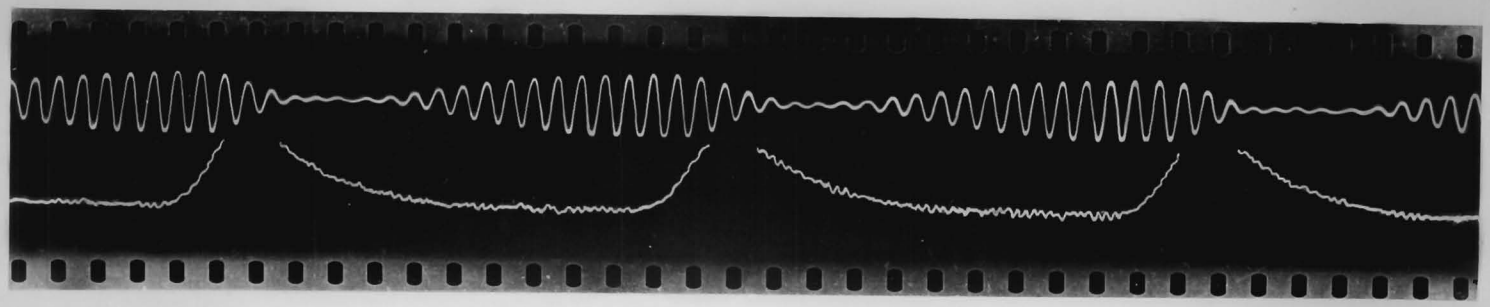
FLOW METER RECORDS OF ROCKET TESTS



SMOOTH RUNNING ROCKET



UNSTABLE ROCKET

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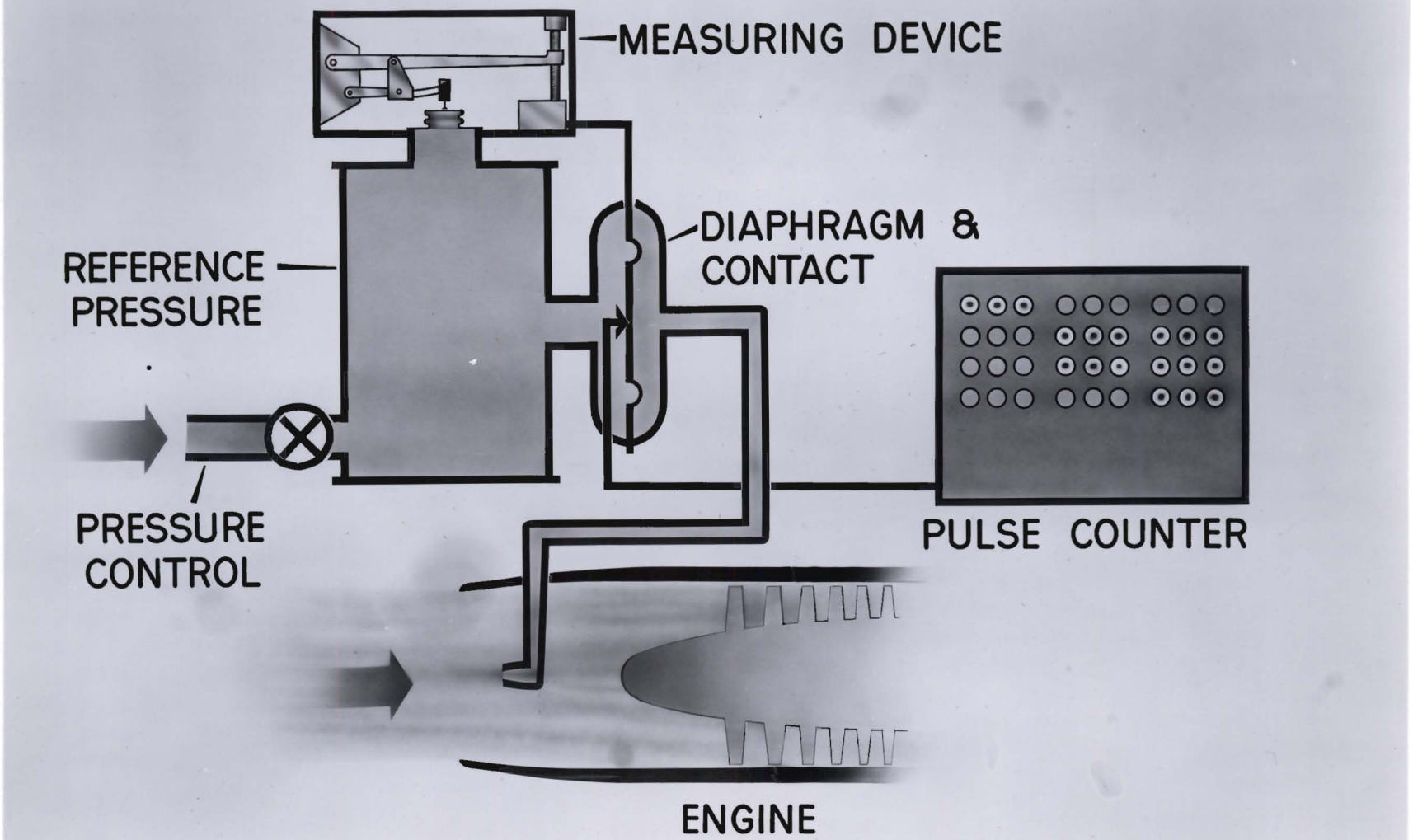
NACA

NACA AUTOMATIC PRESSURE RECORDER



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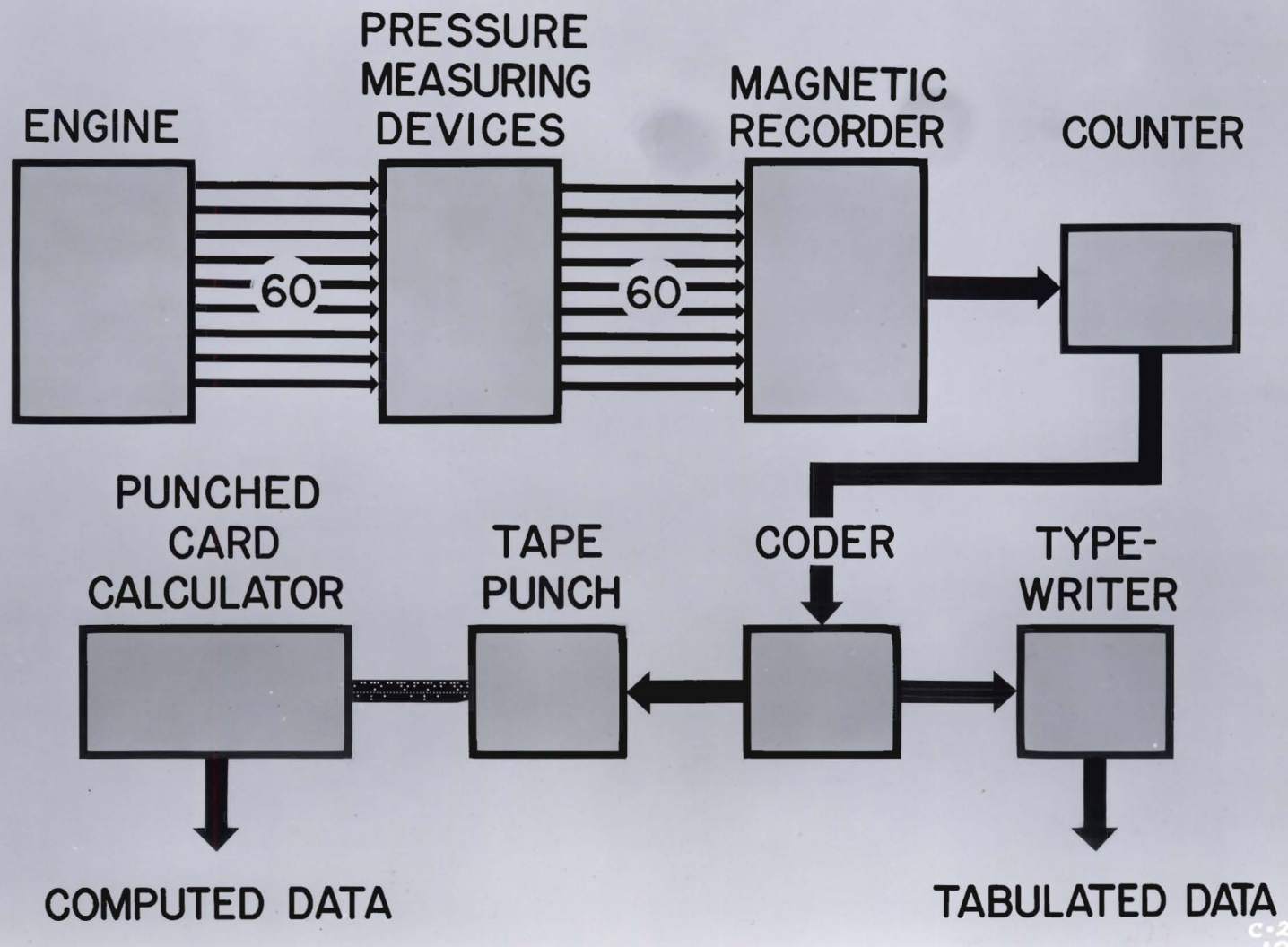
NACA AUTOMATIC PRESSURE RECORDING AND DATA REDUCTION



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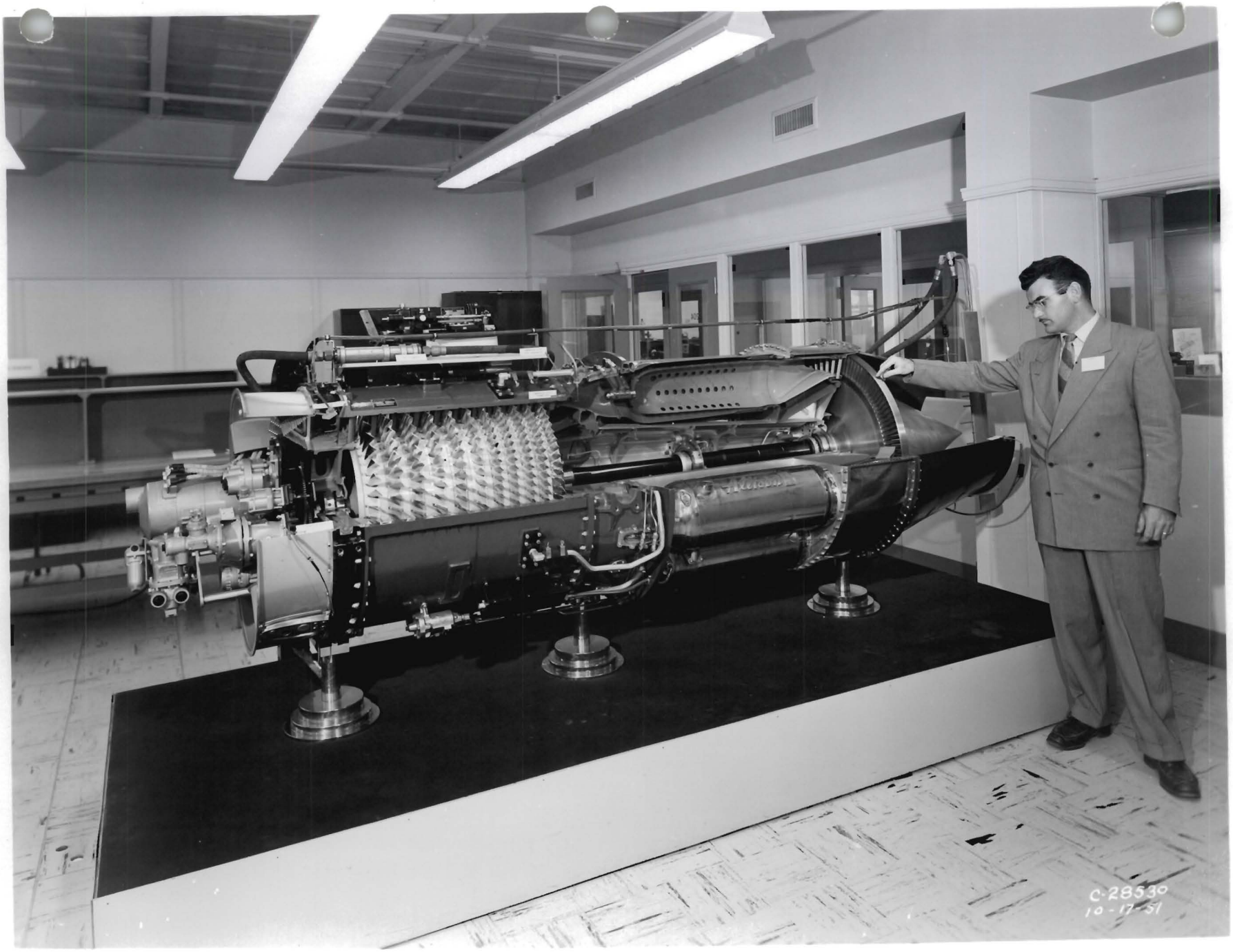

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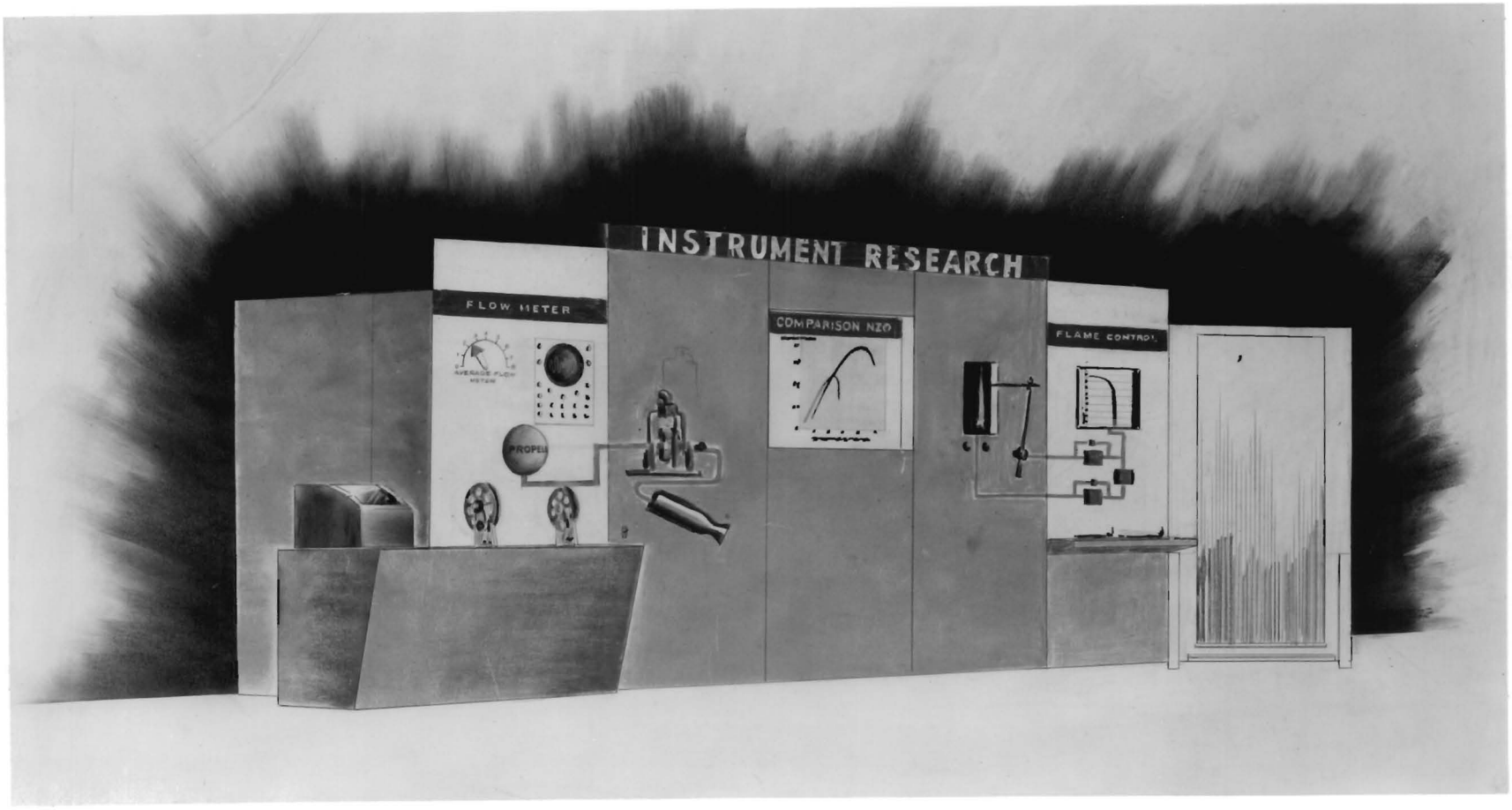
INSTRUMENT RESEARCH
FLOW METER
AVERAGE FLOW METER
PROPELL
COMPARISON N2O
FLAME CONTROL

NACA