PROPOSED TALK FOR HIGH-TEMPERATURE MATERIALS RESEARCH SECTION DEMONSTRATION AT MANUFACTURERS' CONFERENCE

by G.M. Ault

Jet propulsion for aircraft was delayed many years because there were no suitable high-temperature materials to withstand the temperature extremes encountered. The development of the "super alloys" made the jet-propulsion engine possible, but new and improved materials are still required to improve the performance of existing powerplants by permitting operation at higher temperatures. For example, as explained elsewhere today, the turbojet realizes higher thrust and the turbopropeller gains in efficiency and power output as operating temperatures are increased. Even if these better materials are not employed to enable the powerplant to operate at higher temperatures, these materials will increase service life and reliability in any case. At the present time the alloys in the jet-propulsion engine can be used at approximately 1500° Fahrenheit, and with further research in this field, the operating range of these materials can probably be extended a few hundred degrees. Many of these alloys were developed by industry under the sponsorship of the NACA Subcommittee on Heat-Resisting Materials.

Many of the materials now in use were developed during the war by cookbook methods and a part of the research on materials of the Committee is directed towards an understanding of how these materials work so that improvements based on fundamental factors affecting the operation of the materials can be made. Most of the super alloys use large quantities of scarce materials such as cobalt and columbium. In the case of a future emergency, sufficient quantities of these less abundant materials will pose a serious problem of supply. Consequently, part of the work of the NACA is directed toward reducing the use of these scarcer materials.

One method by which the resistance to temperature extremes can be increased is by the use of materials that can be cooled. An example of this is shown in the next demonstration. Here we have a material made by powder metallurgy methods of a copper-tin-bronze. This material was fabricated to have 30 percent porosity. As you can see the oxy-acetylene flame has heated the block to a red heat. We now direct an air stream into a header or hole 3/8 of an inch in diameter that has been drilled into the block. The porosity in the block will disperse and conduct the air stream in such a manner as to give effective cooling of the entire block. Ceramic and ceramal materials can be readily fabricated with almost any desired degree of porosity. A major problem in the use of porous materials is that of obtaining high porosity while retaining high-temperature strength. This problem is also under investigation.

As designers of jet engines want temperatures considerably beyond melting points of super alloys it is natural to turn to those materials having the very highest melting points. These materials are ~~such~~ high-melting-point metals such as tungsten and molybdenum and the oxides, nitrides, carbides, and borides of metals. This latter group are called ceramics.

The temperature scale along the top of this panel has on it some of the materials with which we are working. These materials are located at their respective melting points. The melting points of materials must be considered for the very highest temperatures of operation because they are indicative of the maximum temperatures to which the materials may be heated provided that stress conditions can be made to conform to the material limitations. From the chart we can see that high-temperature alloys have melting points of approximately 2400° F. These ceramic materials being considered run from this point upward to tantalum carbide at 7000° F.

In order to illustrate graphically some factors that enter into the performance of materials, I have here a simulated wheel segment on which are mounted three turbine blades. The first one is fabricated from a typical high-temperature alloy, the second one is a pure ceramic material, and the third one is a metal-bonded ceramic material which we have termed a "ceramal." The best combinations of pure ceramic materials for high-temperature use in turbines have been developed by the National Bureau of Standards under contract to the NACA. We now pass the wheel segment through the oxy-acetylene torches which are set to operate at approximately 2700° F. As you can see, the high-temperature alloy blade has been melted while the ceramic and ceramal blades are undamaged. The ceramal blade, however, possesses greater mechanical shock, particularly at elevated temperatures, because of its metal content. Ceramals may be considered to be suitable for many high-temperature applications, provided that the ceramic and metal constituents may be bonded successfully. Extensive investigations are under way here to determine the basic factors affecting the bonding and sometimes the wetting of the ceramic and the metal. Tools such as electron-diffraction instruments are employed to determine the nature of the layers existing on the surface of the particles of material that make up the ceramal. Photomicrographs are obtained at optical magnifications up to 1500 diameters to study the particles and the manner in which they bond. Ceramals are relatively new materials, but already they have shown excellent strength characteristics at elevated temperatures and we shall continue to investigate them as rapidly as possible.

Some ceramics and ceramals which have desirable high-temperature properties cannot be used because they have poor resistance to oxidation. In order to overcome this disadvantage we are coating these materials with protective ceramic coatings developed with the financial assistance and under the sponsorship of the NACA by the National Bureau of Standards. An example of the protection thus afforded is shown in the next demonstration. Here we have two bars of the same ceramic material, one of which has been given a protective ceramic coating. On the application of the oxy-acetylene oxidizing flame we notice that the bar that has not been protected oxidizes. This results in the materials growing, becoming porous, and losing its strength. The other bar, as you will see later, has retained its shape and has suffered no apparent loss in strength.

Another inherent advantage in ceramic and ceramal materials is their low specific gravities. Materials for high-temperature applications have specific gravities ranging from 7 to 8. Ceramics, on the other hand, have specific gravities ranging from 2 to 5 and ceramals are intermediate with specific gravities that range from 4 to 7. This results in two very desirable effects. First, the use of ceramics or ceramals would reduce the over-all weight of the aircraft propulsion system. Secondly, for applications where the stress is determined by centrifugal force, for example, turbine blades, the stress will be lower for the lighter materials. It is thus not necessary for the material to be able to withstand as high stresses. The material can stand up because its strength-weight ratio is high.

The early attempts to use ceramics were retarded by the poor thermal shock properties of these materials. Although, as yet we cannot equal the thermal shock properties of metals, vast improvements can and have been made in the thermal shock properties of ceramics. For example, the well-known phase inversions of zirconium oxide may be suppressed by proper additions of other materials giving improved thermal shock properties. To demonstrate, in this furnace we have ceramic disks at 1800° F. On air quenching we notice that the disk does not crack or shatter, illustrating that good thermal shock properties can be achieved in ceramic materials. Each material, however, poses its own thermal shock resistance and it is the aspect that we are investigating here.

The fabrication of ceramic shapes has been difficult; however, we believe that this problem is largely one of becoming familiar with the new techniques required to handle a new material. There are on display a variety of intricately shaped engine parts which have been fabricated from ceramic materials. These parts are not necessarily developed to the point where they will withstand prolonged engine operation, but they do indicate the feasibility of fabricating parts from ceramics and ceramals. In general ceramic materials are fabricated by three methods. One consists of casting a slurry of the ceramic, firing, and finish grinding. The quasi-blades shown here are examples of parts made in this manner. The second method consists of grinding the part from bars or rods. The ceramal supercharger blades shown here were made by this method. The third method of fabricating ceramics consists of machining the part from green or partially fired materials, firing, and finish grinding. This method most nearly duplicates metal working and consequently, facilities for production are readily available.

The nozzle guide vanes, turbosupercharger buckets, and I-40 bucket shown on the panel were made in this way.

In conclusion, we are investigating the basic aspects of materials for use in aircraft, including alloys, ceramics, and the new material, a combination of metals and ceramics, called ceramals.

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STRESS AND VIBRATION EXHIBIT FOR FIRST ANNUAL INSPECTION

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by S.S. Manson

INTRODUCTION

In an aircraft engine minimum weight must be combined with absolute insurance against structural failure. An important phase of the research at the NACA is, therefore, the determination of the criteria for structural failure and a search for the methods to increase the life of an engine while at the same time reducing its weight and increasing its efficiency and power output. This phase of the research is known as Stress and Vibration. I shall limit my remarks to those aspects of the research relating to turbine disks and turbine and compressor blades.

TURBINE DISKS

In turbine disks we are concerned with two major stress problems. The first of these is rim cracking, which is common in disks in which the blades are welded to the wheel. It has been found that in such disks cracks occur at the bases between the blades after periods of operation much shorter than would ordinarily be considered the reasonable life of the wheel. Analytical research has linked these cracks with high thermal stresses due to hot operation, plastic flow that results from the high thermal stresses, and a stress concentration inherent at the base of the blades. Here is the approximate length of the cracks present between many of the blades of the disk when the disk was removed from service. It was considered that this was a dangerous length. The analytical research indicated that it would be possible to propagate the cracks by the application of successive heating and cooling cycles, and here are some of the propagated cracks obtained by such cycles. One of the potential solutions indicated by the analysis is the removal of the stress concentration by drilling small holes at the bases of the blades. Here are some of the holes that were drilled prior to the application of the heating cycles, and it will be seen that very few cracks propagated beyond the holes. The merit of this type of solution has yet to be further tested and we are building large spin pits where disks such as these will be able to be tested under conditions of full speed and temperature gradient. These pits will also be used to test the merit of a number of other indicated solutions.

The second problem associated with disks is that of disk bursting. Disk bursting has occurred in practice but one of the major reasons for studying it is the desire to reduce the weight of the wheel, a step that may increase the number of this type of failure. The results of a preliminary investigation of disk bursting are shown on this panel. Here we were studying the effect of ductility or the amount of stretch that the material is capable of withstanding without rupture. Here is a disk with a very high ductility. Characteristic of its fracture are the low number of failed pieces and the fact that the plane of fracture is inclined at an angle of 45° to the thickness of the disk. As we decrease the ductility, the number of fractured pieces increases and the plane of fracture is perpendicular to the thickness of the disk. The problem requires considerable additional investigation, and the pits that will be used for the rim cracking investigations will also be used for testing large disks such as shown on the other panel in disk bursting investigations.

STROBOSCOPIC VIBRATION

I should like to leave now the subject of turbine disks and go on to compressor and turbine blades. In this case we are concerned with blade vibration. Vibration is a movement back and forth of the blade which results, in some cases, in critical stress and fracture of the blade. It is a treacherous type of stress condition, first because at any one time the stress may not be great enough to cause fracture but over a period of time the accumulated damage may cause fracture without warning. It is also treacherous because so little is known about the causes for blade vibration. It may be present in some engines but not in others, and in any one engine it may be present under some conditions but not under others. It has taken a good deal of research to gain even an elementary understanding of blade vibration.

Let me demonstrate a blade in a condition of vibration. Here is a blade which has vibrational characteristics quite similar to those of turbine and compressor blades except that it is constructed to a much larger scale than ordinary blades. Connected to the end of the blade is an electronic exciter by which we can vary the excitation impulses until the natural frequency of the blade is reached. The blade will then go into a condition of vibration. The vibration is too rapid to view with the naked eye and we therefore use stroboscopic light to study it. This light flickers on and off at approximately the same frequency as the blade vibration and therefore makes the blade appear to be standing still or to vibrate slowly, while in reality it is vibrating very rapidly.

COLORED SAND PATTERNS

The vibration you have seen is a very simple type of vibration. At any point along the length of the blade the entire section is merely moving up and down. There are other much more complicated types of vibration, and one of the first problems in the science is to categorize these vibrations. This is done by the use of what we call sand patterns. I shall sprinkle sand over the entire blade and then vary the excitation frequency on the blade until it begins to vibrate in one of its more complex modes. The sand particles bounce around and naturally tend to pile up at the locations of minimum vibration. Here is one pattern. As I now increase the excitation frequency until I reach another vibrational frequency of the blade, the sand bounces around in another pattern, and again in another pattern. In this way we can classify the vibrational characteristics of any blade according to the frequency of vibration and the stress condition in the blade at any one frequency.

HIGH TEMPERATURE STRAIN GAGE

The next problem is to learn which types of vibration actually do exist in an engine. For this purpose we make use of wire strain gages. The strain gage consists merely of a strand of resistance wire which is cemented onto the blade. As this blade vibrates it changes minutely the electrical resistance of the wire. By measuring the change in electrical resistance, the amount and type of vibration can be determined. We had had a great deal of experience with wire-resistan~~t~~ce strain gages as applied to reciprocating engines. When we started to study turbines we learned that the strain gages that had formerly been used were suitable for the temperatures of 400°-500° F previously encountered but were certainly not suitable for the temperatures in the range of 1500°-1800° F which were now of interest. After considerable research we learned, however, that by using the suitable materials and, most important, by using proper electronic circuits it was possible to find strain gages capable of withstanding 1500°-1800° F. I should like to demonstrate to you the operation of such a strain gage. Here we have a strain gage mounted at the base on a typical turbine blade. Surrounding the blade is an induction heating coil. This coil provides a rapidly fluctuating magnetic field around the gage and in so doing induces eddy currents in the blade which heat up to a very high value. At the present time the blade in the vicinity of the gage is fairly close to 1500° F. Attached to the block in which the gage is melted is a small air turbine. If I increase the air pressure the speed of the turbine increases and provides a mechanical excitation which, when it reaches the natural frequency of the blade, causes it to vibrate. The vibration of the blade is indicated by the appearance of a wave on the oscillograph screen above the blade.

STREAMING DOUBLE REFRACTION

Even when we know about the presence of vibration, the frequency of the vibration, and the characteristics of the vibration at the particular frequency, very often we do not know the source of the excitation and therefore it is impossible to find a remedy. In some cases the excitation may be mechanical, as it was in this demonstration. In some cases, however, the excitation is aerodynamic, that is, it is due to fluctuation of air forces on the blade. We have recently introduced the streaming double refraction method of fluid flow into our research in order to gain a better understanding of the flow phenomena that may cause vibration. The equipment for this type of research consists of a source of polarized light and a channel in which a blade contour is suspended in a fluid consisting of bentonite clay in water. This fluid has the peculiar property of double refraction in that a beam of light passing through it may have one or more of its color components retarded so that the portion of the light that leaves the channel has only that color component of the entering white light which is not retarded.

The result is a color pattern which represents the condition of fluid flow in a very colorful and graphical manner. See Fig. 77 If we turn on the equipment, at first slowly so that the flow around the blade contour is streamlined, we see the close adherence of the fluid to the blade contour. Even at this slow speed there is present a small amount of wiggling in the wake of the blade, and this fluctuation of fluid flow may produce excitation forces both on this blade and on any blade that succeeds this blade. If we now increase the rate of flow, the fluid breaks away from the model and the flow becomes turbulent. The excitation forces under this condition are more violent. The color pattern becomes somewhat more diffuse because the flow is so rapid that the various colors are interacting with one another, producing what appears to the eye to be white light. If we had been able to use stroboscopic light as we did in the case of the vibrating blade, we would be able to see the precise fluctuation of the fluid flow. Unfortunately, stroboscopic light does not project very well but we have, by direct observation, studied the pattern of flow. If we now further increase the rate of flow, the flow pattern disappears almost entirely as far as the naked eye is concerned, but the excitation forces are so violent as to make the blade flutter vehemently.

CONCLUSION

Gentlemen, I have demonstrated several of the techniques that we use in the basic research of stress and vibration. In the last analysis, however, it is necessary actually to get into the turbine or compressor in order to study the existing phenomena. Here we have a compressor that was instrumented with strain gages and run under full operating conditions. We have learned from this compressor the effects of such phenomena as surging and the presence of high pressure ratio. Here is a turbine which was instrumented with high-temperature strain gages and operated under hot gas conditions. We have learned from it the effects on the vibration of such factors as the number of combustion chambers. Many of the results of these tests have already been published in NACA reports. Other results are in the process of publication. Much research remains to be done. It is hoped that this research will provide the necessary data to make possible the realization of the more efficient and powerful engines of the future.

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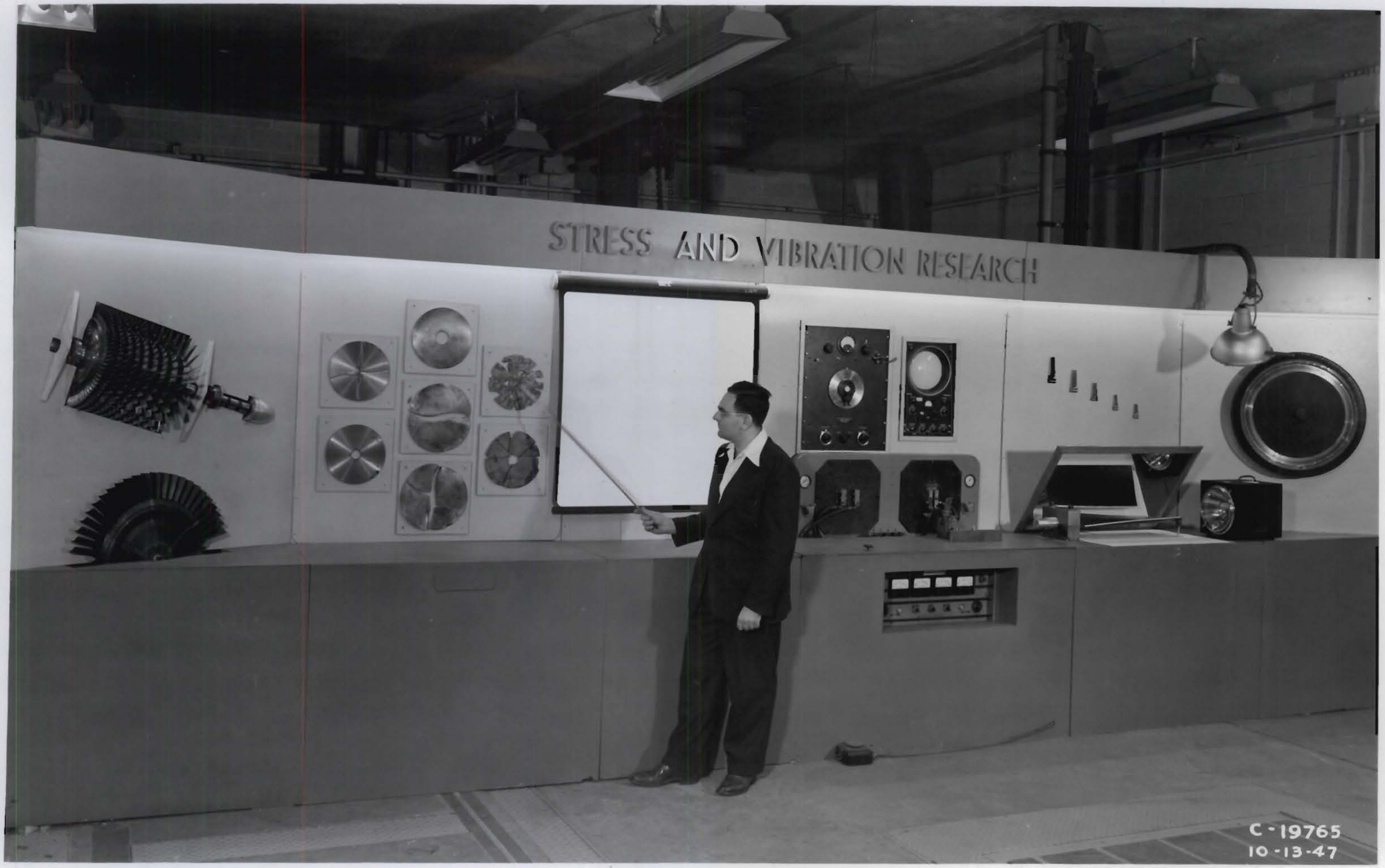

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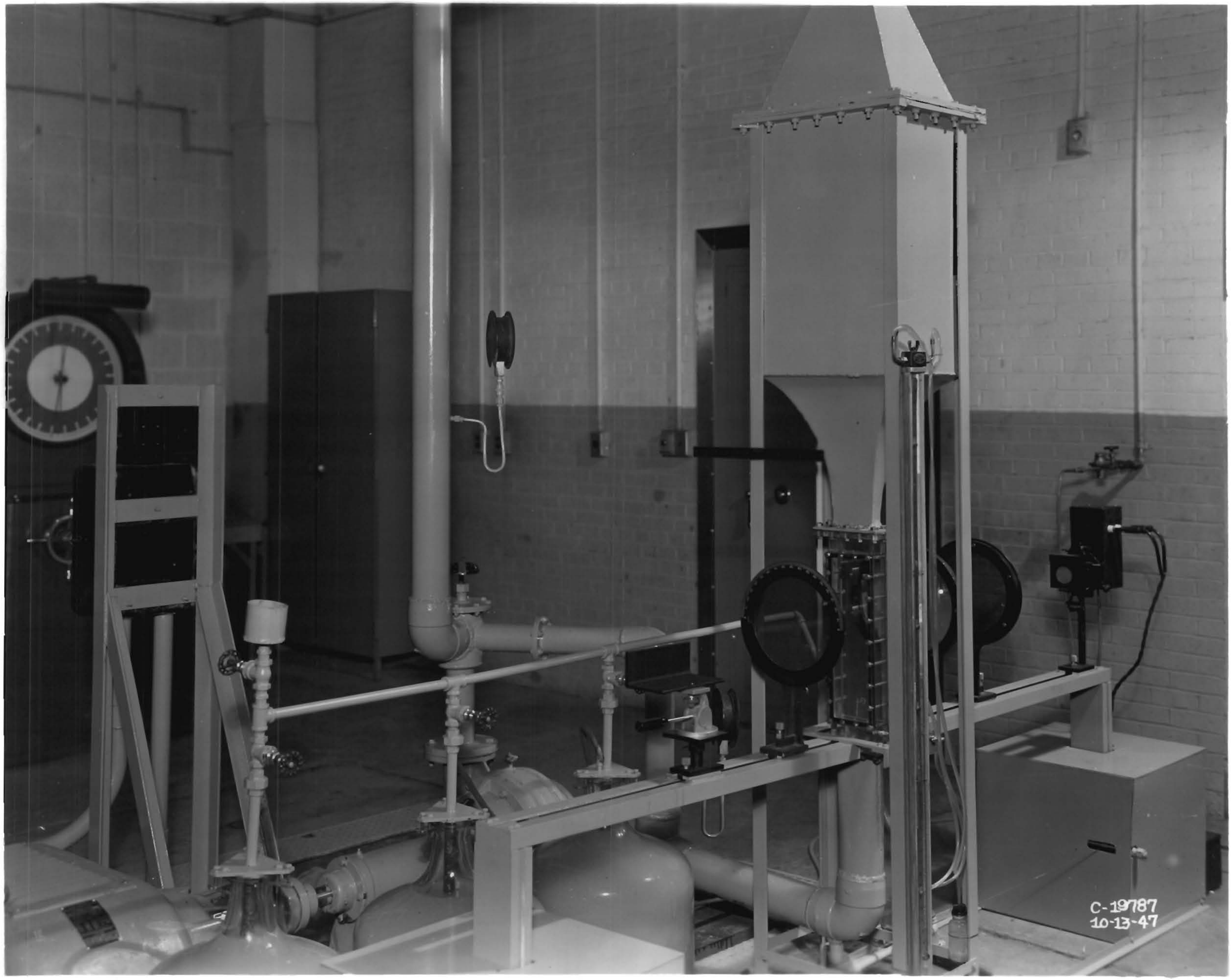

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Fig 77

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