Some Structural Effects of Aerodynamic Heating

By

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The surface temperature of an airplane or missile flying at supersonic speeds can become very high as a result of the friction of the surrounding air. For example, the skin temperature would exceed 1000°F during a flight in the stratosphere at four times the speed of sound. Consequently, if supersonic aircraft are to be built successfully, the structural problems that arise from high temperatures must be recognized and solved.

The most well-known structural effect of high temperature is to reduce the basic strength of materials. Therefore, the structural analysis and design of supersonic aircraft must be based on accurate information concerning the high temperature strength characteristics of the materials used. However, the possible troublesome effects of high temperature do not end there - and in this talk I will discuss two less obvious problems that can arise from the high temperatures generated by aerodynamic heating. One of these problems stems from the fact that at elevated temperature aircraft structural materials tend to creep - that is, under the action of a constant load, the material suffers deformations that continually increase over a period of time. (Turn to first chart.) This chart shows a typical time history of deformation of a specimen creeping under constant load at elevated temperature. This distance (point) represents the initial deformation of the specimen that occurs immediately upon load application; as you can see, the deflections that grow with time as a result of creep can increase well beyond the initial deflection, and will eventually result in failure. These additional deflections (point) are permanent and will remain in the material or structure after the high temperature and the load are removed. In terms of aircraft structures, this means, for example, that the useful lifetime of an airplane might be limited by excessive distortion of its wings after continued flight at elevated temperature. Depending on the temperature and load, the creep lifetime of a structure can vary between thousands of hours and just a few minutes; the designer must be sure that this lifetime limitation does not occur before the desired service life of the aircraft is over, whether it is an expendable guided missile or a piloted fighter plane.

Until recently most research work in creep has been concerned with investigations of the creep properties of various materials. For such work simple specimens, such as this (hold specimen up), are adequate. However, research work on more complete, built-up aircraft structural specimens is necessary. For this purpose we have just completed assembly of this furnace (walk over and touch furnace with pointer) which is capable of accomodating specimens up to 8 feet long and maintaining temperatures as high as 900°F. We are now operating the furnace for the purpose of checking its performance characteristics with a typical test specimen in place. For the past few days, a built-up aluminum box beam, like the one here, has been in the furnace and has been subjected to loading by means of these weights. The temperature in the furnace is 400°F and the load on each end of the beam is 4200 pounds. As a result of the high temperature and the load on the beam, the deflections of the beams have been continuously increasing. On this chart we are automatically recording the creep deflections as time passes. Note the similarity between the curve drawn here for the built-up box beam and the typical curve shown on the chart for a simple specimen. We will now raise the walls of the furnace so that you may see the specimen in place. (When furnace is up, point out specimen, support, load, and curvature.) Of course, in a creep test in which research data is being obtained, the furnace would remain closed for the duration of the test. (After furnace is lowered, walk away; pause.)

In contrast to the effects of long time heating just shown, another entirely different effect of temperature occurs when portions of an aircraft structure are subjected to very rapid heating. As many of you know, aircraft wings and tails, unless they are properly designed, can flutter at high speed and the resulting violent vibration could destroy the aircraft. Whether an airplane will flutter depends strongly on its vibration characteristics, which in turn depend on the stiffness properties of the structure. Aerodynamic heating now enters the picture because such heating generally produces non-uniform temperature distributions in the structure, these non-uniform temperatures cause thermal stresses, and the thermal stresses so produced may change the effective stiffness.

(Walk over to Δ-wing specimen)

This simplified model of a delta wing airplane or missile, now at room temperature, will be vibrated by a mechanical shaker inside the fuselage. The shaking frequency is shown in cycles per minute on this dial. One revolution of the pointer represents 1000 cycles per minute. At a frequency of 1425 cycles per minute the structure will be excited in a natural mode of vibration and will respond with large oscillations. (Wait while model is vibrated 3 to 5 seconds.) Now, the shaking frequency is being reduced to 1200 cycles per minute and, as you see, the violent oscillations of the wing have disappeared. (Turn next chart into place.) Next, we will create a non-uniform temperature distribution by radiating heat into the leading edge of the wing. We will obtain a temperature distribution across each wing like this - peaking up at the leading edge - and a resultant thermal stress distribution in the plane of each wing something like this - compression near the leading and trailing edges and tension in between. The effect of such a temperature distribution on stiffness will be demonstrated by showing how the natural frequency of vibration of this delta wing is reduced by temperature. This reduction in the natural frequency will be evidenced by the violent response of the wing to the shaking force of 1200 cycles per minute, which you now see has negligible effect at room temperature.

The heating elements will now be turned on - and as they start getting hot, you see the wing responding at its newly acquired natural frequency of 1200 cycles/min. (Wait while wing vibrates and until vibrator is shut off completely.)

In a fashion analogous to the sudden inception of oscillation you have just witnessed, an actual aircraft designed to be flutter free only at normal temperatures might suddenly begin to flutter when subjected to rapid heating in flight.

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Display for Presentation of Talks on Structures Research

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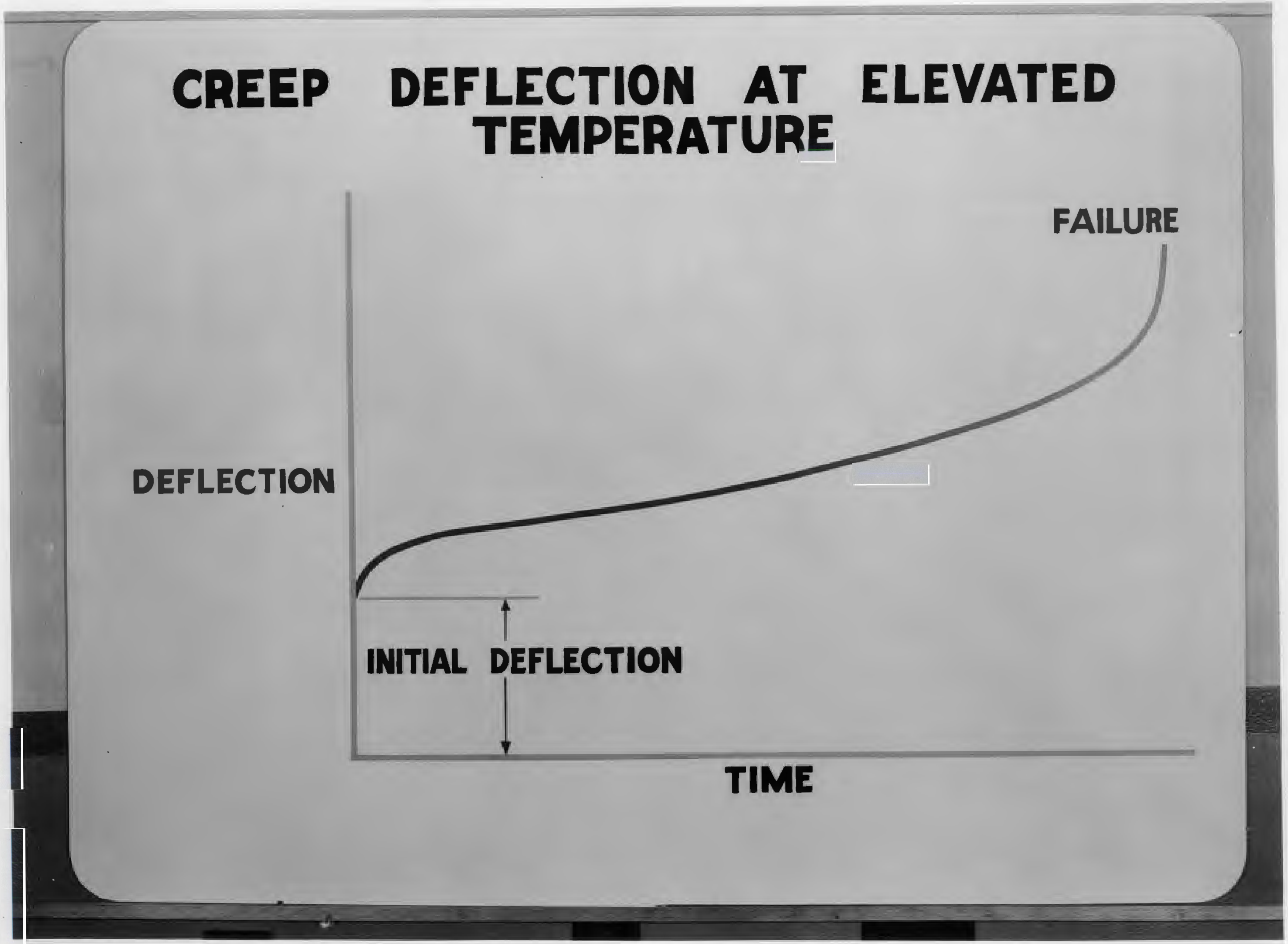
CREEP DEFLECTION AT ELEVATED TEMPERATURE
FAILURE
DEFLECTION
INITIAL DEFLECTION
TIME

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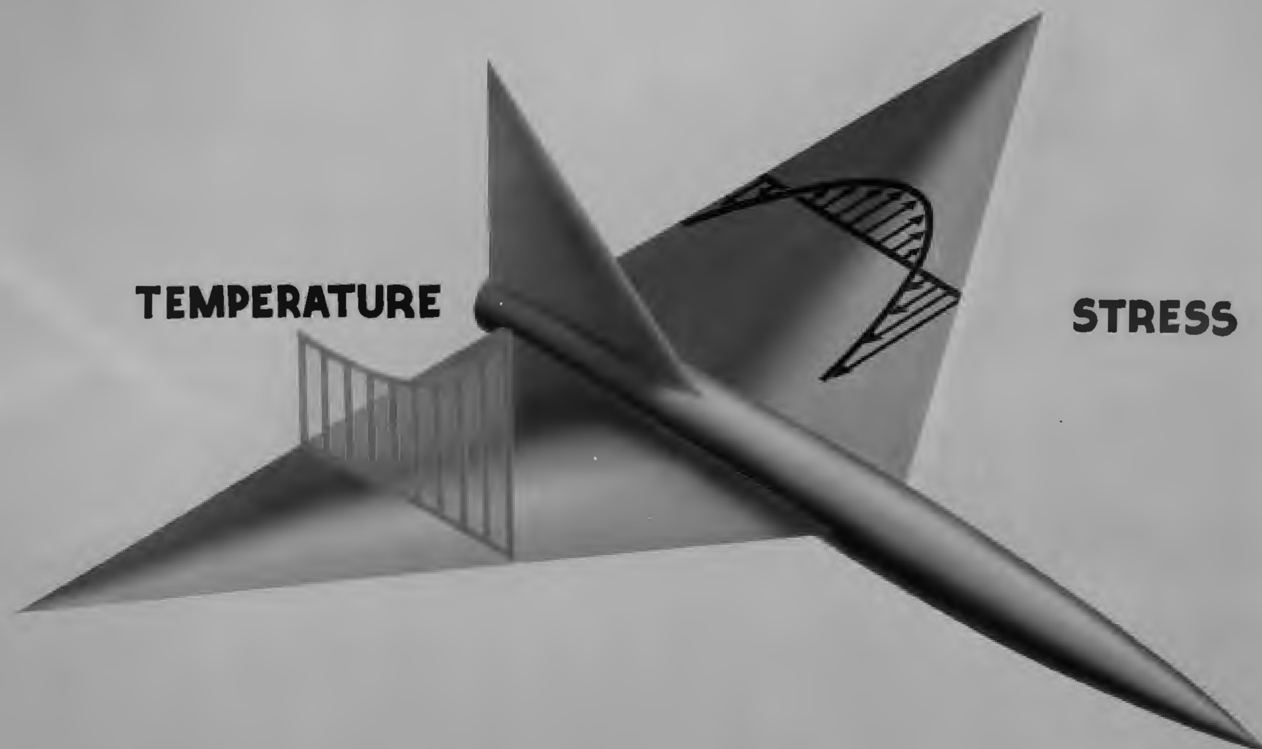
STRESS IN A DELTA WING DUE TO NONUNIFORM TEMPERATURE



Demonstration of the Effect of Heating on the Vibrational Characteristics of a Model

Strength of Multiweb Wing Structures

By

B. Walter Rosen, Melvin Anderson, and Richard A. Pride

One of the activities at this Laboratory is the determination of factors which control the strength of aircraft structures. During the past year an extensive experimental and theoretical investigation has been made of multiweb wing construction. As part of this program strength tests have been made on beam specimens such as the ones you see here. Each of these beams may be thought of as a portion of the primary structure of a wing. Design data have been obtained which show how the strength of such beams is affected by changes in any of the major dimensions.

One of the interesting results of this work is the discovery of the effect which small changes in the joint details have on the behavior of these beams. The design of joints is often decided by shop practice and convenience; however, we have found that the effect of joint construction on beam behavior is of major importance. Two general types of web-skin joints are illustrated on this chart. Here the web material is bent to form an attachment flange with a round corner. This second type of skin-web joint is fabricated from an extrusion which has a square corner here and a small fillet here.

The difference in behavior of beams built with these two types of joint construction will be illustrated with a motion picture. The beams will be loaded to failure in bending by the testing machine which you see beyond and to the right of this chart. (Start motion picture.)

The beam specimen is located here in the center of the picture. Loads are applied by the loading unit on the right and are measured by the weighing unit on the left. The next scene will show a more detailed view of the beam prior to testing.

The surface visible is the compression skin of the beam. Black stripes have been painted on the skin midway between webs to help show the distortions of the skin as failure approaches.

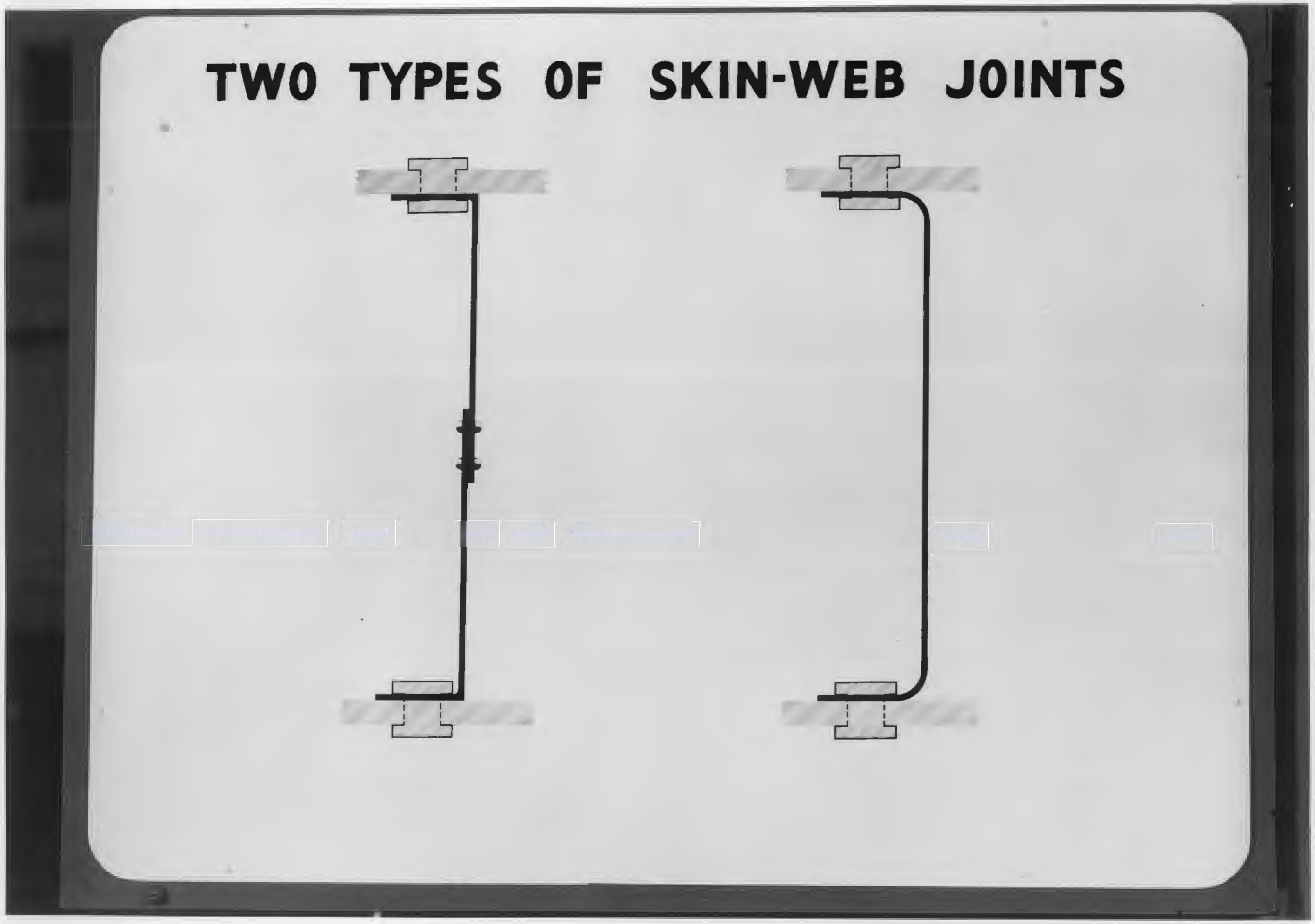
The first failure sequence will be for a beam with round cornered webs and will begin just before the loading buckles the skin. When buckling occurs a type of skin distortion will take place which shows up as a sort of washboard pattern. (Indicate by hand motion.)

Note these black stripes on the skin between webs; and the lines along the webs formed by the protruding rivet heads. These lines will move up and down together when the beam buckles. The buckles are developing now and grow more distinct as the loading approaches failure. Failure will occur here with a sudden downward snap of the skin. This failure sequence will be repeated.

We see here that the flexibility of the round cornered webs permits skin distortions that carry across the webs and extend over the full width of the compression surface.

The next beam is similar to the first one except that the webs are square cornered extrusions. The first scene will show the specimen with the skin in a buckled condition. Note that with square cornered webs the rivet lines remain straight while only the painted stripes on the skin between webs are wavey. Here, the improved stiffness of the square-cornered webs has confined the skin distortions to the regions between webs. These distortions grow with loading until violent failure occurs over this central region. This failure sequence will also be repeated. These wires are part of the strain gage instrumentation.

We have seen how changing the joint construction from flexible, round-cornered webs to stiff, square-cornered webs changes the buckle pattern. Now let us look at the failing loads associated with these two types of joint construction. On this chart are presented the failing loads for these four beams which have the same weight and moment of inertia. They differ only in the detail of joining the webs to the skin. The differences may be too small for you to see here, but the joint detail of each beam has been magnified on the chart. Three of the beams have round cornered webs with a variation in the bend radius as indicated - radii of 6 times the web thickness, 4 times the web thickness and 2 times the web thickness were used. The fourth beam has a square cornered web. The curve shows the large variation in failing strength of similar beams obtained by varying the corner radius. Changing from a round cornered web of 6t radius, which is typical of current practice for high strength aluminum alloys, to a square cornered web increases the strength of the beam by 65 percent. The strength increase produced by changing this detail is equivalent to that which would be achieved by the addition of 2 more round cornered webs to this beam.


TWO TYPES OF SKIN-WEB JOINTS

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Combined-Loads Test Machine

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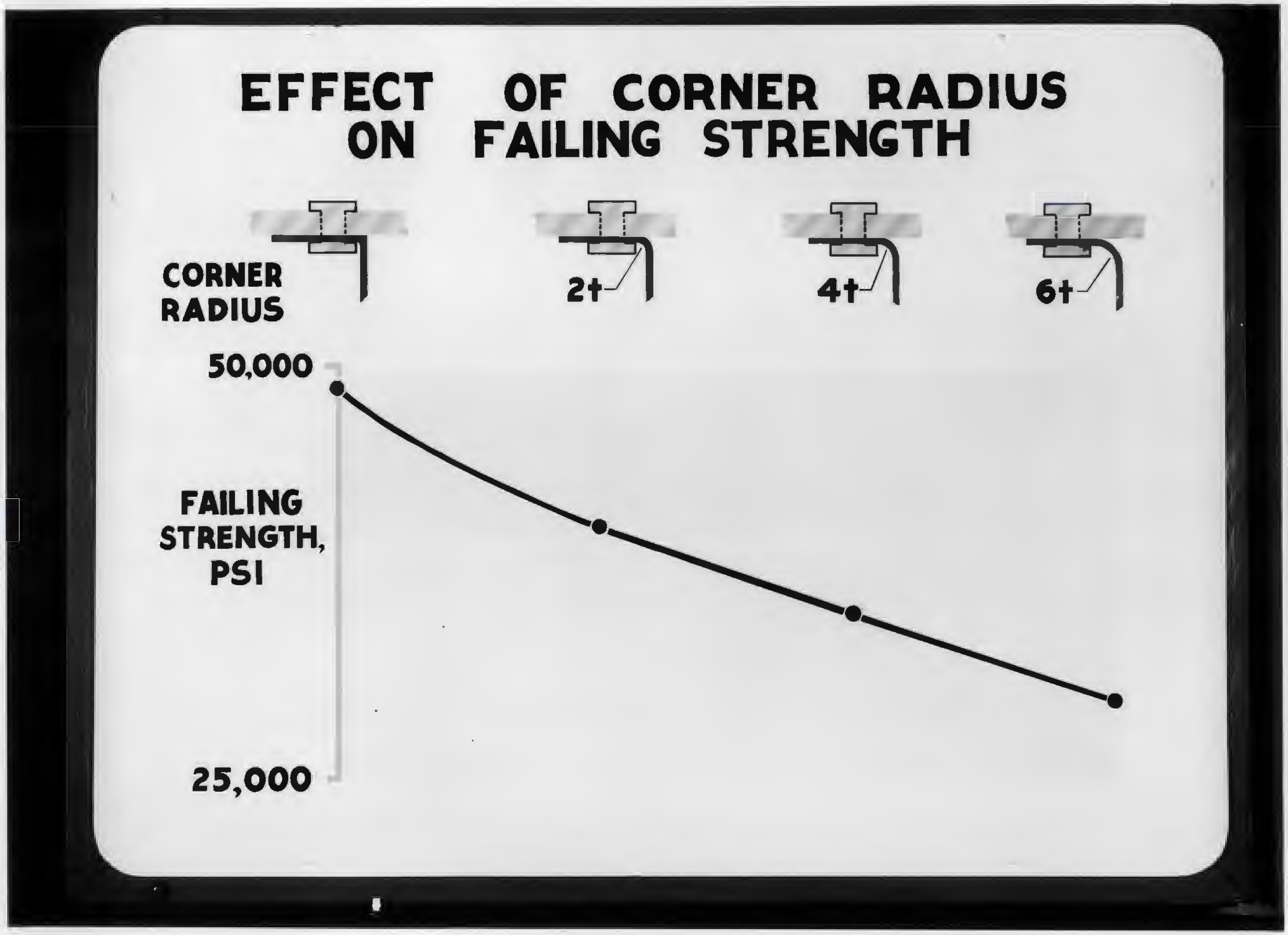

EFFECT OF CORNER RADIUS ON FAILING STRENGTH
CORNER RADIUS
2t
4t
6t
50,000
FAILING STRENGTH, PSI
25,000

Fatigue Failure at High Stress

By

C. B. Landers, W. Illig, A. J. McEvily, Jr., and H. F. Hardrath

Many failures of machines and structures have been caused by repeated application of a load which, if applied only once, could be carried with complete safety. This type of failure starts by forming a submicroscopic crack at some critical location within a part and this crack then grows with successive load applications until fracture occurs. Such failures are called fatigue failures.

(Turn Chart)

The results of fatigue tests of laboratory specimens are usually plotted as curves of fatigue strengths versus number of load cycles to failure. As one would expect, the lower the stress the greater the number of cycles required to produce failure. This curve represents tests of aluminum alloy specimens, like this one, subjected to repeated tensile loads.

Of more direct interest to the designer is information on more complicated shapes containing discontinuities such as are almost always present in practical parts. This specimen is typical of one type which is used to represent grooves or discontinuities in machined parts. Although the static strength of this specimen is about the same as the static strength of a plain specimen with the same cross-section, its strength in fatigue is drastically reduced as shown by this lower curve. (Attach part of curve and notched specimen to chart.)

In the past, most investigations in fatigue have been concerned with the fatigue properties of parts subjected to many load cycles (point to proper region of chart). One reason for this is that in most cases the part to be designed is required to have a very long, or preferably, an unlimited life. With machines, which you will see on your right as you leave this building, we have been studying this aspect of the fatigue problem for several years. In another building, complete wing structures of C-46 airplanes are being subjected to fatigue tests. These full scale test results will be correlated with the information gained in laboratory tests on simple specimens. All of this work has been concentrated on establishing the fatigue strengths for lives greater than 100,000 cycles. (Indicate on chart.)

There are cases, however, where other factors make it necessary or desirable to design parts for higher stresses. One example of such a part is the aircraft landing gear which is loaded heavily only once per flight, is never used while the airplane is in the air and yet contributes substantially to the weight of the aircraft structure. The design of the landing gear for infinite life would appear to be not only unnecessary, but would incur prohibitive weight penalties. In this and other similar cases the fatigue behavior at high stresses is an important consideration.

This Laboratory is currently engaged in research which is intended to fill this gap (point) in knowledge of fatigue behavior. Early results of this work are represented by this part of the curve. (Attach remaining part of lower curve to chart.) It is one of many such curves which must be obtained to gain an understanding of fatigue behavior in the high stress range.

Fatigue failures occur at so few cycles in the high stress range that we can demonstrate for you just how such a fatigue failure takes place.

We have tested plain specimens like this one under tension loads varying repeatedly between zero and about 90 percent of the static strength and established that failure occurs in about 23,000 cycles, as indicated by this point on the upper curve. This notched specimen has the same minimum cross-section as the unnotched specimen and has about the same static strength. A specimen similar to this will be tested at 90 percent of its static strength and it will last only 30 or 40 cycles, as shown by this point on the lower curve.

A light and lens system will project an image of the middle portion of the notched specimen on the screen. If you will focus your attention on the areas of the specimen just inside the bases of the notches you will notice first a slight deformation of the surface, then the initiation and propagation of a crack, and finally the fracture of the specimen. Each cycle of load application will cause a small but visible motion of the specimen image on the screen. When the image moves upward, load is being applied. The vertical lines in the image are reflections from fine longitudinal scratches left when the specimen was polished. These scratches are very shallow and are in the direction of the load, therefore do not influence the fatigue failure.

(Wait while fatigue test is made.)

You have witnessed a fatigue test of a notched specimen loaded repeatedly in tension from 0 to 90 percent of the static strength of the specimen. Fracture took place in ________ cycles.

This concludes the program in the structures research laboratory. Please follow your group leader to the bus.

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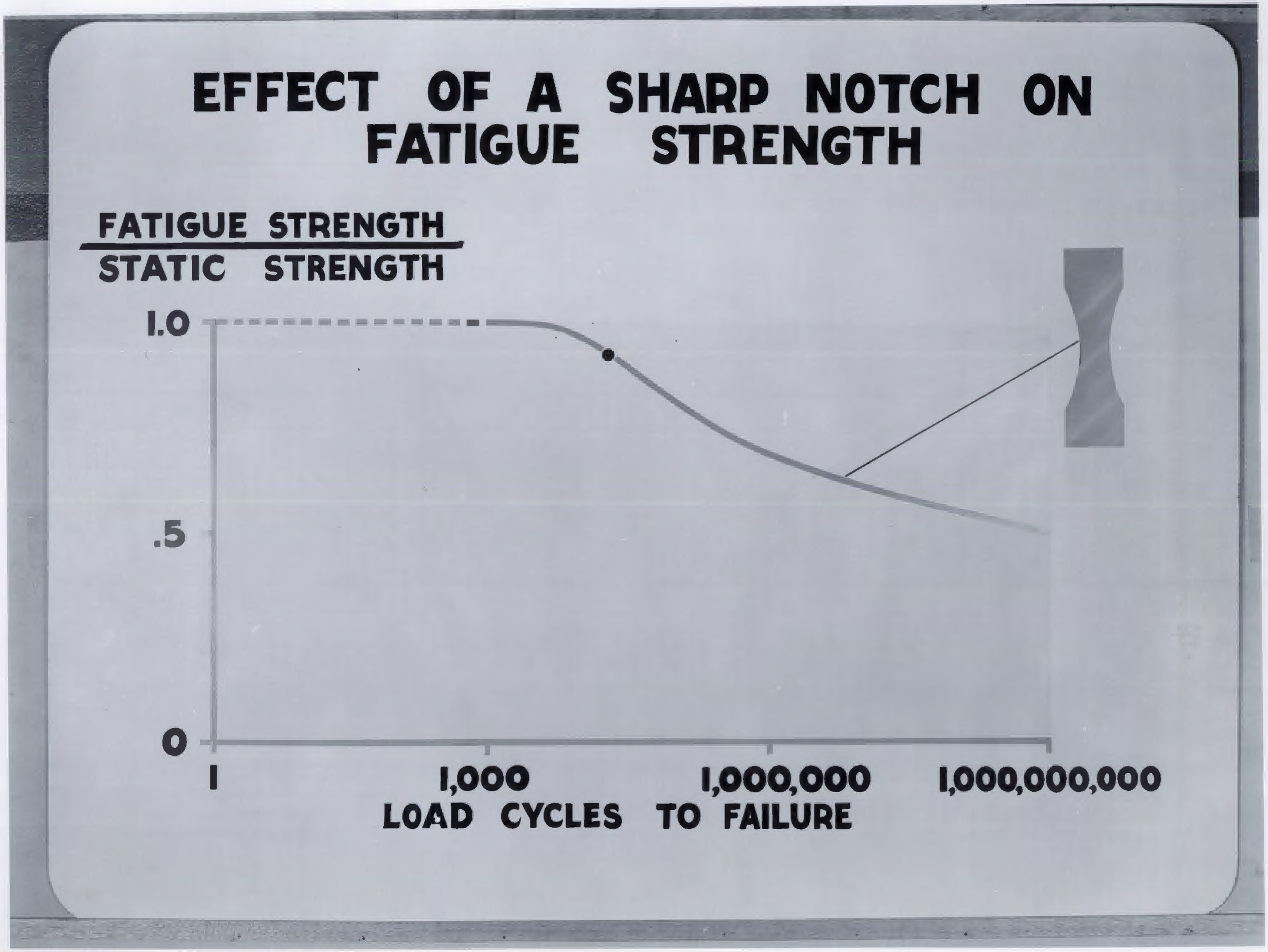

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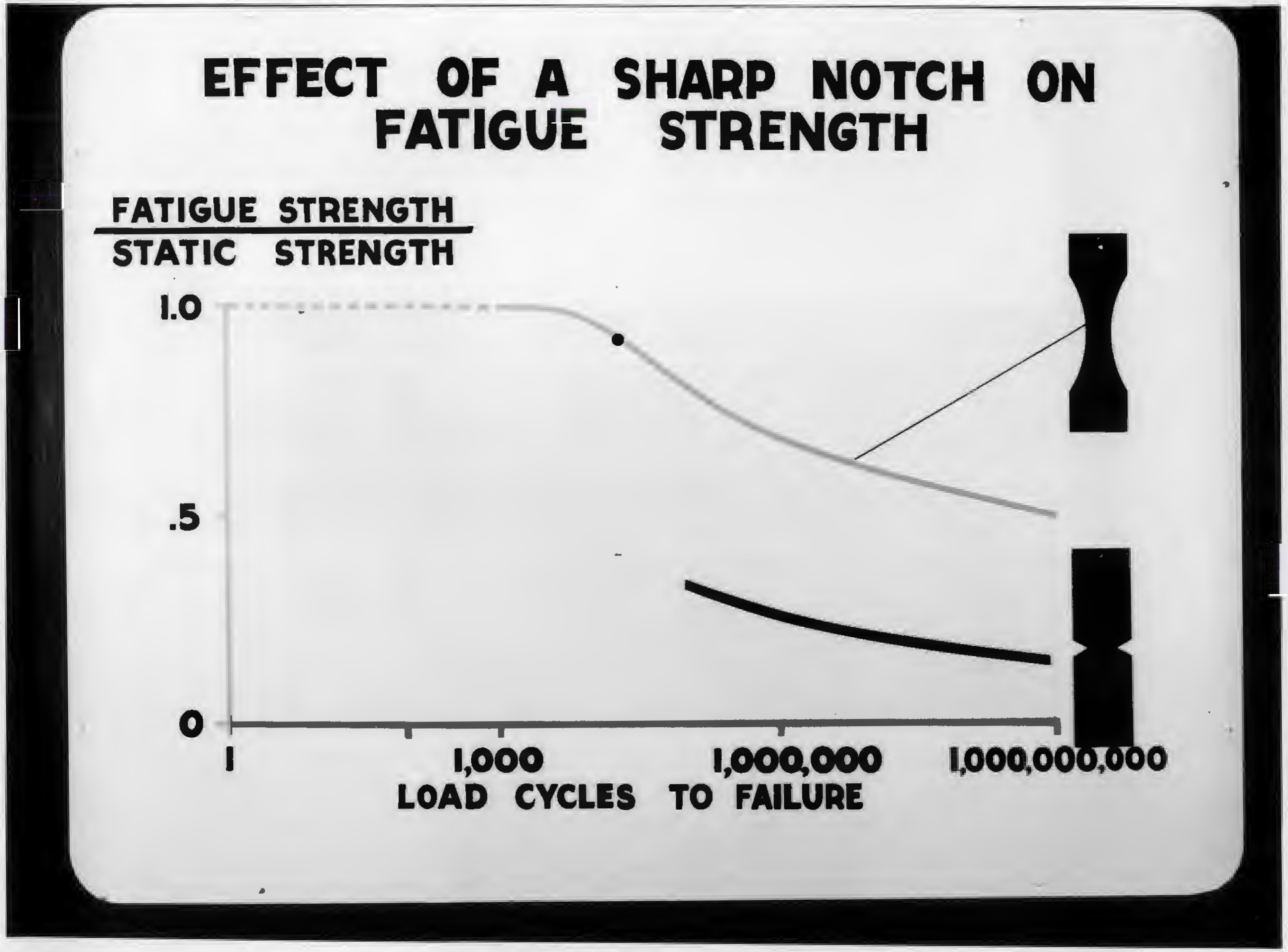

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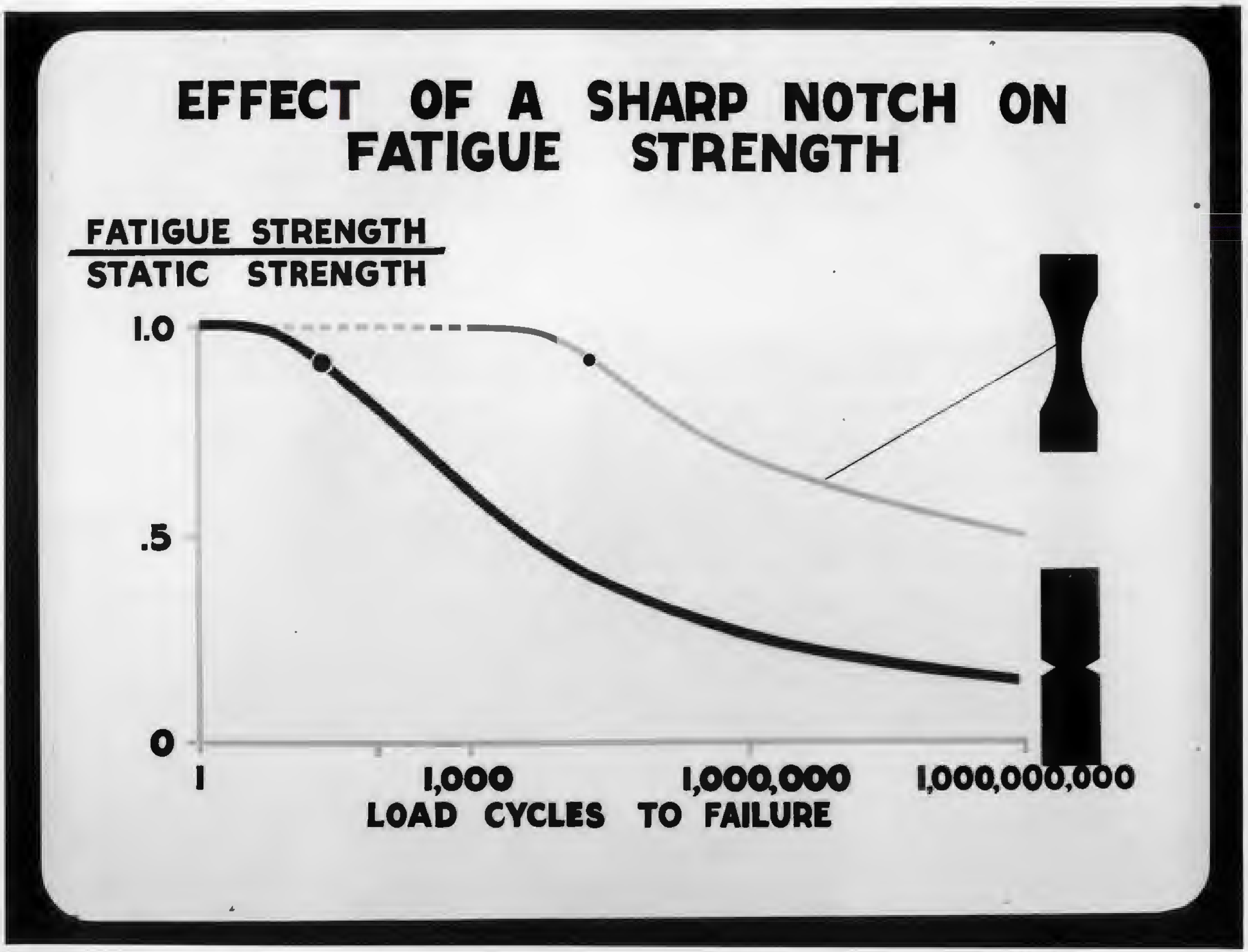
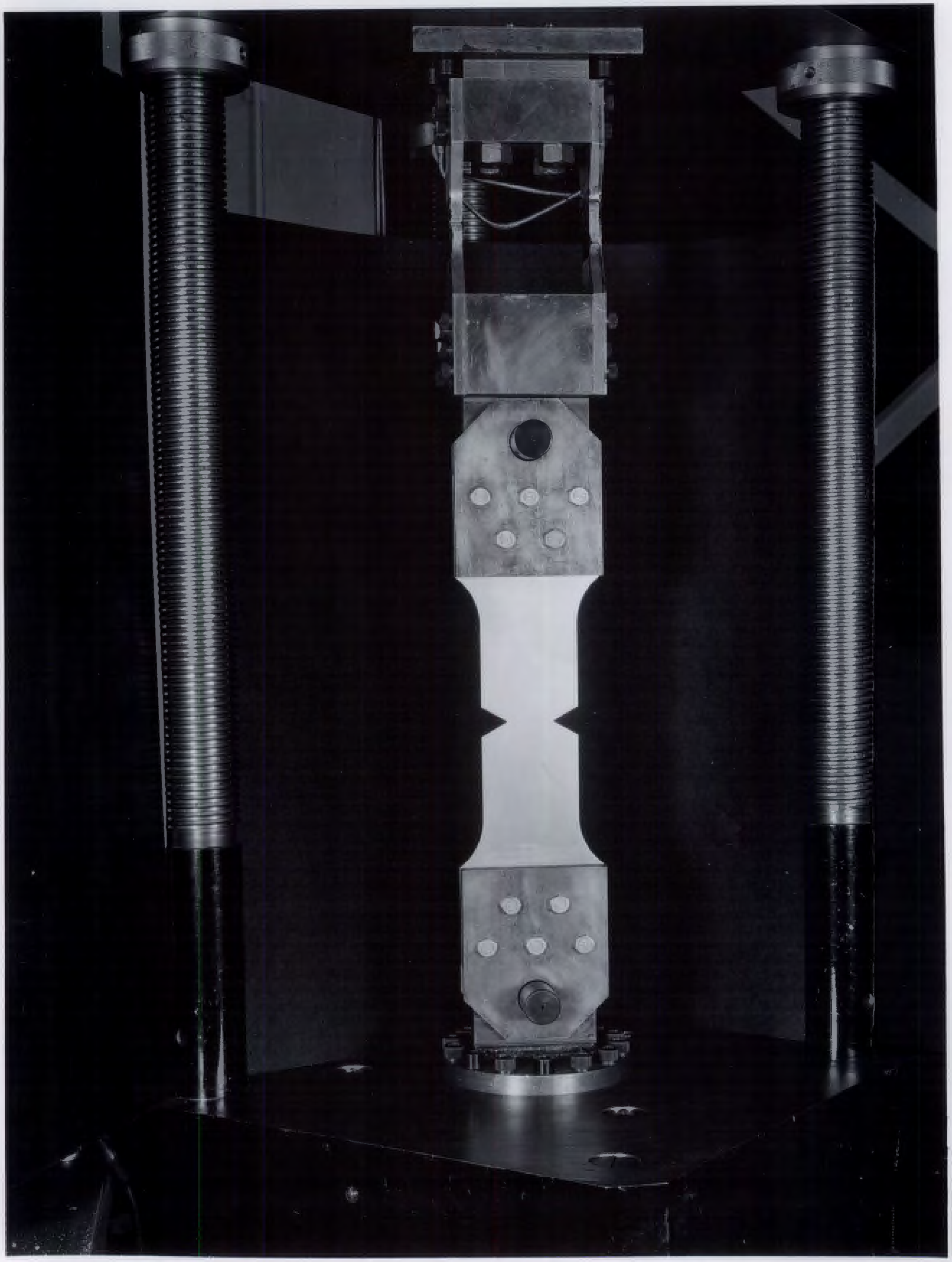


EFFECT OF A SHARP NOTCH ON FATIGUE STRENGTH
FATIGUE STRENGTH / STATIC STRENGTH
1.0
.5
0
1
1,000
1,000,000
1,000,000,000
LOAD CYCLES TO FAILURE



Setup Used for Demonstration of High-Stress, Low-Cycle Fatigue

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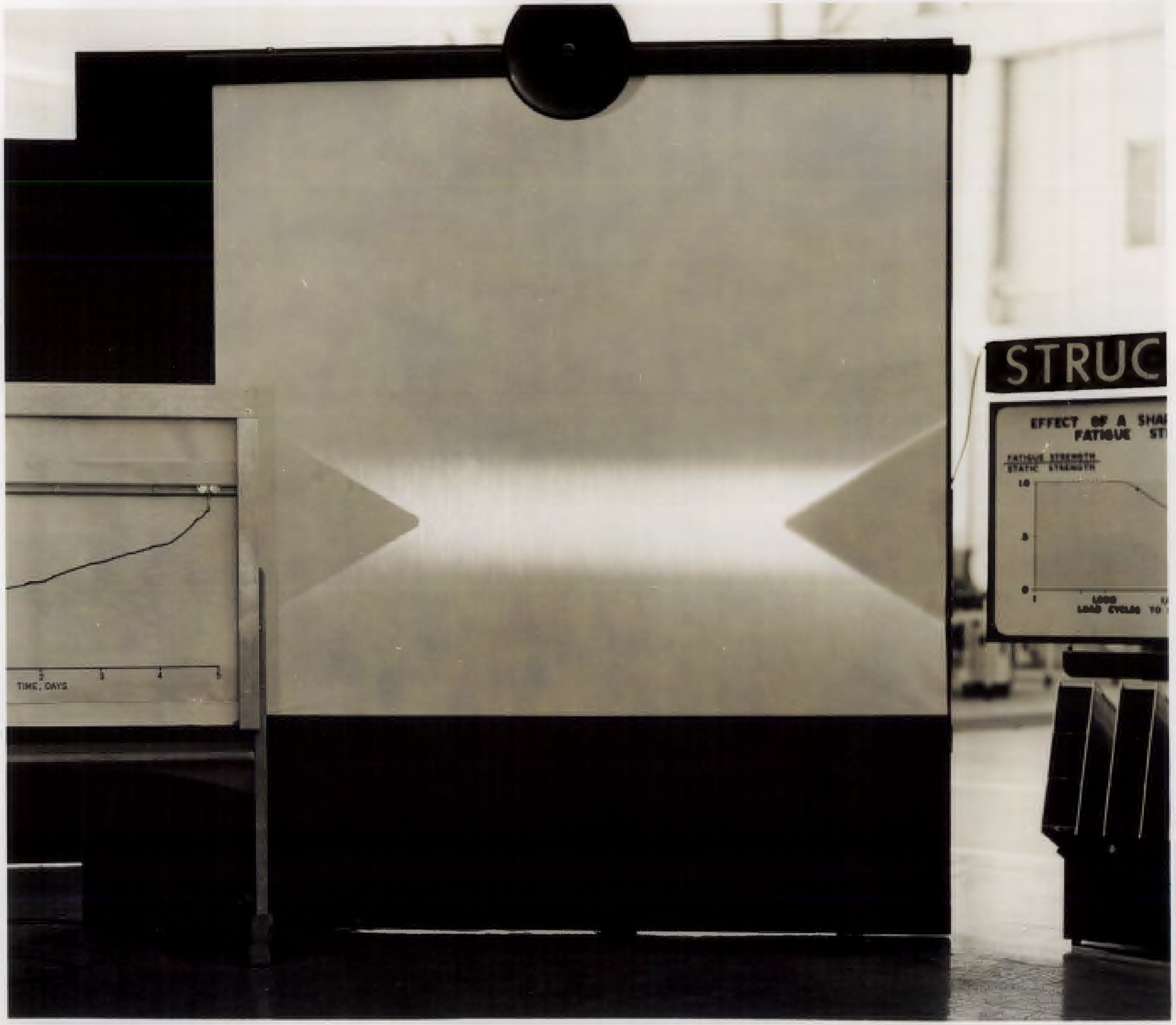

Image of Notched Specimen Projected During Demonstration of High-Stress, Low-Cycle Fatigue