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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF GUY ALLOY AS A TURBOJET-ENGINE BUCKET MATERIAL FOR USE AT 1650° F

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NATIONAL ADVISORY COMMITTEE
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PRELIMINARY INVESTIGATION OF GUY ALLOY AS A TURBOJET-ENGINE BUCKET MATERIAL FOR USE AT 1650° F

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SUMMARY

Guy alloy, a cast nickel-base material, was evaluated as a turbine bucket material for operation at a temperature of 1650° F. As-cast buckets were run in a J33-9 turbojet engine for cycles of 15 minutes at rated speed and 5 minutes at idle speed. Stress rupture, impact, and engine-performance data indicate that Guy alloy may be considered for bucket use at a temperature of 1650° F. Ductility and impact strength of Guy alloy is limited but appears to be adequate for bucket applications.

INTRODUCTION

Significant increases in thrust may be obtained by increasing the operating temperatures of turbojet engines. Since the operating temperatures of turbojet engines are limited by high-temperature-material properties, perhaps the most direct approach to advancing engine temperatures is to develop improved heat-resisting materials.

The development of a new, cast, nickel-base alloy considerably stronger than many of the currently used alloys was reported by Guy (ref. 1) in 1949. This alloy will be termed Guy alloy hereinafter. The stress-rupture properties reported in reference 1 indicated that the alloy could be considered for use as a turbojet-engine bucket alloy at advanced temperatures. At the time the present investigation was started, relatively little effort had been expended to determine the potentiality of this material.

The study reported herein was conducted to evaluate the potential of cast Guy alloy as a turbine-bucket material for use at 1650° F.

Prior to evaluating buckets in the engine at 1650° F, castings were made at the Lewis laboratory which demonstrated that the reported rupture properties could be reproduced and that turbine buckets could be cast which, although not of production standards, had a soundness suitable for engine studies. Because of the known low ductility of the alloy, "proof tests" of buckets were run in a test engine at 1500° F that proved the alloy had adequate impact resistance and structural integrity to warrant further study. The results of these preliminary studies are reported in the following section. The preparation for and the results of the evaluation of Guy alloy in an engine at a bucket-material temperature of 1650° F are described in the remainder of the report.

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For engine evaluation of Guy alloy at 1650° F, 52 investment-cast Guy alloy buckets were run in a J33-9 turbojet engine. The engine was operated for repeated cycles of 15 minutes at rated speed and 5 minutes at idle speed with a bucket temperature of 1650° F and a stress of 18,800 psi at about midspan, where the bucket might be expected to fail by stress rupture.

PRELIMINARY STUDIES

Stress-Rupture and Tensile Tests

To reproduce and extend the stress-rupture data of reference 1, rupture bars were cast and evaluated. The stress-rupture results obtained (fig. 1) indicated that Guy alloy could be considered for use as a bucket alloy at bucket temperatures 150° to 200° F higher than normal operating temperatures of current engines. The low elongation values obtained in these rupture tests (3 to 6 percent at fracture) and in tensile tests at room temperature indicated limited ductility, however.

The results of room-temperature tensile tests performed on as-cast bars are as follows:

Ultimate strength, psi	Yield strength (0.2 percent offset), psi	Elongation (1 in. gage length), percent	Reduction of area, percent
119,120	108,500	1.3	4.4
119,800	95,460	1.6	2.6

Casting of Buckets

Since it was not known whether bucket shapes could be cast from Guy alloy, it was necessary to conduct preliminary casting studies. Buckets were successfully cast to shape using the lost-wax investment process.

Melting was performed in air using an induction furnace. Buckets were centrifugally cast in air directly from the melting crucible. Unfortunately, buckets that appeared sound upon radiographic inspection were found to have surface defects when post-emulsion zyglo inspection was used. These surface defects were attributed to dross, which is not surprising considering the high aluminum content of the alloy and the air atmosphere used. It was felt that satisfactory castings of Guy alloy could be made using inert-atmosphere equipment and exercising care in adding the aluminum to minimize dross formation.

Impact Tests

Because of the limited stress rupture and tensile ductility of the alloy, data on impact strength were obtained. Laboratory impact data obtained in the NACA drop test (ref. 2) are shown in table I. The impact values for Guy alloy are lower than those of some alloys included for comparison but are higher than those of cermets and some other cast alloys shown. Also, it appears from table I that the impact resistance of Guy alloy increased with temperature. It is possible that the impact resistance of Guy alloy is appreciably higher at 1650° F, the test temperature used for this engine evaluation.

Engine Proof Test

Inserted at various times as replacement buckets in a J33 engine, which was being run at 1500° F, were 12 buckets selected from the group made in the preliminary casting studies. These buckets ran in the proof test without fracture for times ranging from 150 to 230 hours when the test was discontinued. (The time on each bucket varied with the time of insertion.)

During the course of the proof test, several buckets of other alloys fractured, and fragments struck the rotating Guy alloy buckets. Several were dented and nicked, but none had to be removed because of impact failure. Thus, the alloy was considered ductile enough to withstand the impact of fragments of failed buckets in an engine test.

MATERIALS, APPARATUS, AND PROCEDURE

Turbine Buckets

Cast J33-9 buckets and stress-rupture bars of Guy alloy were obtained from a commercial source. To minimize dross formation, alloy melts were prepared using an argon cover and the alloy was remelted, deoxidized, and cast into investment molds in a closed system with an argon atmosphere.

Test bars and buckets were investment cast to the following nominal chemical analysis:

	C	Ni	Cr	Mo	Al	Cb	Fe	B	Mn	Si
Weight percent	0.1 max.	64-70 bal.	12-15	5-6	5.5-7	2	4.5	0.5	0.5	0.5

All buckets were inspected for internal and surface defects using X-ray radiography and post-emulsified fluorescent-dye penetrant inspection. 4124
All buckets selected for engine evaluation were required to be free of defects detectable by radiographic inspection. Buckets with surface defects near the leading or trailing edges or with oxide or dross inclusions in the airfoil were rejected. Buckets were allowed to contain a limited number of small surface defects in the central portion of the airfoil and in the base.

Engine Operation

A full turbine wheel of 52 as-cast Guy alloy buckets and two thermocouple buckets was installed in a J33-9 turbojet engine. The engine was operated for repeated cycles of 15 minutes at the rated speed of 11,540 rpm and 5 minutes at the idle speed of 4000 rpm. Only the time at rated speed is considered in the subsequent discussion of bucket life.

Stress and Temperature Distribution

The distributions of centrifugal stresses and temperature in buckets during engine operation are shown in figure 2. The stresses in bucket airfoils were calculated using density and cross-sectional-area measurements by the method described in reference 3. To obtain the bucket temperature distribution prior to evaluating the Guy alloy buckets, a full turbine wheel of S-816 buckets was operated in the engine for a few minutes. The bucket temperature was obtained from thermocouples installed in buckets and connected to a recording device through slip rings, using the method described in reference 4.

During the engine evaluation of Guy alloy, bucket stress and temperature were controlled by regulating the engine speed and exhaust-nozzle opening, respectively; bucket temperatures were measured by thermocouples installed in two S-816 alloy buckets. Since S-816 does not have adequate strength to operate at 1650° F for long times with normal J33-9 bucket stresses, a 1-inch section was cut from the tip of the airfoil to reduce centrifugal stresses to an acceptable level.

Bucket Elongation Measurement

Four buckets were scribed near the trailing edge as shown in figure 3. Bucket elongation measurements were made of the scribe marks after 15 and 60 hours of operation using an optical extensometer.

Stress-Rupture Tests

4124 Stress-rupture bars were cast along with the buckets, and these were tested at 1650° F and 15,000 to 30,000 pounds per square inch.

RESULTS

Bucket Performance

All buckets were operated in the engine test for 102 hours. A fatigue failure of the centrifugal compressor rotor at 102 hours ended the test.

The damaged compressor rotor and housing are illustrated in figure 4(a). Fragments of failed components passed through the combustion section and damaged the buckets as shown in figures 4(b) and (c).

Elongation of Buckets

Elongation measurements were taken after 15 and 60 hours at rated speed. The greatest elongation observed was 0.0035 inch in a 1/2-inch-gage length, or less than 0.8 percent.

Microstructure and Grain Size

Photomicrographs of the typical as-cast structure of Guy alloy buckets are shown in figure 5(a). The photomicrographs in figure 5(b) illustrate the structure after engine testing. Comparison of figure 5(a) with figure 5(b) shows that no visible change occurs as a result of engine testing. Photographs of as-cast macroetched buckets are shown in figure 6. The grain size is small and uniform within each bucket with a small difference in grain size between the two buckets.

Stress-Rupture Strength

The 1650° F stress-rupture data obtained from as-cast cylindrical test bars are shown in figure 7. The 100-hour stress-rupture strength at 1650° F is 25,500 psi.

Since the evaluation of Guy alloy buckets was terminated by the compressor failure, it may be of interest to determine what the life of the buckets might have been if they failed by stress rupture. The stress-rupture life of the material at each point along the bucket length can be predicted using the stress and temperature distributions of figure 2 and extrapolating stress-rupture data. A plot of the resulting rupture life against distance above the base of the buckets indicates the location of the minimum life of buckets in stress rupture. This section of the bucket has the most severe combination of centrifugal stress and temperature.

The curve shown in figure 8 is typical of several constructed using mathematical and graphical extrapolation methods. The minimum is the most important section of the curve; this area is obtained from stress-rupture data and is not extrapolated. The rest of the curve should be considered qualitative. If failure results solely from the centrifugal stress and temperature, the buckets should fail about 2 inches above the base and should have an operating life of about 400 hours. In addition to centrifugal stress, it should be remembered that factors such as vibratory stresses, thermal shock, and corrosion may influence blade failures. The influence of these factors usually reduces bucket life below the stress-rupture life.

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DISCUSSION

The operation of a full wheel of Guy alloy buckets for 102 hours without a failure at a bucket temperature 150° F above current temperatures indicates that it has considerable potential as a bucket material for advanced temperatures. The termination of the test after 102 hours because of a compressor failure was unfortunate, but a life of 102 hours at 1650° F without a failure compares favorably with S-816 alloy evaluated at 1500° F. Alloy S-816 evaluated at 1500° F in similar tests has a mean life of about 200 hours with time to first failure as low as 34 hours (refs. 5 to 8). The life of the Guy alloy buckets being studied probably would have been appreciably longer than 102 hours; on the basis of stress-rupture considerations alone, the alloy should have run about 400 hours in this engine.

The J33 engine is a relatively high-stress engine, with bucket stresses of about 20,000 psi in the zone where stress-rupture failure is most probable. Many engines of more recent design operate with bucket stresses of the order of 13,000 to 15,000 psi; in these relatively low-stress engines, Guy alloy might be suitable for operation at temperatures above 1650° F.

The impact resistance of Guy alloy appears adequate for bucket applications even though the alloy has less impact resistance than most forged alloys now in use. The impact data of table I from the drop

impact test indicates that Guy alloy has less impact resistance than X-40 alloy, but has more impact resistance than some of the other materials shown. Alloy X-40 with an impact strength of 48 inch-pounds is known to have adequate impact strength for bucket applications, while some other materials shown in table I (such as alloy 35-100 and the cermets) with about 3 inch-pounds are known to be inadequate for bucket applications similar to that described herein. The impact strength necessary for bucket applications is therefore known to be within these limits. The exact value, however, is not known. Thus, other impact-strength evidence must
4124 be considered in evaluating Guy alloy as a bucket material.

The resistance of a bucket to impact failure when a foreign object or failed components pass into the path of the rotating buckets during engine operation is a very practical criterion for evaluation. Foreign objects entering an engine can do considerable damage to buckets (ref. 9) and may destroy a large percentage of the buckets, if the bucket meterial is extremely brittle. The large quantity of material that passed through the engine into the path of the buckets when the compressor failed imposed a much more severe impact test on the buckets than a normal foreign object. Despite the abnormally severe conditions, the buckets did not shatter or break off at the base. The damage was confined to the point of impact. Thus, the failure of one bucket should not cause a catastrophic chain reaction of bucket failures as more brittle materials have done. The general nature of damage sustained by most of the buckets, was an "eroding off" of numerous small pieces (figs. 4(b) and (c)). Many fragment collisions were absorbed without causing fracture (fig. 4(c)). Evidence of resistance to impact damage in an engine was also obtained in the preliminary proof test.

Additional testing of Guy alloy buckets in an engine test at 1650° F is needed to determine the scatter of normal failure times for the alloy.

SUMMARY OF RESULTS

During a program conducted to evaluate Guy alloy as a turbine-bucket material for operation at a bucket temperature of 1650° F, buckets in the as-cast condition were run in a J33-9 engine at a bucket temperature of 1650° F. The engine was operated over cycles of 15 minutes at rated speed and 5 minutes at idle speed. The results obtained are as follows:

1. Guy alloy buckets were operated successfully for 102 hours at a bucket temperature of 1650° F, indicating that Guy alloy is a potential bucket material for advanced temperatures. The test was terminated at 102 hours by a compressor rotor failure that resulted in extensive damage to the engine and the test buckets.

2. While not as ductile as forged materials now in use, Guy alloy appeared to have sufficient ductility to be considered for bucket use. The buckets did not shatter when the compressor failed and a large quantity of material passed through the turbine. Numerous small pieces were chipped off the upper portion of bucket airfoils by impact collisions, but the impact of other fragments was absorbed with no fracture occurring.

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Cleveland, Ohio, September 21, 1956 4124

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TABLE I. - IMPACT DATA

[Obtained by H. B. Probst and H. T. McHenry at the Lewis laboratory.]

Material	Room Temperature		1200° F		1500° F	
	Notched	Unnotched	Notched	Unnotched	Notched	Unnotched
Impact strength, in.-lb						
Alloy						
Guy	12.9	16.7	15.2	22.7		
35-100	1.6	2.0		2.5		2.5
HE1049	3.7		3.2		4.5	
73J	5.1					
Wrought Inco 550	25.8		56.0			
Heat-treated X-40	48.0					
Cermet						
K152B	2.1	4.1	1.6	3.7	1.6	
K154B	2.8	5.2	2.3	5.2	2.3	5.5
K162B	3.3	6.3	1.3	2.6		

[redacted]

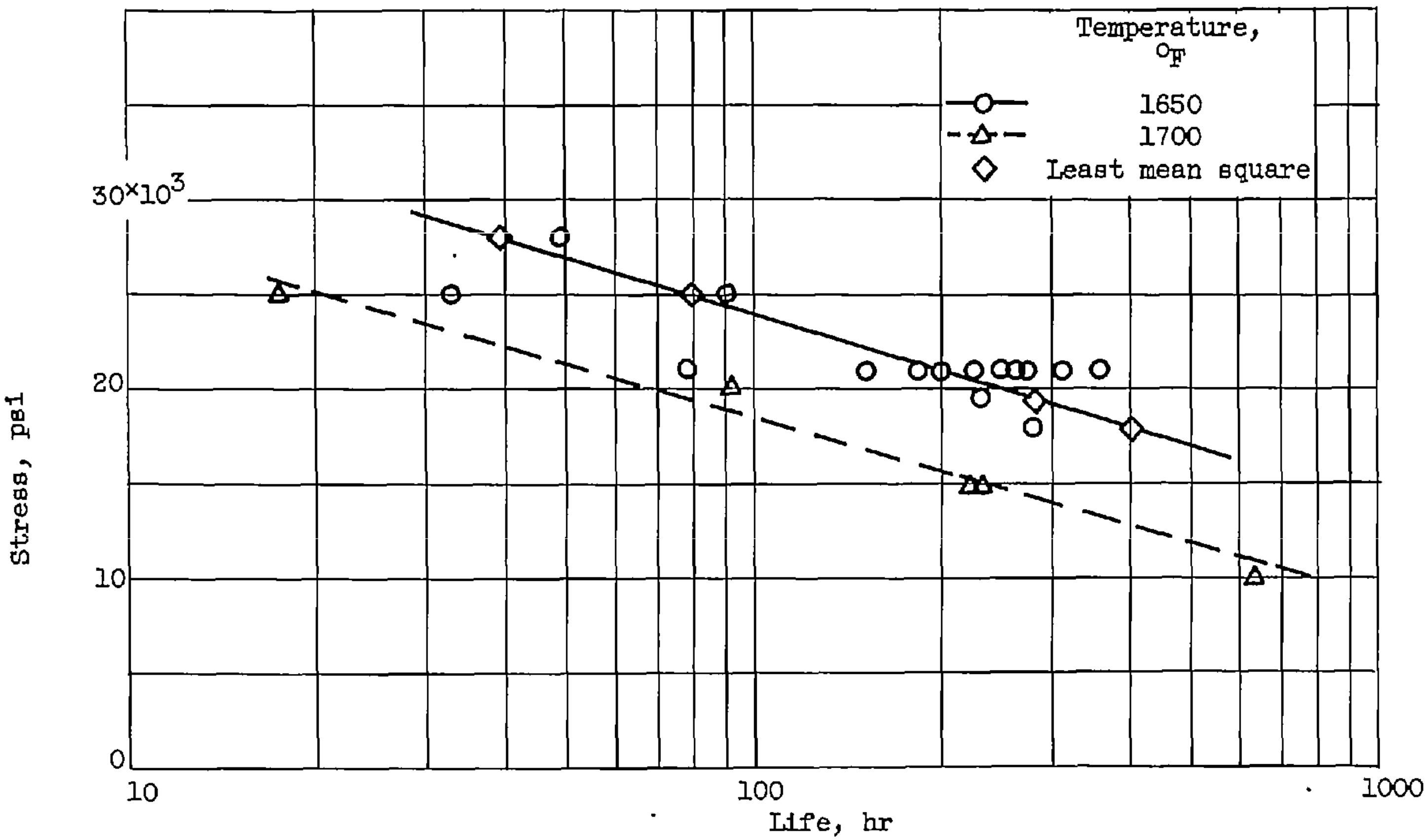

Figure 1. - Stress-rupture properties of Guy alloy cast at Lewis laboratory.

[redacted]

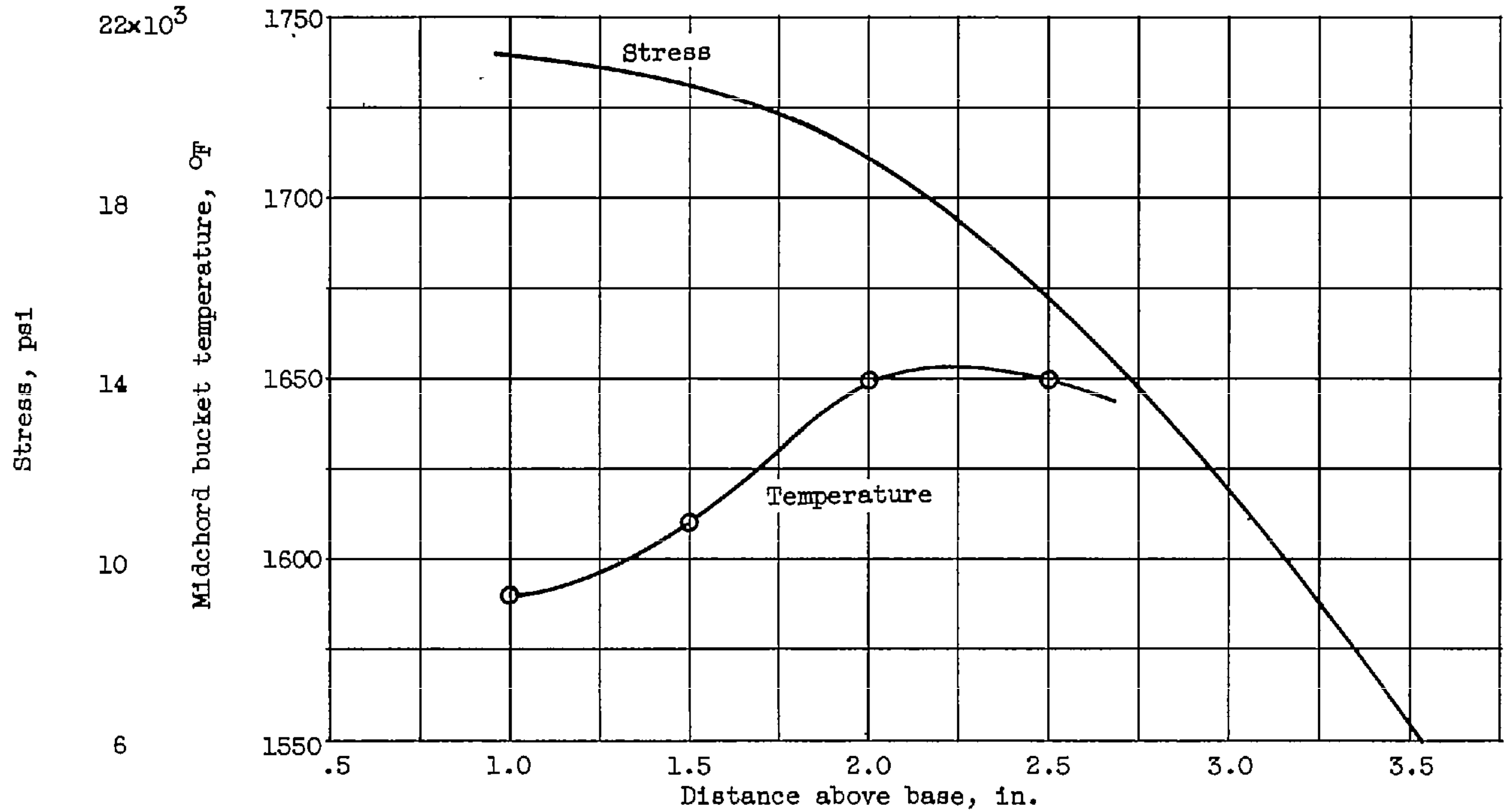

Figure 2. - Distribution of centrifugal stress and temperature in Guy alloy buckets.

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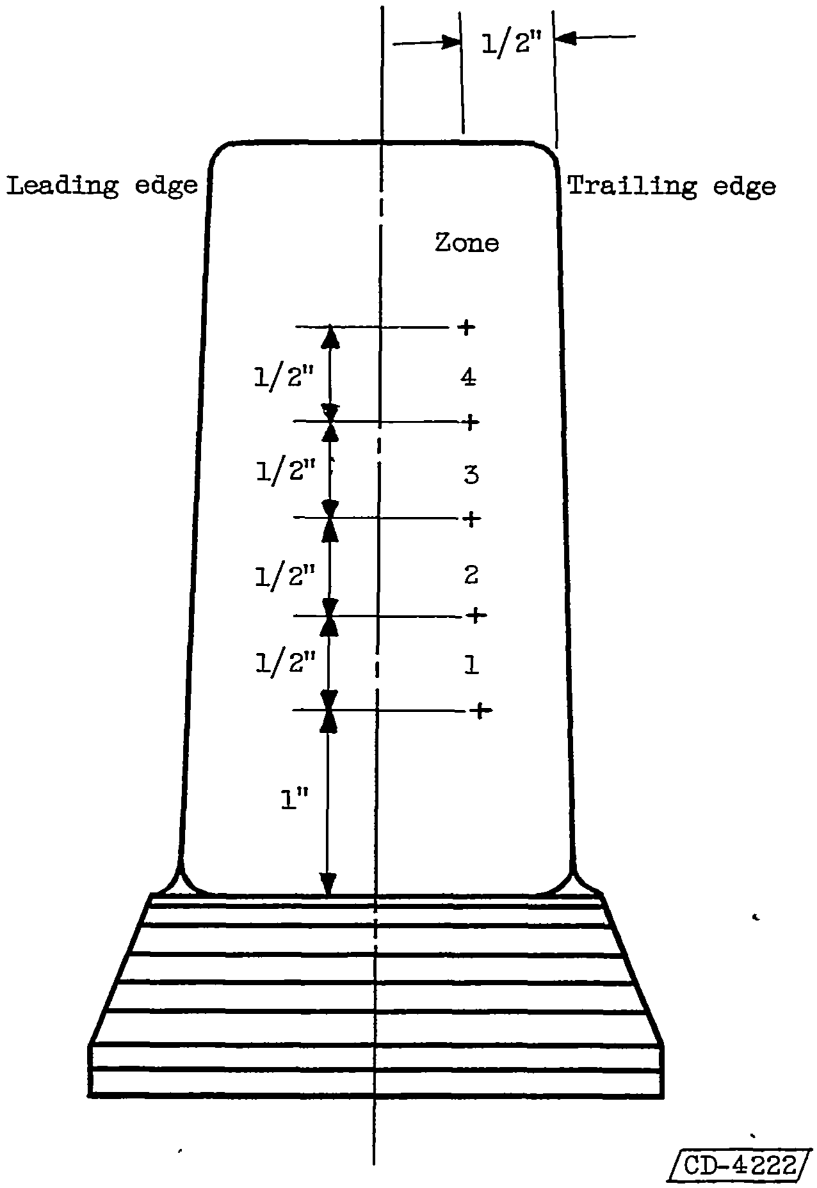

Figure 3. - Scribed bucket for elongation measurements.

(a) Compressor housing.

Figure 4. - Damage to engine.

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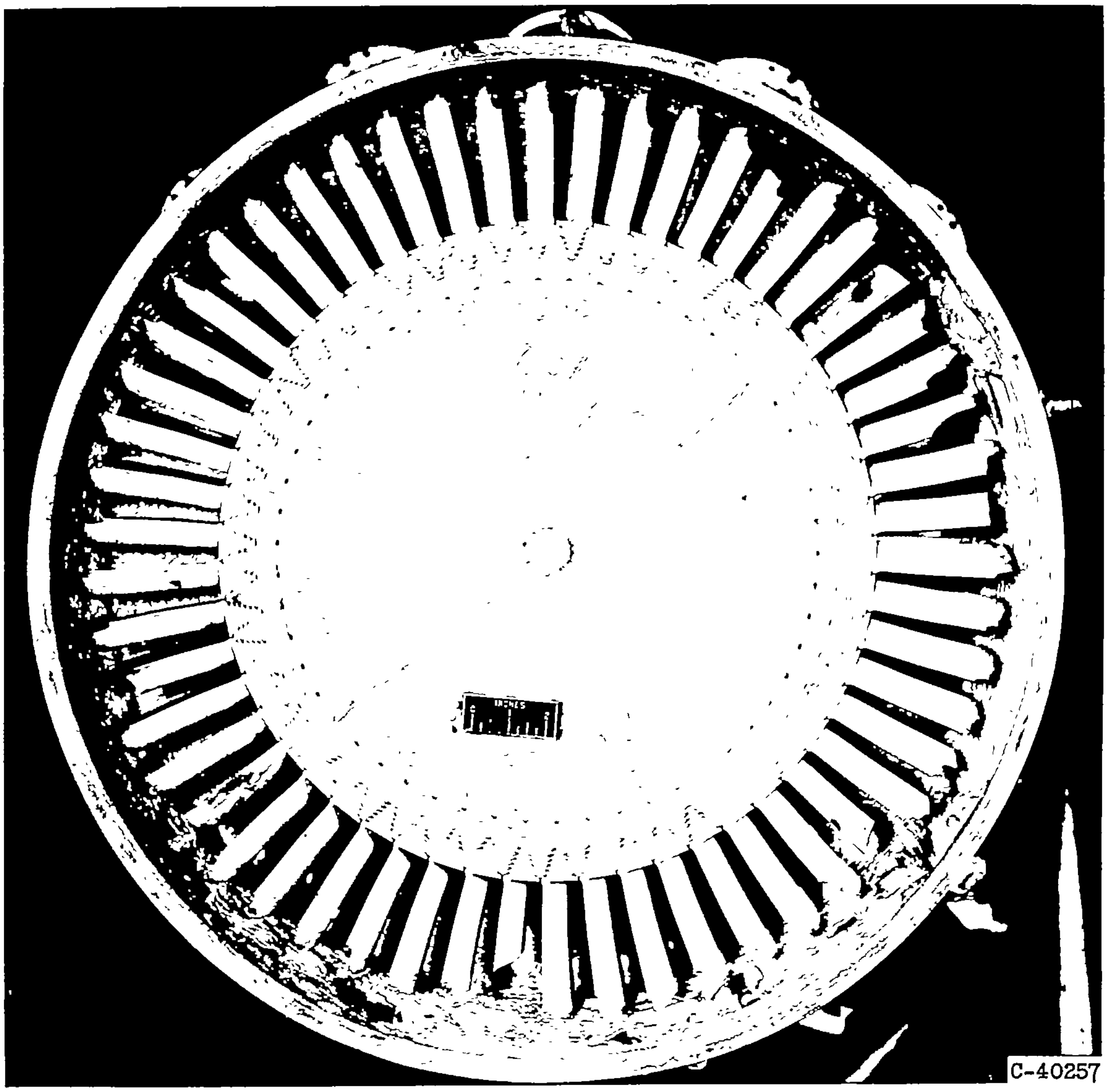

(b) Turbine; resulting from compressor failure at 102 hours.

Figure 4. - Continued. Damage to engine.

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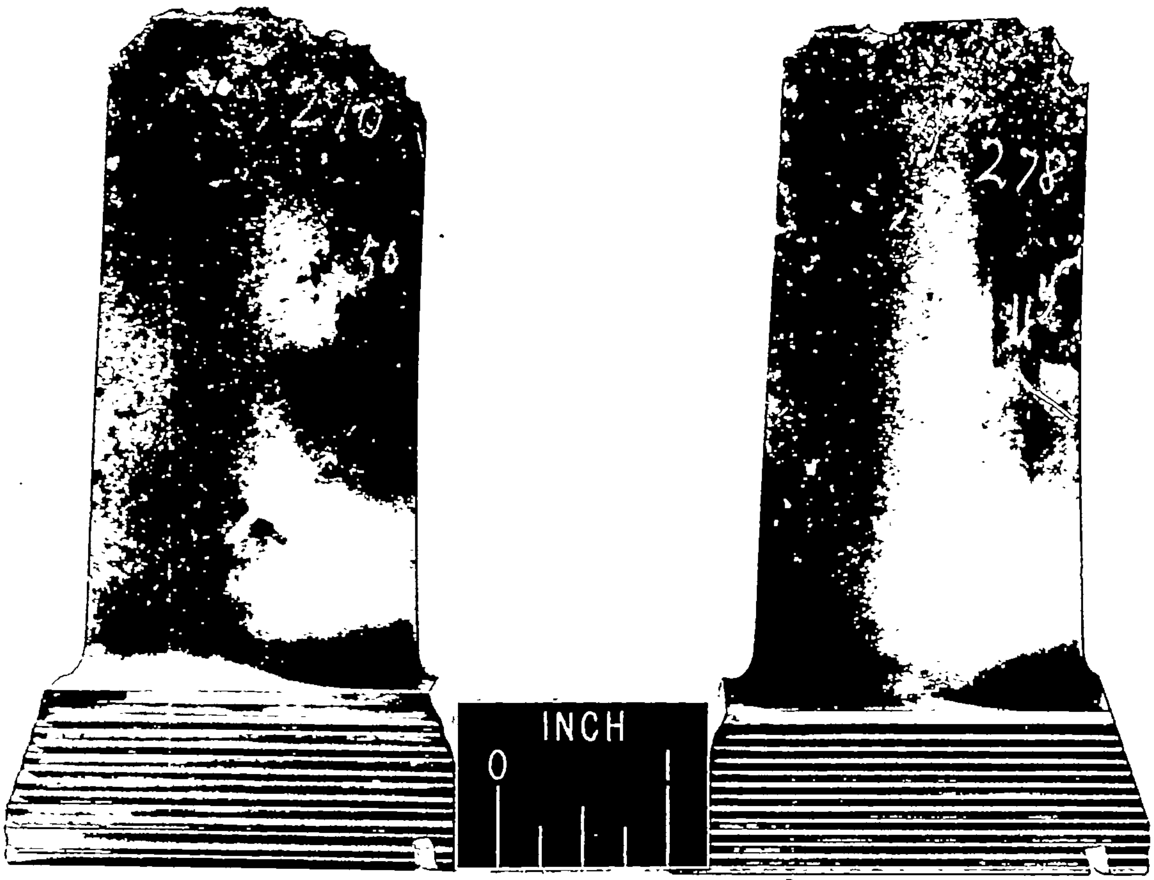

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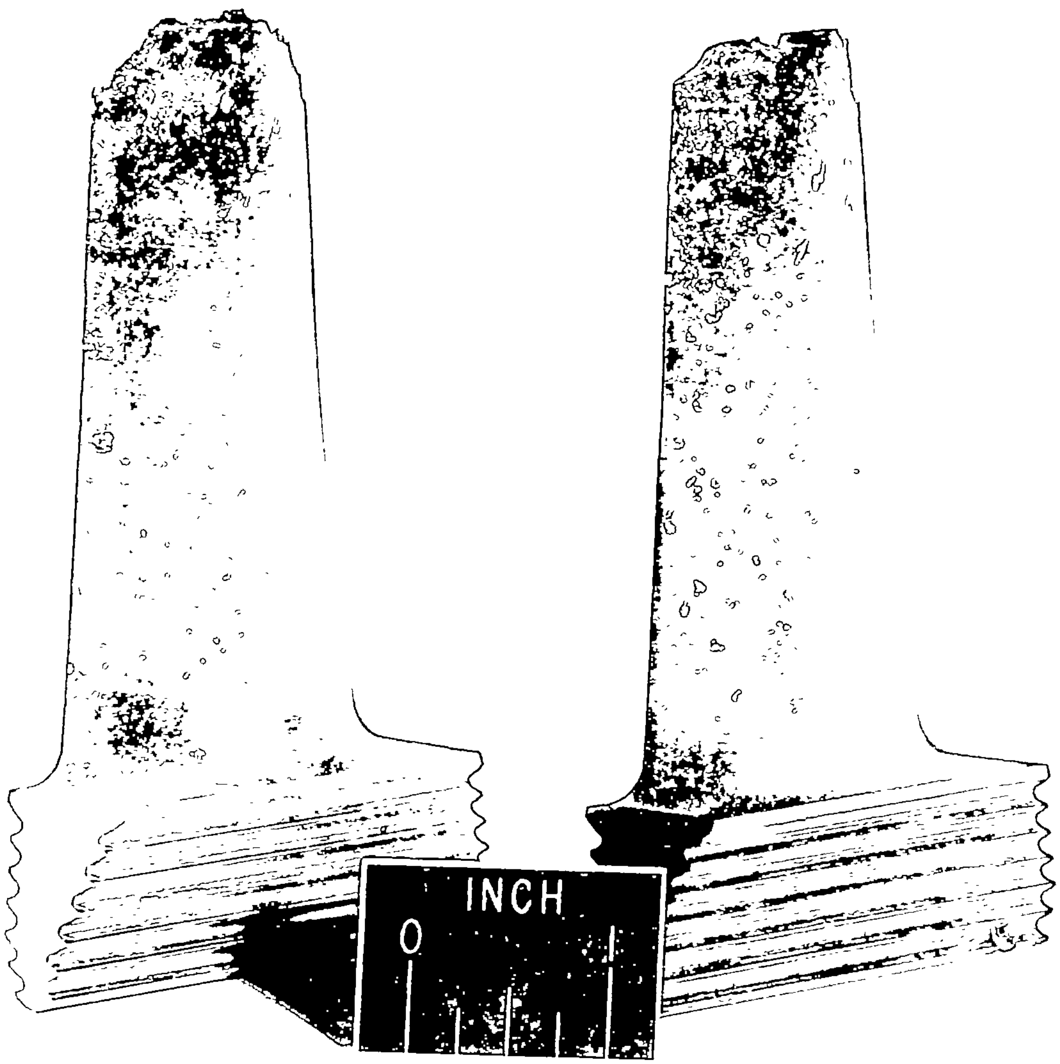
(c) Turbine buckets.

Figure 4. - Continued. Damage to engine.



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(c) Concluded. Turbine buckets.

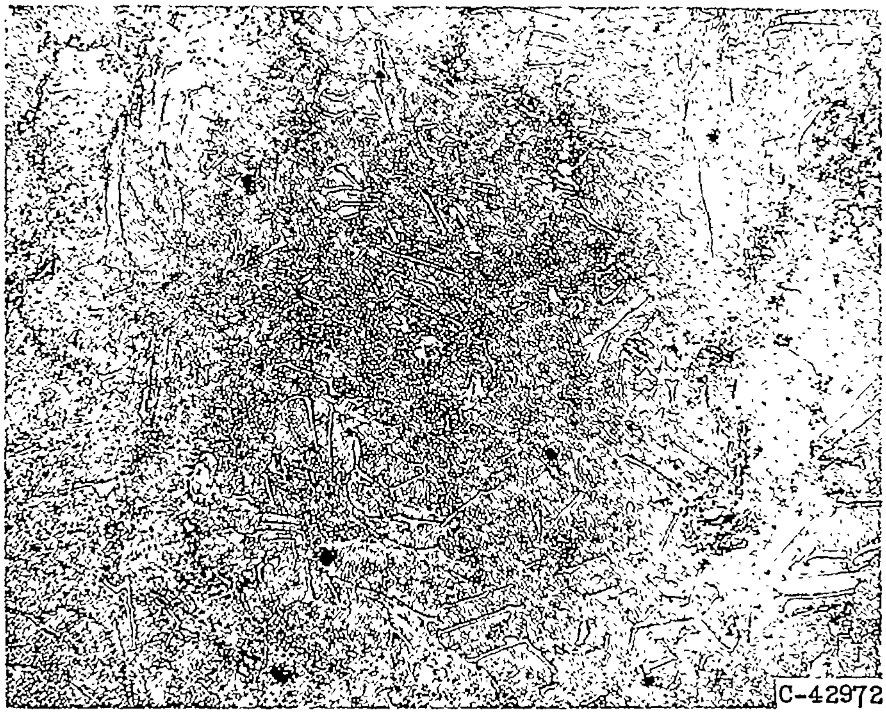
Figure 4. - Concluded. Damage to engine.

X250

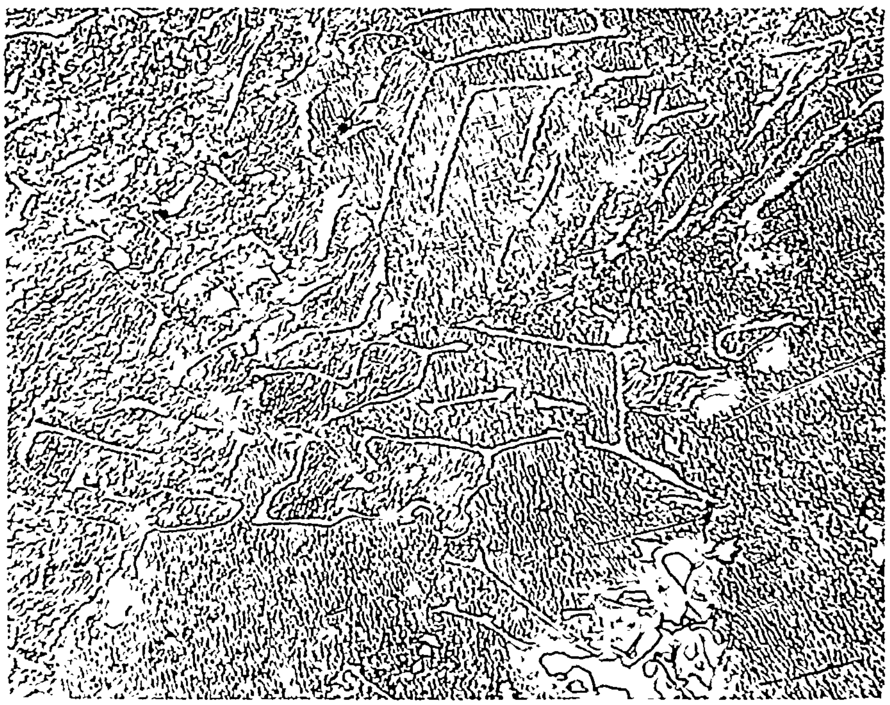
X750

(a) Before engine testing.

Figure 5. - Typical microstructure of Guy alloy. Etchant: 45 percent water; 45 percent glycerol; 10 percent hydroflouric acid.



X250



X750

(b) After engine testing.

Figure 5. - Concluded. Typical microstructure of Guy alloy. Etchant: 45 percent water; 45 percent glycerol; 10 percent hydroflouric acid.

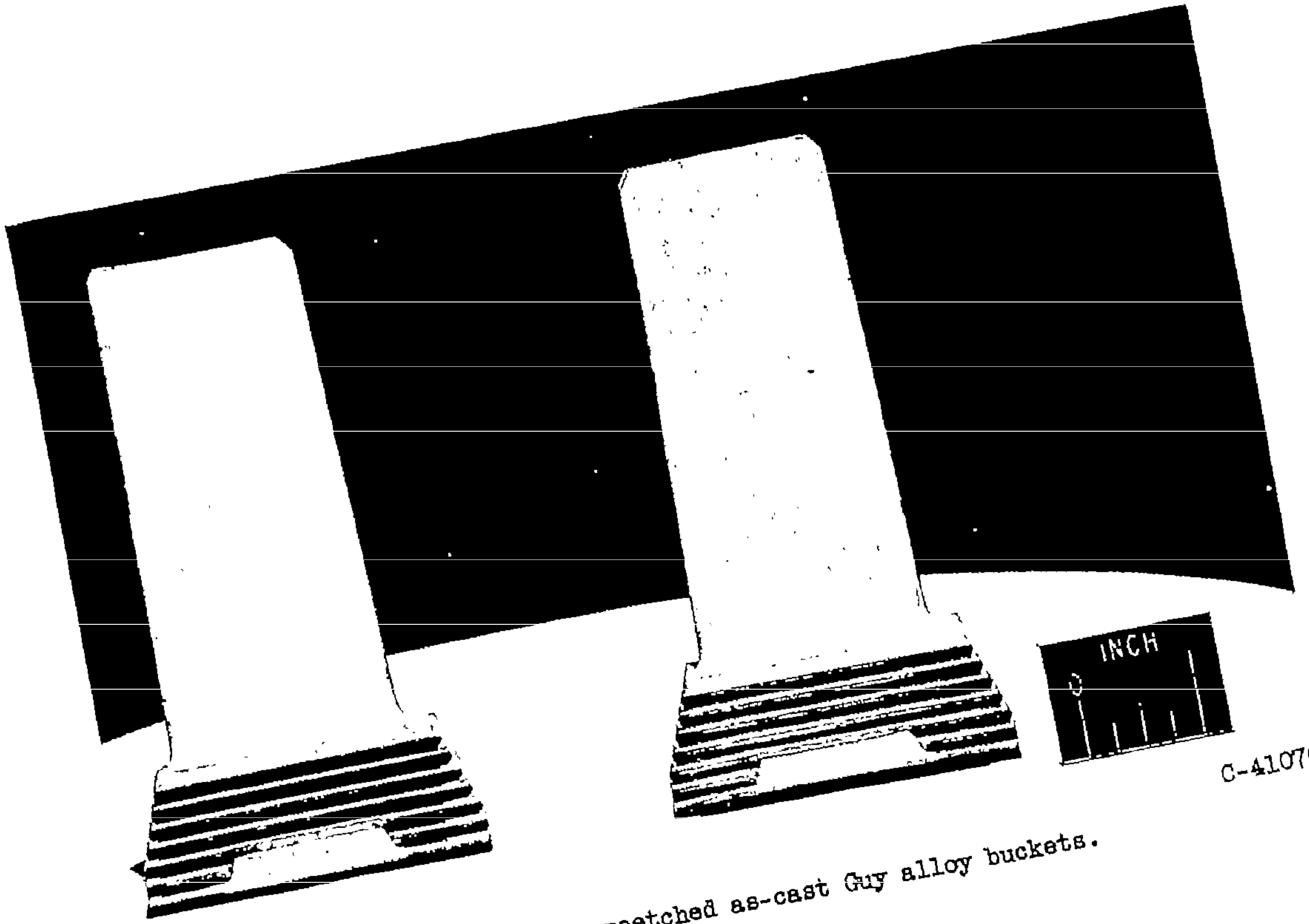


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Figure 6. - Macroetched as-cast Guy alloy buckets.

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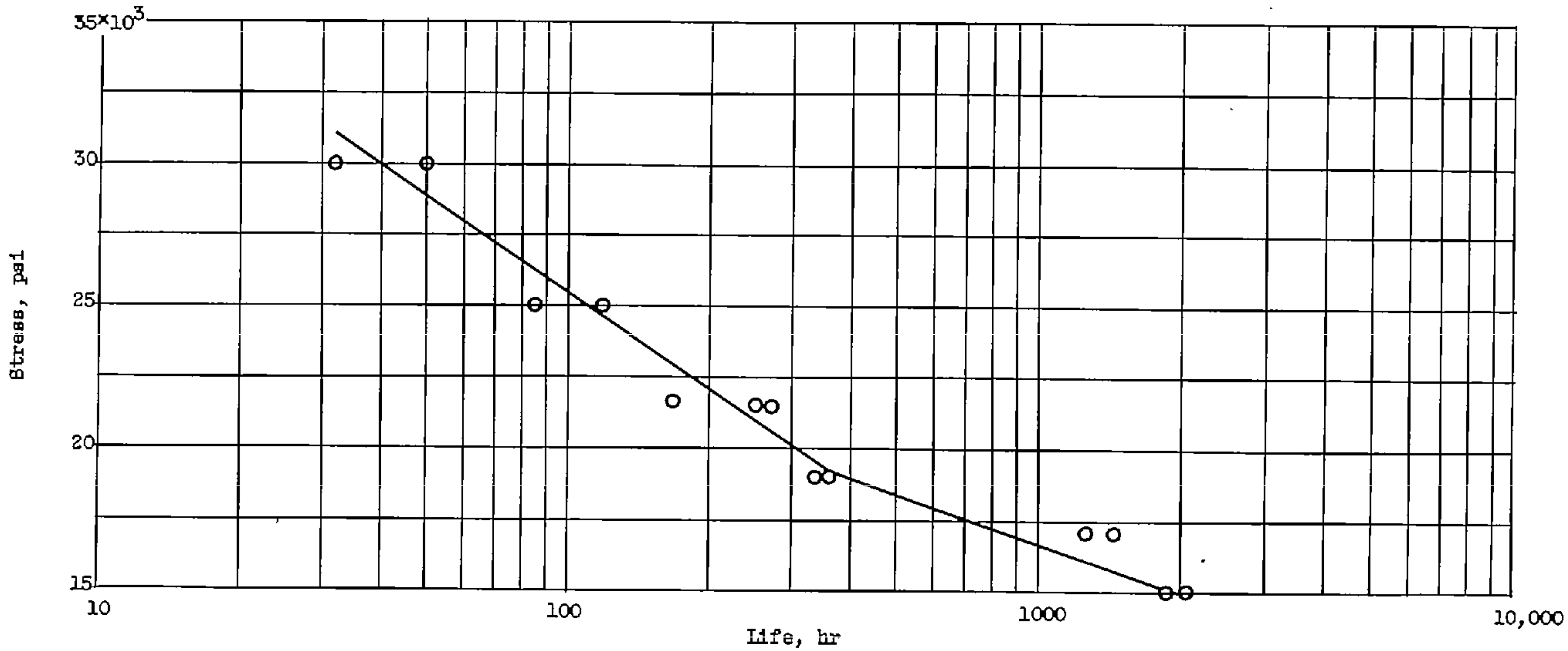

Figure 7. - Stress-rupture properties at 1650° F of as-cast test bars obtained from commercial source.

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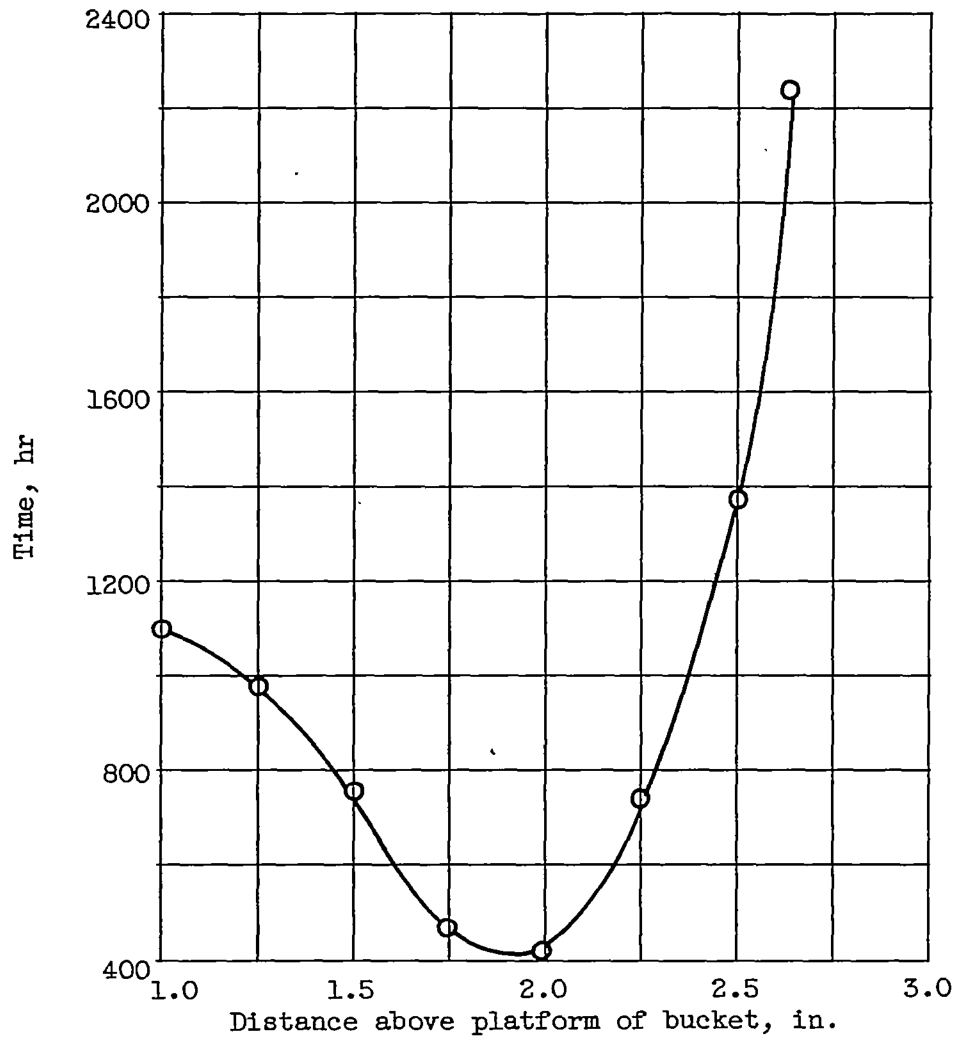

Figure 8. - Time to rupture at various distances above platform of Guy alloy buckets.

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