ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Interim Report

PRECISION-CAST ORDNANCE COMPONENTS
PROGRESS ON CRANKSHAFT AND CRANKCASE
FOR AV-1790 ENGINE FOR M-48 TANK

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Project 2400

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ABSTRACT

The present report has been prepared to give the results of the initial development effort on two complex but extremely important parts, namely, the crankshaft and crankcase for the AV-1790 engine (M-48 tank). A discussion devoted entirely to these parts should be helpful at the prestime since funds are being requested to carry on these projects to the final stages of manufacture and testing of the parts.

OBJECTIVE

The purpose of this investigation is to apply the most advanced precision-casting methods to the production of large ordnance components to obtain substantial reduction in cost or critical materials as well as improvement in design.

CAST CRANKSHAFT

With the help of the Continental Aviation and Engineering Corporation, stress analyses of single-throw sections of several precision-cast designs were compared with the present forged product. These measurements have resulted in the design of a lighter replacement which can be cast with a 14% reduction in stress and with substantial saving in SAE 4340 steel and machining time. In addition to these advantages in processing and design, the survey given in the text indicates that the cost of the cast shaft should be 50% lower than the present forged shaft. It is proposed to proceed with precision-casting crankshafts of this new design using semi-permanent graphite molds with shell-molded cores in some sections.

CAST FERROUS CRANKCASE

The requirements for components carrying greater loads in advanced tank design have led to very heavy (4-in.-thick) sections of aluminum alloy in the crankcase. Because of the susceptibility of these heavy sections to porosity and shrinkage, only very low design stresses can be used (3500 psi). An initial model of a lighter, stronger crankcase, which can be made of either cast steel or ductile iron has been designed and a pattern for casting is now ready. It is proposed to cast and proceed with stress analysis of the model section prior to final design and production of a full-size crankcase for service testing.

The detailed description of these parts may be given in two separate divisions: the cast steel crankshaft and the cast ferrous crankcase.

A. CAST-STEEL CRANKSHAFT, PART NO. 8717036

The production of a precision-cast steel crankshaft offers very great potential savings in machining and material costs. The present forged crankshaft requires extensive machining and is limited in design because of its method of manufacture. It is estimated that the reduction in machining and material by casting would reduce the final cost of the crankshaft by 50%.

PROCEDURE

The general procedure followed in the study of these two components was the same. Initially the design and production personnel of Continental Aviation and Engineering were contacted to assist in the study. A thorough engineering study of possible components was made, based on drawings and field inspection trips. If a part was considered suitable after this, a careful redesign was made to take full advantage of the casting process and flexibility of chemical analysis. At the completion of the phase, new drawings and section models were made for test purposes.

To illustrate the importance of the steps of redesign and model construction, Figs. 1 and 2 have been included. These are photographs of the single-throw wooden model produced as a result of the redesign study of the forged crankshaft. This model was split and used as a pattern at The University of Michigan to produce a cast SAE 4340 steel crankshaft test section, Fig. 3. After machining the bearing surfaces to the proper dimensions, the casting was submitted to Continental Aviation and Engineering for stress analysis.

Since prior work indicated that torsion was not critical, a comparison of bending stress was made between the forged and the cast shaft. Figure 4 shows the experimental section under testing conditions. A bending moment was applied to the shaft and the resultant strains were measured. Stresscoat was used to determine the location and direction of the principal strains. SR-4 strain gages were applied at these locations to measure the magnitude of the strains. The results of these tests are reported in units of strain. Although the stress is proportional to strain, a Mohr Circle analysis would be required to obtain the absolute magnitude of the stress as the stress is not uniaxial.

DISCUSSION OF RESULTS

The results of the tests performed by Continental Aviation and Engineering offer an interesting comparison of the forged and cast sections.

1. <u>Forging</u>.—Stresscoat indicated that the maximum principal strain in bending was in the fillet joining the crankpin and journal. Figure 5 is a photograph showing the strain concentration in the fillet area of the forged shaft. With the applied bending moment of 10,000 in-lb, the maximum strain was 670 μin./in. The range of strain was from 518-670 μin./in.

2. <u>Casting</u>.—The original design of the casting resulted in a maximum strain of 650 μin./in., a reduction of only 3% from the forged design. To make a more significant improvement the re-entrant fillet in the cheek was enlarged to .250-in. radius and blended as shown in Fig. 6.

The maximum bending strain was reduced to 575 μin./in. This modification results in a 14% reduction of maximum strain as well as a reduction in the range of strain from 152 μin./in. in the forging to 105 μin./in. in the casting.

Figure 7 and Table I give the results of this comparison of forging and casting.

TABLE I

Design	Position of Strain Gage	Bending Load (lb)	Strain (μin./in.)
Forged	1	100	325
Cast	1	100	290
Forged	2	100	257
Cast	2	100	235
Forged	3	100	330
Cast	3	100	275
Forged	1	200	651
Cast	1	200	575
Forged	2	200	518
Cast	2	200	470
Forged	3	200	668
Cast	3	200	554

Other interesting design features are indicated by Figs. 8 and 9. Figure 8 shows the small increase in strain, 10 μin./in., as a result of varying the hole size in the cheek of the cast shaft from 1/2- to 7/8-in. diameter.

To survey the variation in strain, and to confirm the stresscoat indications, the strain field at the fillet was surveyed as illustrated in Fig. 9 (modified shaft with .250-in. fillet radius).

A comparison of the new cast design and the present forged design is presented in Fig. 10. The barrel-shaped lightening holes provide a reduced hole size at the surface and strengthen the shaft in torsion. By locating the lightening hole more centrally in the crankpin, torsional resistance is also gained at the oil hole. The addition of large re-entrant fillets in the cheek results in lower maximum bending strain and a more uniform bending strain distribution. A more detailed drawing of these changes is shown in Fig. 11.

Table II contains a comparison of estimated material and matching costs for the present forged and proposed cast design crankshaft.

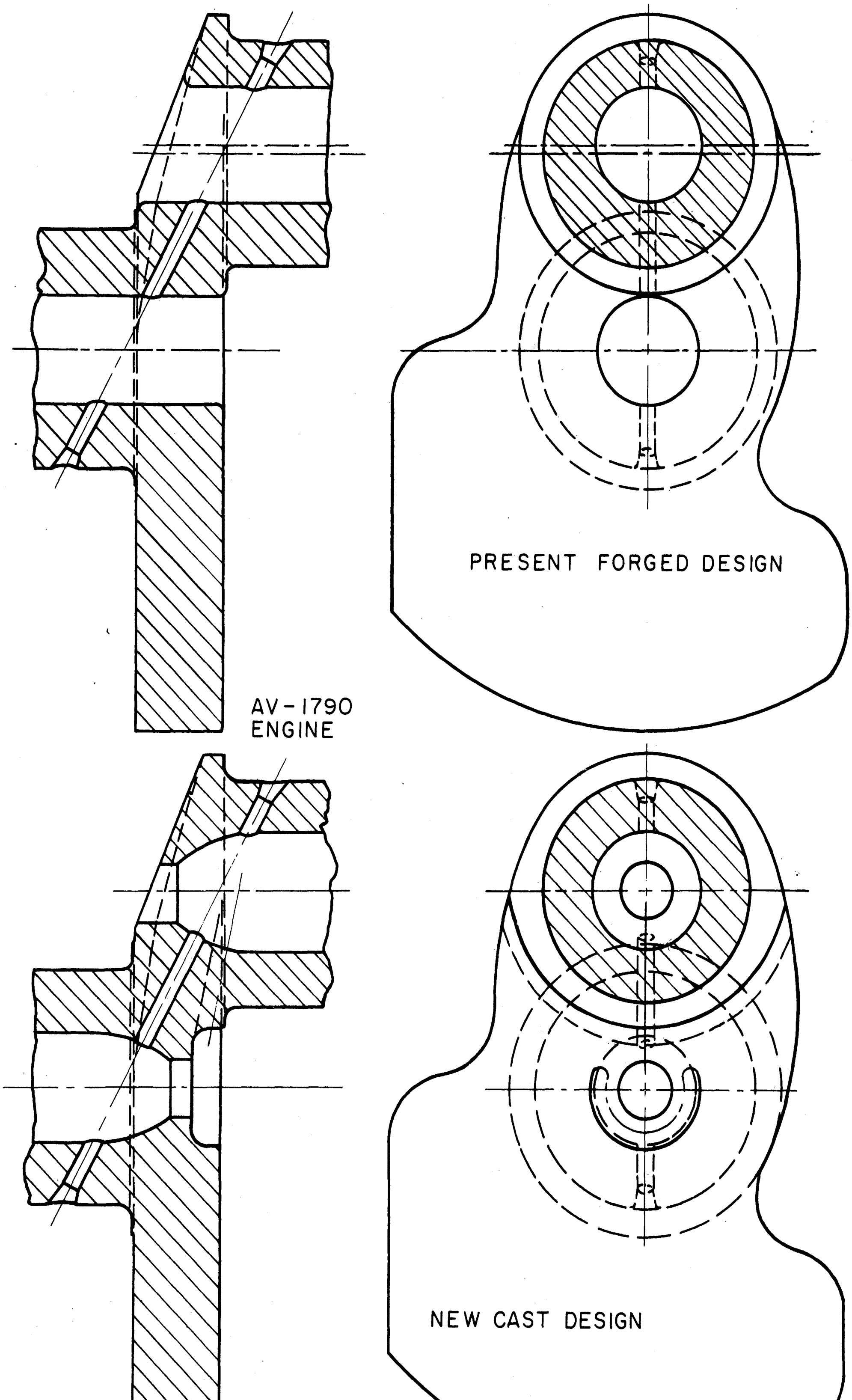


Fig. 10. Comparison of cast and forged sections of crankshaft for AV-1790 engine.

TABLE II

	Present Crankshaft	Cast 1790 Crankshaft
Material	SAE 4340	SAE 4340
Weight of stock	418 lb	315 lb
Finished weight	250 lb	232 lb
Scrap material	160 lb	77 lb
Finished cost	$500.00	$250.00
Estimated savings per crankshaft		$ 250.00
Estimated production		900 vehicles
Total estimated savings		$225,000.00

These design advantages, which cannot be obtained in forging, coupled with the savings in machining costs and materials certainly justify the production of full-size cast steel crankshafts for engine evaluation.

Based on prior success with the graphite-mold pressure-pouring process, it is proposed to produce the full-size shaft by a combination of graphite mold and ceramic cores. Griffin Wheel Company has submitted a proposal for this investigation.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the redesign and testing performed on a section model, the following conclusions and recommendations appear justified:

1. The new cast-design crankshaft provides a 14% reduction in bending strain and develops a more uniform strain distribution in the most critical areas of the crankshaft.

2. The combination of redesign and precision casting by the graphite-mold pressure-pouring process will reduce the machining and material cost to 50% of the present forged component.

3. A sub-contract should be negotiated with Griffin Wheel Company for the experimental production of cast crankshafts for ordnance engine evaluation.

B. FERROUS CAST CRANKCASE

Until the present time, sand cast aluminum alloys have been used exclusively for the 1790 M-48 tank engine and other similar engines (Figs. 12 and 13). With the increase in design stresses this material is fast becoming inadequate. The heavy sections of this component make it susceptible to shrinkage and gas porosity. Because of this susceptibility, the allowable design stress for this material is extremely low, 3500 psi. In the present crankcase and to a greater extent in the new diesel engine it would be advantageous to have a material of much greater strength and reliability. A ferrous cast crankcase (either steel or ductile iron) offers these possibilities.

PROCEDURE

Initial redesign work on the crankcase was undertaken to produce a permanent mold aluminum-alloy case. More recent study of material and the advent of the experimental diesel engine necessitated a change of objective. The high stresses especially developed by diesel service demanded a material of much better mechanical properties. In view of this, two new studies have been pursued. A cast steel crankcase has been designed for production in cast sections for subsequent assembly by welding. This same design will be used for production of a complete ductile iron crankcase.

A test-section model of this new design has been produced at The University of Michigan. This wooden model is suitable for use as a pattern to produce the cast steel sections. A complete test program for evaluating this design and these materials will be performed prior to producing a number of full-size test crankcases for ordnance evaluation.

DISCUSSION OF RESULTS

A section of the present design aluminum crankcase is shown in Fig. 14. A comparison of the present aluminum and proposed ferrous crankcase can be obtained by reference to Fig. 14. The much greater strength of the ferrous base alloy will permit a drastic reduction in wall thickness. The gain in mechanical properties will be far more than the 3-to-1 density increase from aluminum to iron. Thus the over-all weight of the ferrous case should be approximately the same as that of the present one, but it will be more compact and much stronger.

A proposal for the production, welding, and testing of the cast steel crankcase sections has been submitted by Continental Aviation and Engineering. The ductile iron crankcase will be produced at The University of Michigan or by a suitable sub-contractor.

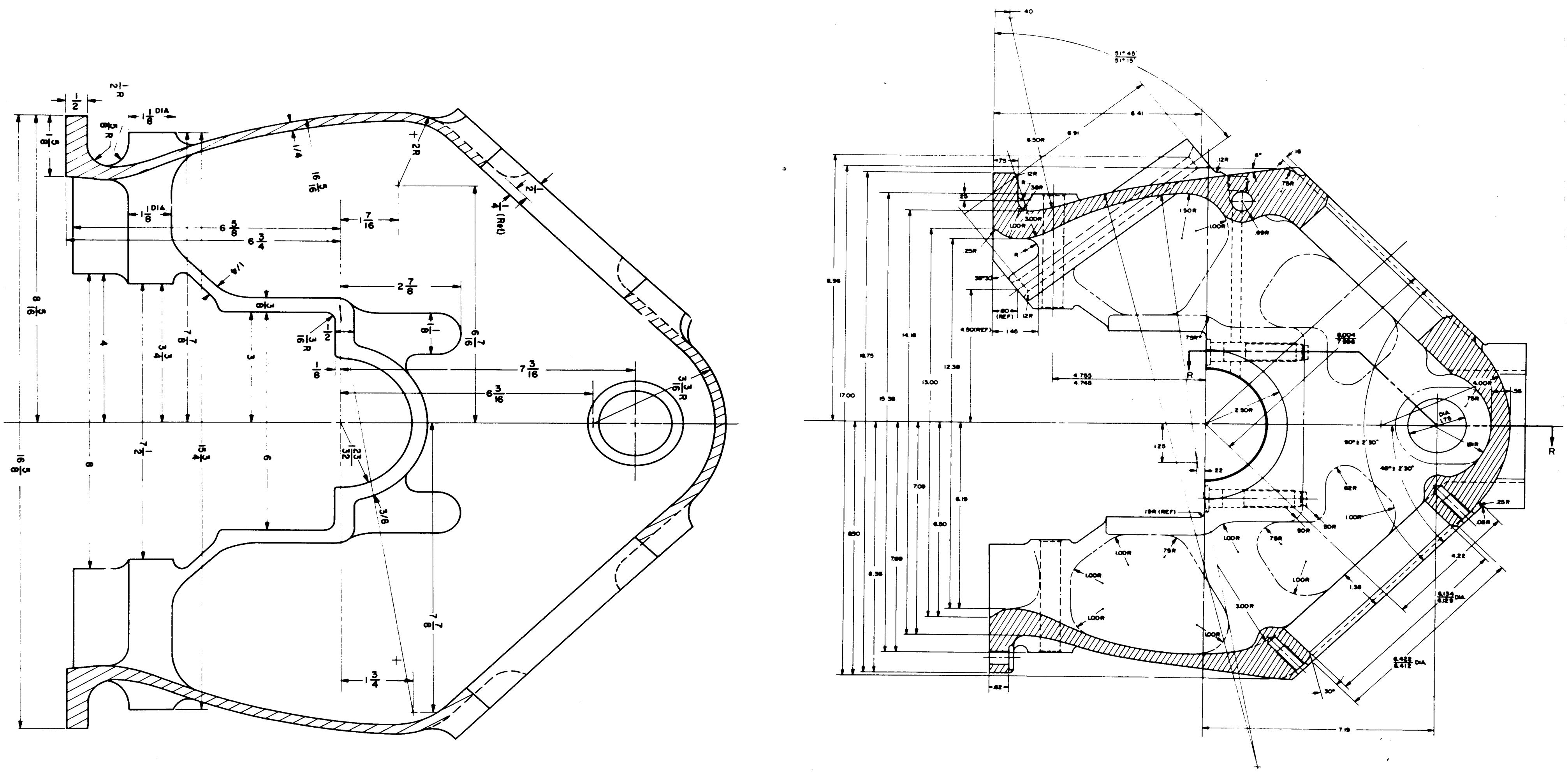


Fig. 14. Section of present cast aluminum-alloy crankcase for AV-1790 engine and new cast ferrous-alloy crankcase.

CONCLUSIONS AND RECOMMENDATIONS

The redesign and engineering evaluation of the cast aluminum crankcase yields the following conclusions and recommendations:

1. The cast aluminum crankcase should be replaced by a higher strength cast ferrous base alloy.

2. The new cast ferrous design crankcase should be subjected to a thorough stress analysis prior to producing a full-size crankcase.

3. The stress analysis of the cast steel weldment design will be performed on a five-section full-scale model produced from the single-section wooden model.

4. A sub-contract should be negotiated with Continental Aviation and Engineering for the experimental production and testing of the cast steel crankcase model and testing of the ductile iron crankcase. Development of a ductile cast iron crankcase would be carried on by The University of Michigan.

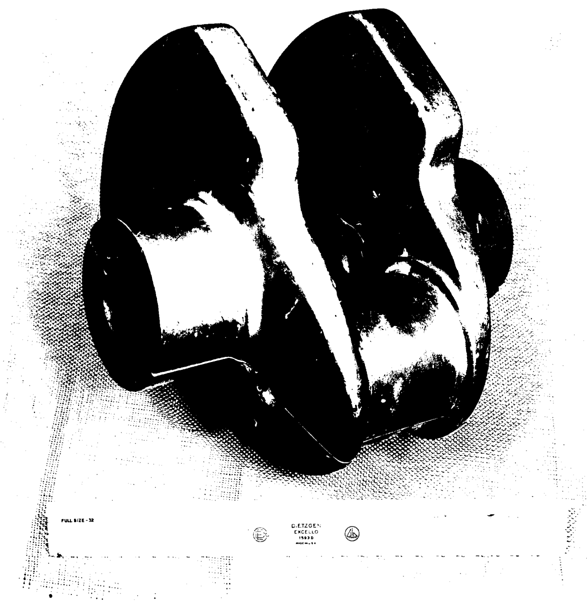


Fig. 1. Wood model of cast design crankshaft for AV-1790 engine.

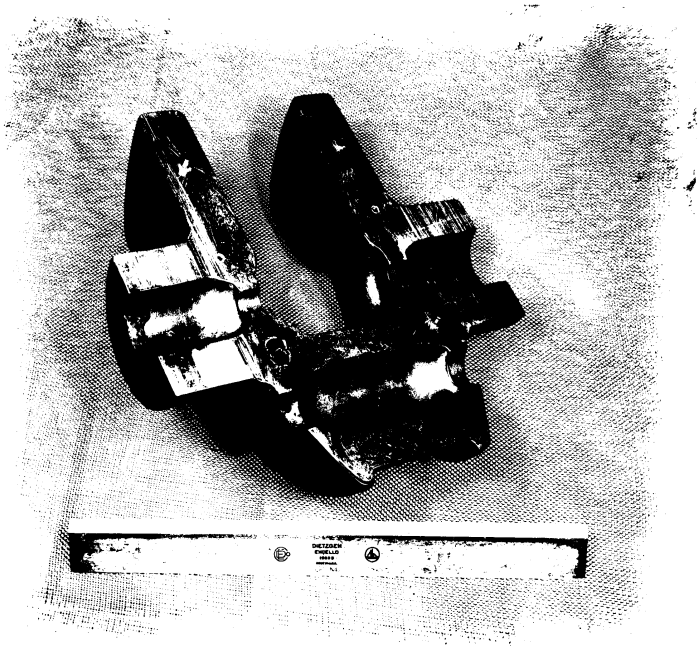
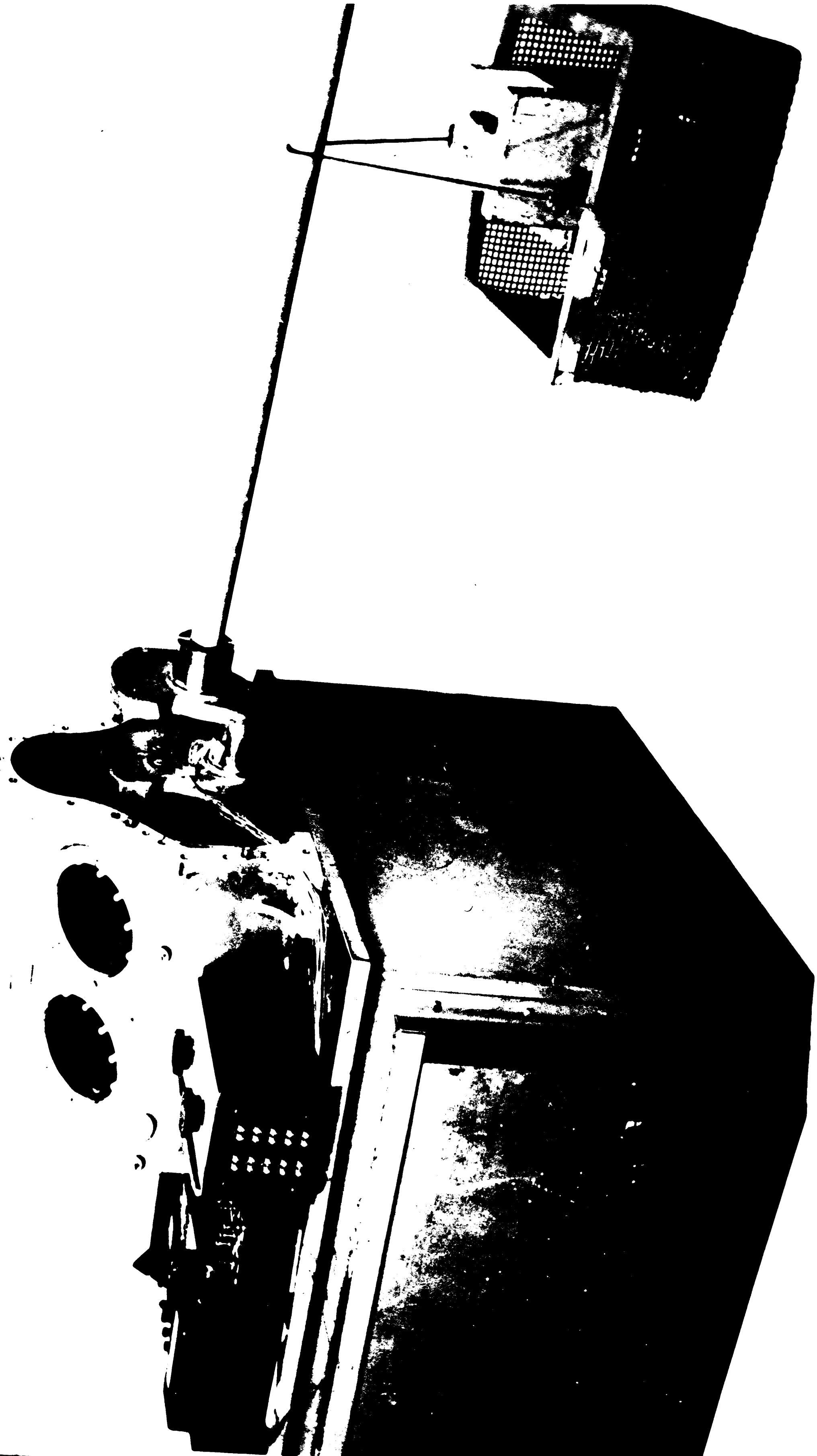


Fig. 2. Wood model of cast design crankshaft for AV-1790 engine.

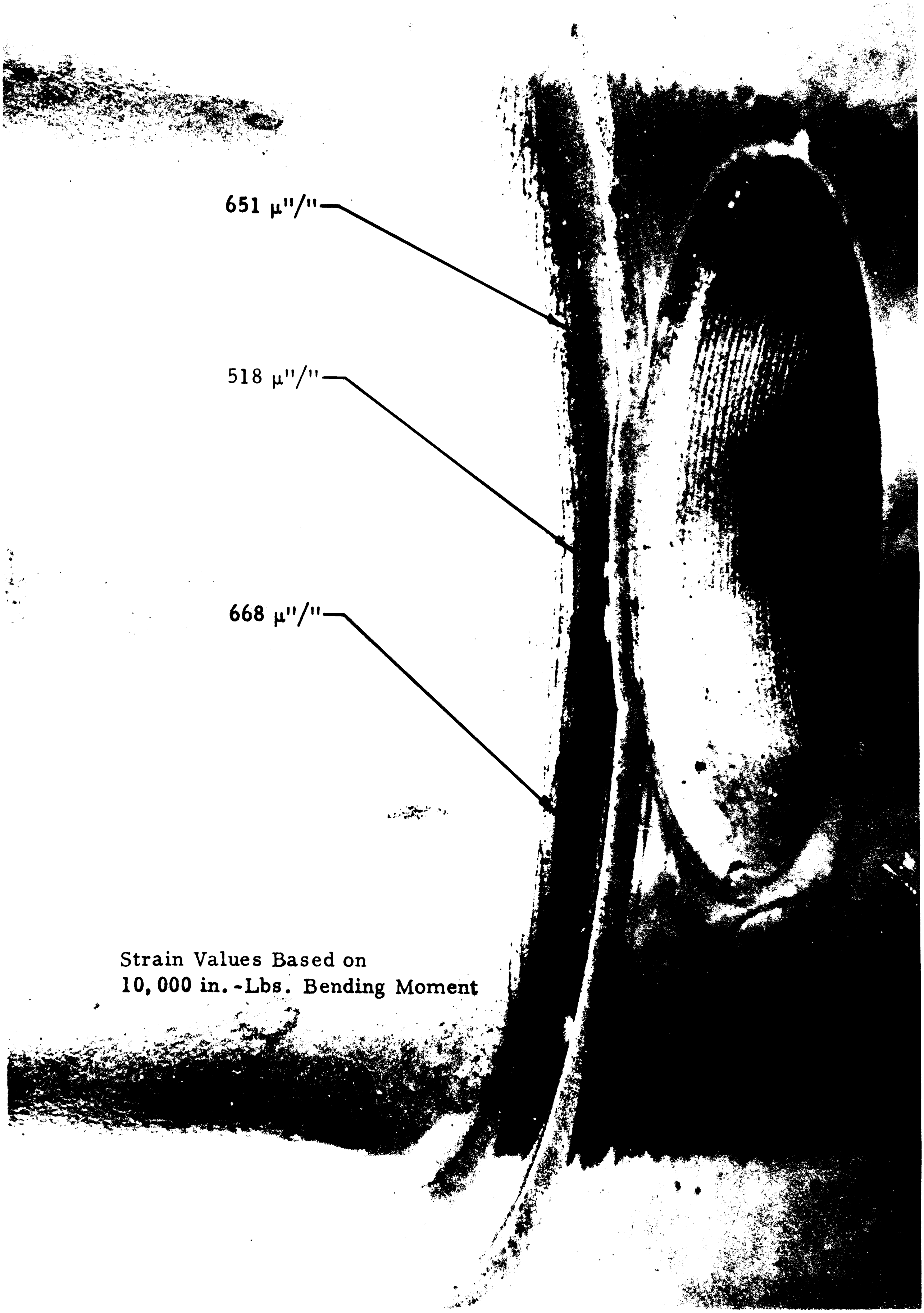
Fig. 3. SAE 4340 cast steel crankshaft test model.



· · 21207	A&T No.	Engine: AVI-1790	Date: 4-17-57

Test Set-up for Experimental Cast Steel Crankshaft Design S... 253

Fig. 4.



Neg. No. 21114	A&T No.	Engine: AVI-1790	Date: 4-10-57
Description: Stresscoat Pattern on Present Design, Forged Crankshaft, P/N 529083 - S.L. 258			

Fig. 5.

Neg. No. 21113	A&T No.	Engine: AVI-1790	Date: 4-10-57
Description:	Stresscoat Pattern on Experimental Cast Steel Crankshaft (Modified Fillet) S.L. 258		

Fig. 6.

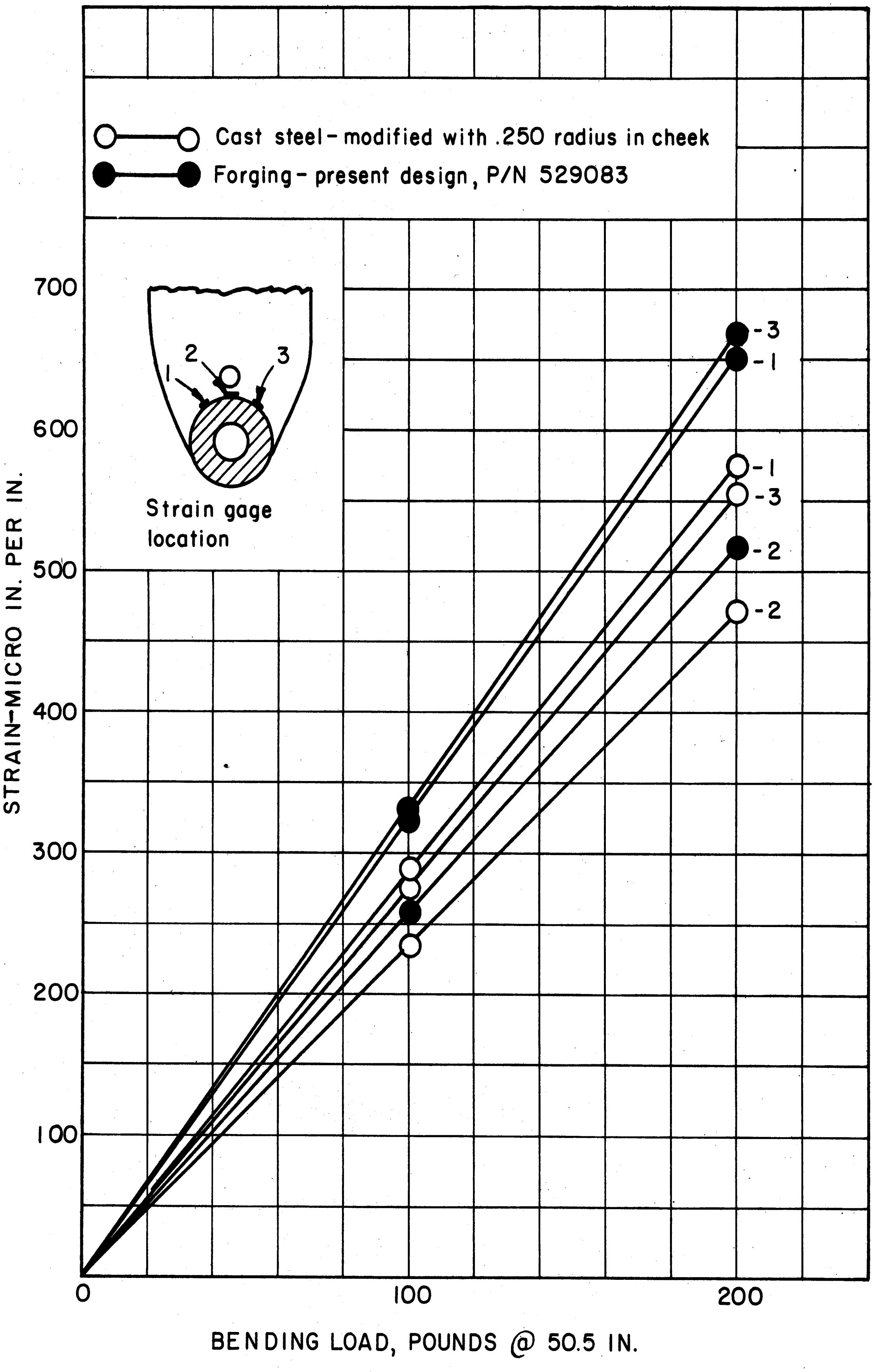


Fig. 7. Comparison of strain versus bending load in forged and cast crankshaft test sections.

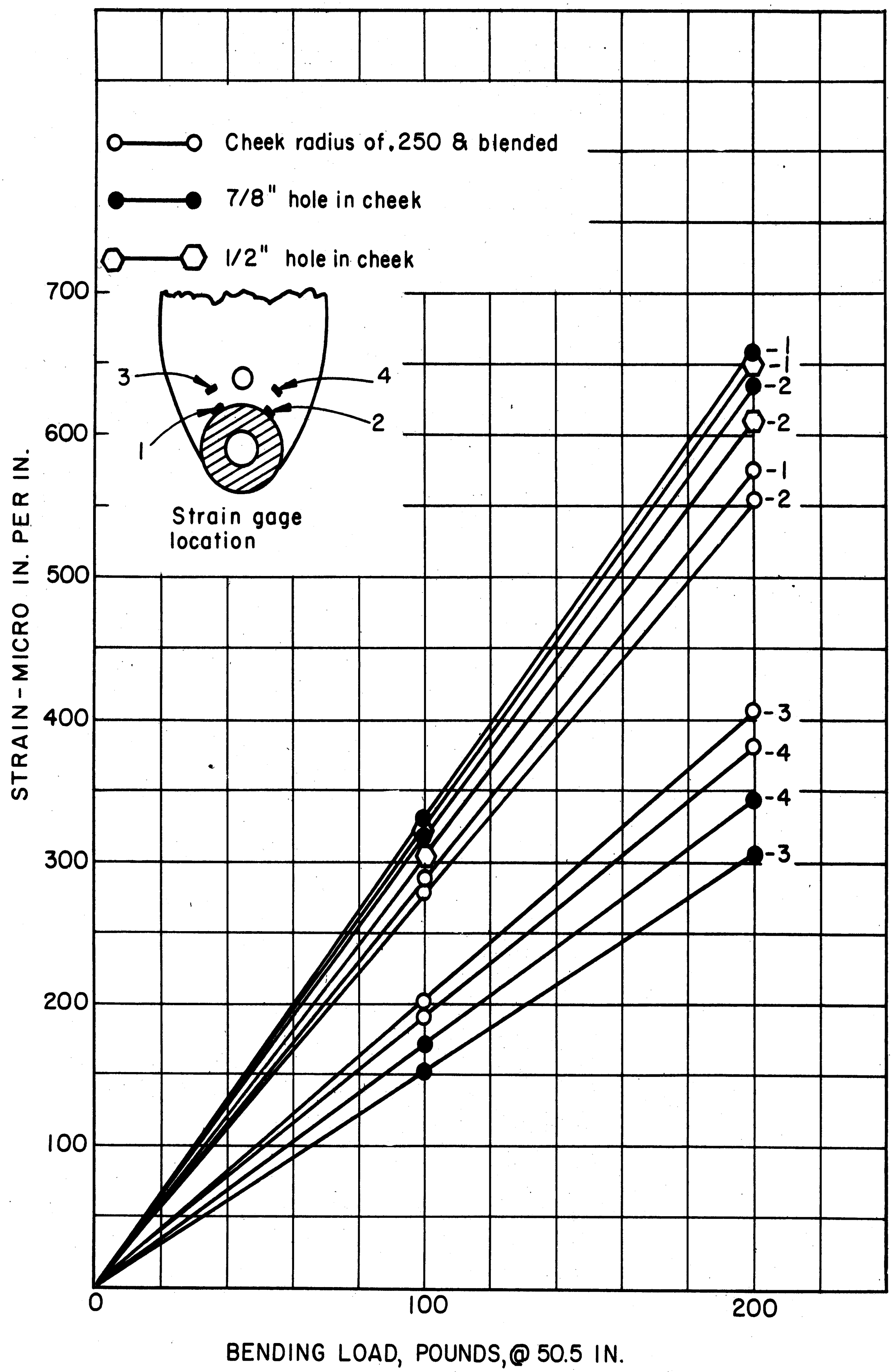


Fig. 8. Effect of cheek-hole size on strain versus bending load in cast crankshaft test section.

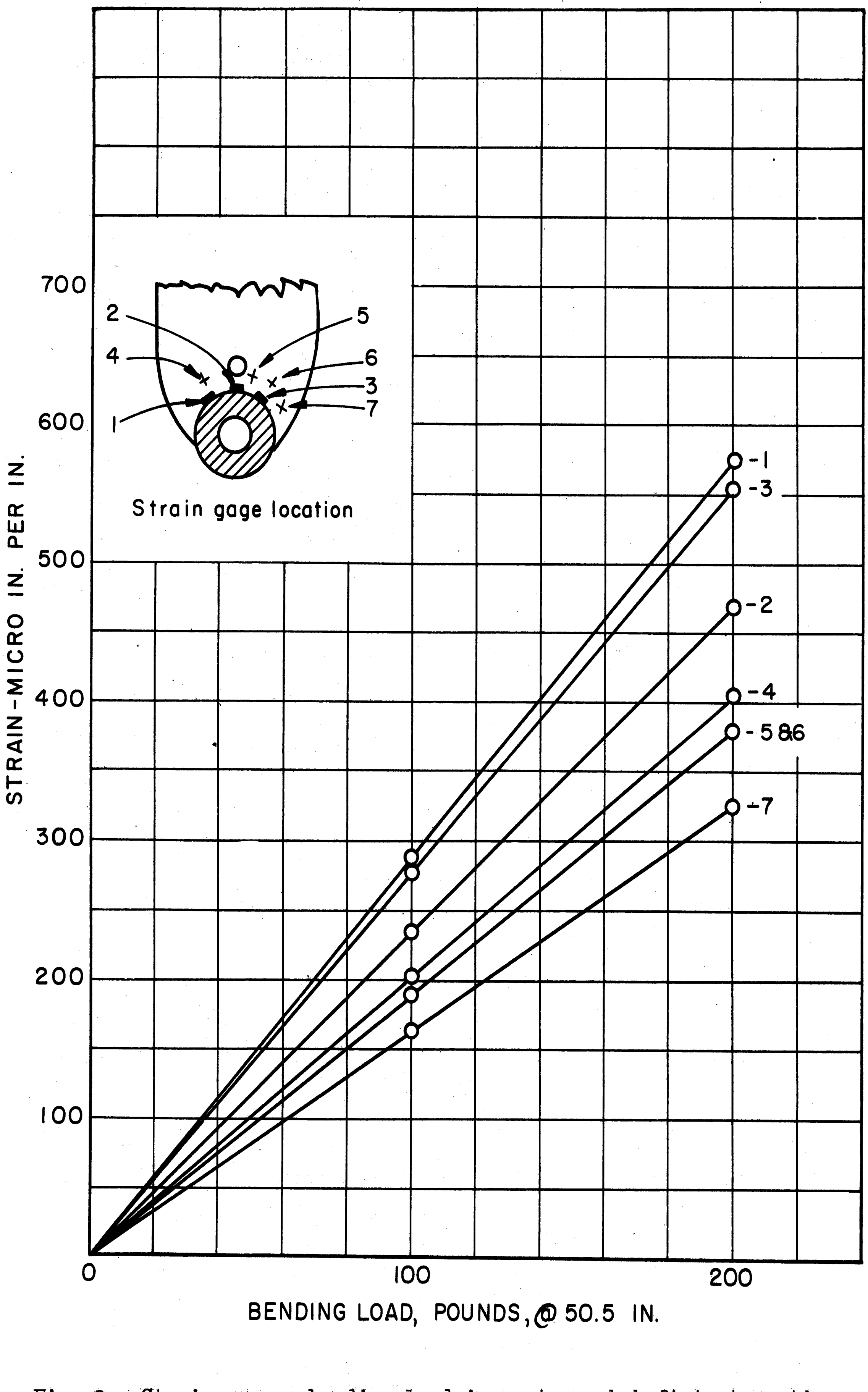


Fig. 9. Strain versus bending load in cast crankshaft test section.

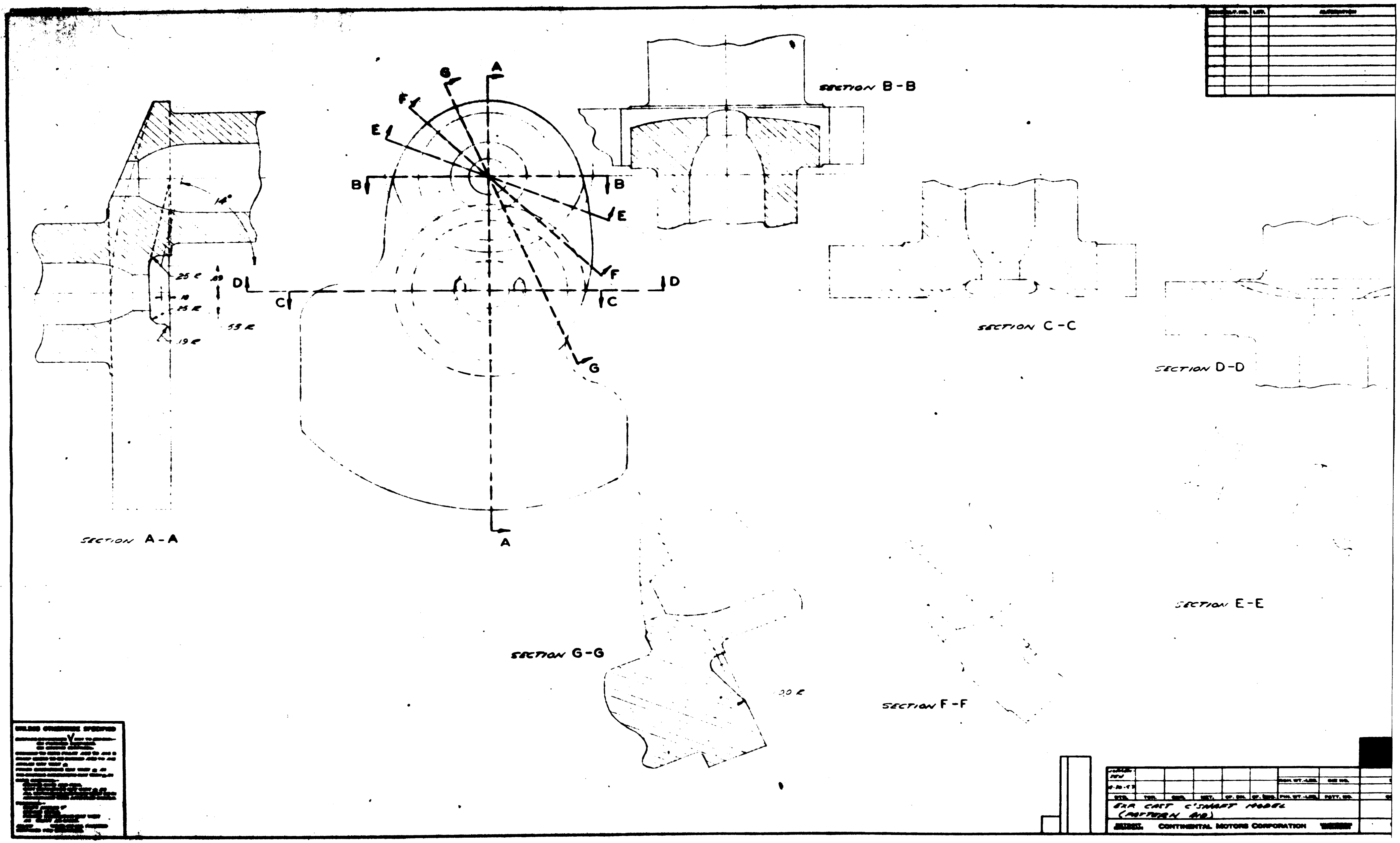

SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
EXP CAST C'SHAFT MODEL
(PATTERN AID)
CONTINENTAL MOTORS CORPORATION

Fig. 11.

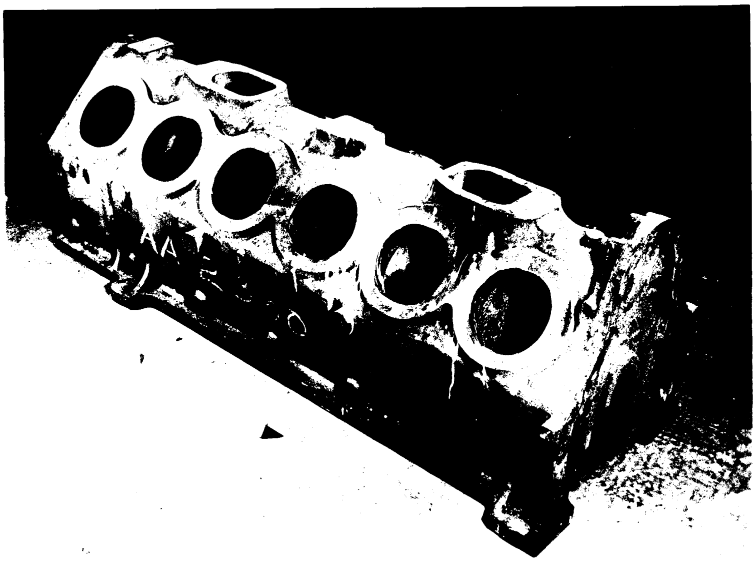


Fig. 12. Photograph of sand cast aluminum-alloy crankcase for AV-1790 engine.

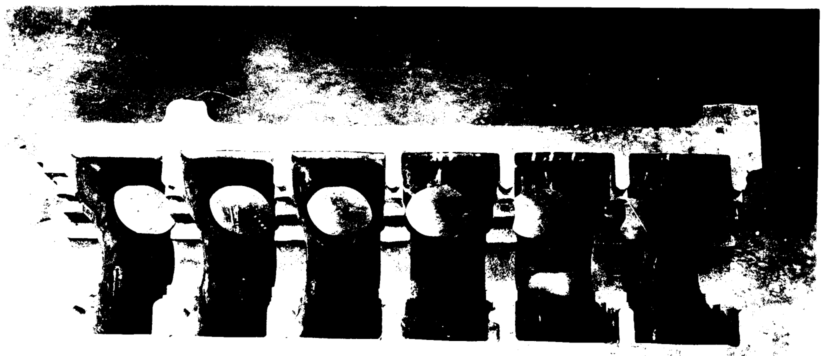


Fig. 13. Photograph of sand cast aluminum-alloy crankcase for AV-1790 engine.