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O T T A W A February 10th, 1944.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1594.

Investigation of Failure of Connecting Rod Boltsfrom a Merlin XXIX Aircraft Engine.

(Copy No. 10.)

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Origin of Request and Object of Investigation:

On January 10th, 1944, fragments of an aircraft engine connecting rod, together with broken attaching bolts, were received from the Royal Canadian Air Force, Department of National Defence for Air, Ottawa, Ontario, accompanied by the following letter:

"File 935DD-5-5(AMAE DAI)

Ottawa, Ontario,
January 10, 1944.

Department of Mines and Resources,
Ore Dressing and Metallurgical Laboratory,
568 Booth Street,
Ottawa, Ontario.

Attention Mr. C.S.Parsons

Merlin XXIX Connecting Rods

1. There will be delivered to you fragments of a Merlin XXIX engine connecting rod together with portions of attaching bolts. While the connecting rod has been damaged by mechanical action, the appearance of the bolts indicates that fatigue was the original cause of failure. It is requested that the parts be examined and a report submitted on your findings.

(Sgd.) A. J. Smith, W/C.,
for A. L. Johnson,
Air Commodore,
for Chief of the Air Staff."

(Continued on next page)

(Origin of Request and Object of Investigation, cont'd) -

It was obvious that the cause of the breakage of the connecting rod was the failure of the connecting rod bolts. The connecting rod broke up due to mechanical action. Figure 1 is a photograph of the broken pieces of the connecting rod and bolts. Figure 2 is a photograph of another bolt, indicating the points at which failure occurred. Figure 3 is a photograph showing the fracture at one point on the bolt.

Chemical Analysis:

Shavings were milled from the bolt and the following analysis was found:

		Per cent
Carbon	-	0.46
Manganese	-	0.70
Silicon	-	0.27
Sulphur	-	0.018
Phosphorus	-	0.014
Nickel	-	1.79
Chromium	-	0.13
Molybdenum	-	0.31

This analysis is very close to that specified for SAE 4640 steel. It is not known whether this is the class of steel specified for this bolt, but information received from the Packard Motor Car Company indicated that SAE 4635 is the class of steel used by them.

Microstructure:

One of the pieces of the fractured bolts was slit longitudinally and polished for microscopic examination.

The steel was examined, unetched, under the microscope, both at the point of fracture and farther up the bolt. The steel was found to be clean, with very few inclusions.

The specimen was then etched in 2 per cent nital and examined under the microscope at X500 magnification. The

(Microstructure, cont'd) -

microstructure is shown in Figure 4. A specimen was cut from another bolt which had not failed and this also was examined under the microscope at X500, after etching in 2 per cent nital. The microstructure of both bolts is the same, showing that both bolts were given the same heat treatment.

Hardness:

Vickers hardnesses were taken on the two specimens used for microscopic examination:

Fractured bolt	-	302-304 V.H.N. (32 Rock.'C')
Whole bolt	-	314 V.H.N. (33 Rock. 'C')

Discussion of Results:

Metallurgical examination of the failed bolts indicates that the metal was clean and had been heat-treated properly. There being no specification or drawing available, it was impossible to say whether the analysis or hardness conformed to the specification.

The design of the bolt is the accepted one for aircraft bolts and failure cannot be attributed to faulty design.

Information given verbally was to the effect that the bolts are tightened with a torque wrench.

The tension load which is applied to these bolts should be equal to or greater than the service load. Fatigue tests have shown that the fatigue strength of metal decreases as the range of dynamic stress to which the metal is subjected is increased and, conversely, that the fatigue strength is increased as the dynamic stress range is decreased. As the stress change approaches zero, the dynamic load that can be supported approaches the tensile strength of the material.*

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* "On the Strength of Highly Stressed Dynamically Loaded Bolts and Steels" - by J. O. Almen, Research Laboratories Division, General Motors Corporation.

(Discussion of Results, cont'd) -

If, therefore, the bolts in this connecting rod are tightened to produce a tension in the bolt equal to or greater than the working tension load, there will be practically no stress change in the bolt. Consequently, danger of fatigue failure from this cause is virtually eliminated.

Prof. J. M. Lessells[*], to whom thanks are due for advice on this problem, has stated that trouble was experienced with this type of failure in the U.S.A. until the bolts were stressed initially in tension very nearly to the yield point of the material. The amount of initial stress was determined by measuring the extension of the bolt and not relying upon a torque wrench. Much variability in initial tension will result from use of a torque wrench since the lubricating conditions and the operator constitute variables.

CONCLUSIONS:

1. The steel is metallurgically satisfactory.

2. The strength of the bolts is satisfactory.

3. The design of the bolts is satisfactory.

4. The bolts have, so far as it was possible to ascertain, a satisfactory finish.

5. It is concluded that the bolts failed in fatigue, due likely to the fact that they were insufficiently tightened while being assembled.

6. It is quite possible that the bolt was tightened

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[*] Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

(Conclusions, cont'd) -

sufficiently in the first instance but had to be slackened somewhat to admit the cotter pin. It is better practice to advance the nut to admit the cotter pin rather than to slacken it, even if this means stressing the bolt somewhat above the yield point.

7. If connecting rod bolts are tightened to such a degree that measurement of the extension shows that they have been stressed to the yield point or slightly beyond, they will not fail by fatigue, provided, of course, the operating tension load is equal to or less than the tension load placed on the bolt.

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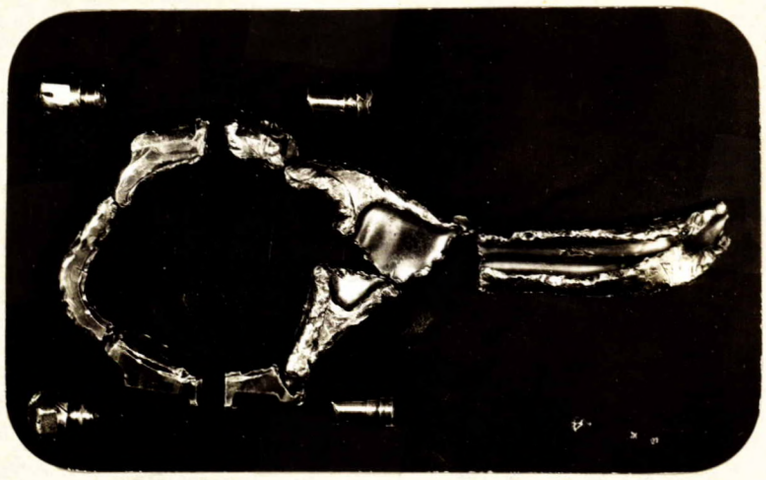
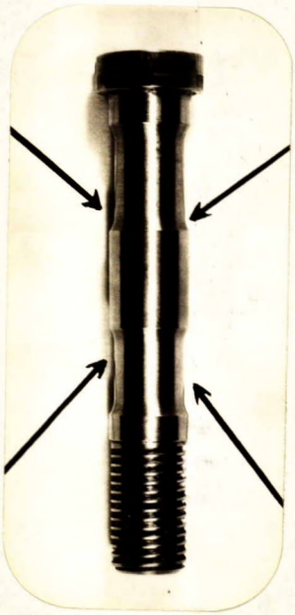
HLL:GHB.

Figure 1.



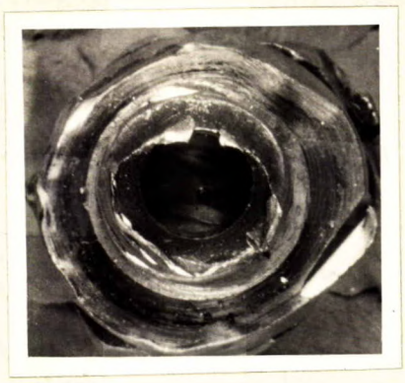
PHOTOGRAPH OF BROKEN MERLIN ENGINE
CONNECTING ROD AND BOLT.

Figure 2.



PHOTOGRAPH OF A BOLT, INDICATING THE POINTS
AT WHICH FAILURE OCCURRED.

Figure 3.



SHOWING THE TYPICAL FATIGUE
TYPE OF FAILURE.

Figure 4.

X500, nital etch.

PHOTOMICROGRAPH OF BOLT, SHOWING TEMPERED
MARTENSITIC OR SORBITIC STRUCTURE.

HLL:GHB.