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THE FAILURE OF A WING EYEBOLT FROM NORSEMAN V AIRCRAFT CF-BHW

by

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PHYSICAL METALLURGY DIVISION

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THE FAILURE OF A WING EYEBOLT FROM NORSEMAN V AIRCRAFT CF-BHW

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E. G. Eeles* and R. C. A. Thurston**

SUMMARY OF RESULTS

The port front wing attachment eyebolt from aircraft CF-BHW, which failed in service, was found to be at variance with the manufacturer's specifications, but this was not considered to be a major contributory factor. Failure is attributed to the superimposition on normal flight loads of a cyclic bending load transverse to the wing.

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INTRODUCTION

In January 1963, a Norseman V aircraft, CF-BHW, was reported missing, and the wreckage was subsequently located in late May. The cause of the accident was established as fracture of the port front wing eyebolt with subsequent loss of the wing. A similar failure had occurred in aircraft CF-BSJ in September 1958, and was investigated in some detail, including laboratory fatigue tests on components removed from service. However, no conclusive results were obtained from this investigation.

In view of the similarity of the two failures, the Department of Transport requested on June 5th, 1963, (their reference 5002-1902 (AIGT)) that a detailed study be made of the failed component. To assist the investigation, there were made available the earlier fractured eyebolt (CF-BSJ), the various components laboratory-tested and the manufacturer's drawings and specifications for the part.

The eyebolt (Figure 1) consists of a cross-head boss and a threaded stem; it is machined from a forging and cadmium-plated, although no detailed specifications to this effect were available. The stem screws into a rigid welded-up rigging strut, being locked by a bronze or brass lock-nut. The boss carries a cross-pin on a fitting attached to the main wing spar, the pin axis being parallel to the longitudinal axis of the aircraft. The rigging strut is at an angle of about 25° to the horizontal, so that normal flight loads on the fitting are axial and bending.

The manufacturer's drawing for the part calls for QQ-S-684 steel (SAE 4130) in the normalized condition. However, the manufacturer states in the aircraft manual that SAE 2330 steel, heat-treated to 125,000 psi is acceptable. The heat treatment details are not specified.

Two types of fitting have been used in this application, as shown in Figure 1.

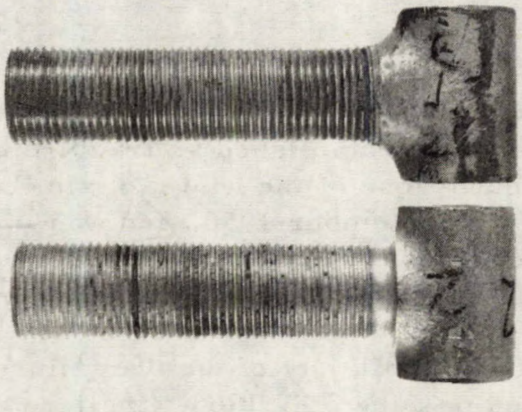

Figure 1. Two Types of Eyebolt Fitting.

The original design (upper eyebolt) did not have the fillet undercut, and this modification was introduced on March 1st, 1944. It is understood, however, that there are a number of the old design fittings in service at the present time. The failure under investigation, CF-BHW, involved an eyebolt of the earlier design, whereas the first failure (CF-BSJ) involved one of the later, modified design.

Five fittings were examined in detail; these included the failed port front fitting from aircraft CF-BHW, the port rear fitting from the same aircraft, which had fractured in pure bending, and the starboard front fittings from aircraft CF-OBN and CF-IGG that had both failed during fatigue tests in the course of the earlier investigation. The fifth sample was the stud portion of the starboard rear fitting from aircraft CF-BSJ, which had also failed in bending at the time of the original accident.

VISUAL EXAMINATION

Figure 2 shows the fracture surface of the failed port front fitting from aircraft CF-BHW. It is apparent that the failure was primarily due to fatigue, and that the crack initiated in a thread root and propagated through about one-third of the cross-section. At this stage, brittle fracture of the remaining cross-section occurred. The most significant feature of the failure is that initiation and propagation lie parallel to the axis of the cross-bolt, and thus along the longitudinal axis of the aircraft. An examination of the remains of the fractured fitting from aircraft CF-BSJ showed that the failure initiated and propagated in a similar manner.

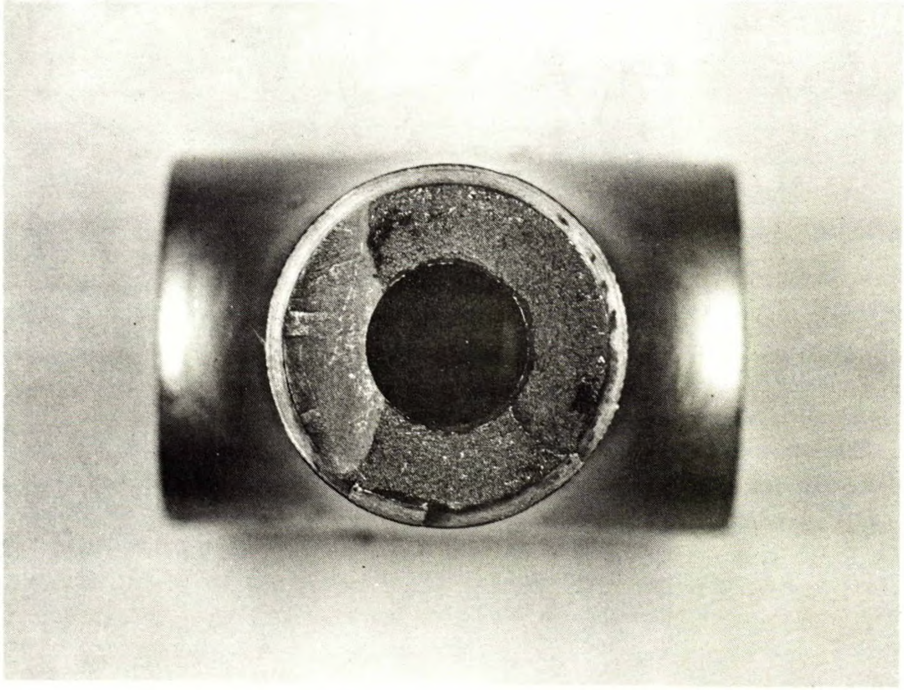

Figure 2. Fracture Face, Port Front Fitting, CF-BHW.

MATERIAL ANALYSIS

Both wet chemical and quantitative spectrographic analyses were made on each of the five samples under study. The results are given in Table 1. The compositions of all samples except the CF-BHW port rear eyebolt correspond reasonably to the SAE 2330 specification. The composition of CF-BHW port rear eyebolt is comparable to the SAE 4140 specification.

HARDNESS TESTS

Rockwell hardness tests were made on polished cross-sections of the stems of each of the five eyebolts under study. In all cases the sections were comparable in position. The results are given in Table 2, together with the estimated tensile strengths of the materials.

METALLOGRAPHIC EXAMINATION

Polished and etched cross-sections from each of the samples were examined. Three of the four samples of SAE 2330 composition exhibited normalized structures with small differences in structure and grain size, probably reflecting differences in thermal history. The other SAE 2330 type sample, CF-BHW port front, showed a quenched and tempered structure as would be expected from the hardness readings. CF-BHW port rear (SAE 4140) eyebolt had an annealed type of structure of much coarser grain size than any of the other samples. The photomicrographs are shown in Figures 3 to 7.

TABLE 1

Chemical and Spectrographic Analyses (in wt %)

Eyebolt	C Chem./Spec.	Mn Chem./Spec.	Ni Chem./Spec.	Cr Chem./Spec.	Mo Chem./Spec.	Specification
CF-BHW port front	0.35/-	-/0.52	3.2/3.7	0.39/0.37	0.03/n.d.	SAE 2330
CF-BHW port rear	0.40/-	-/0.69	0.3/0.15	0.89/0.82	0.19/0.23	SAE 4140
CF-IGG stbd.front	0.30/-	-/0.78	3.36/4.41	0.15/0.20	0.05/n.d.	SAE 2330
CF-OBN stbd.front	0.28/-	-/0.87	3.36/4.13	0.15/n.d.	0.05/n.d.	SAE 2330
CF-BSJ stbd.rear	0.32/-	-/0.59	3.38/4.33	0.11/0.15	0.08/0.13	SAE 2330
	0.28-0.33 0.38-0.43	0.60-0.80 0.75-1.00	3.25-3.75 -	- 0.80-1.10	- 0.15-0.25	SAE 2330 SAE 4140

n.d. = not determined as below accuracy limits.

TABLE 2

Mean Rockwell Hardness Values for Eyebolts

Eyebolt	Hardness	Corresponding Ultimate Tensile Strength (psi)
CF-BHW port front	$R_c 33$	154,000
CF-BHW port rear	$R_A 57$	96,000
CF-IGG stbd. front	$R_A 61.5$	116,000
CF-OBN stbd. front	$R_A 60.5$	110,000
CF-BSJ stbd. rear	$R_A 60.5$	110,000

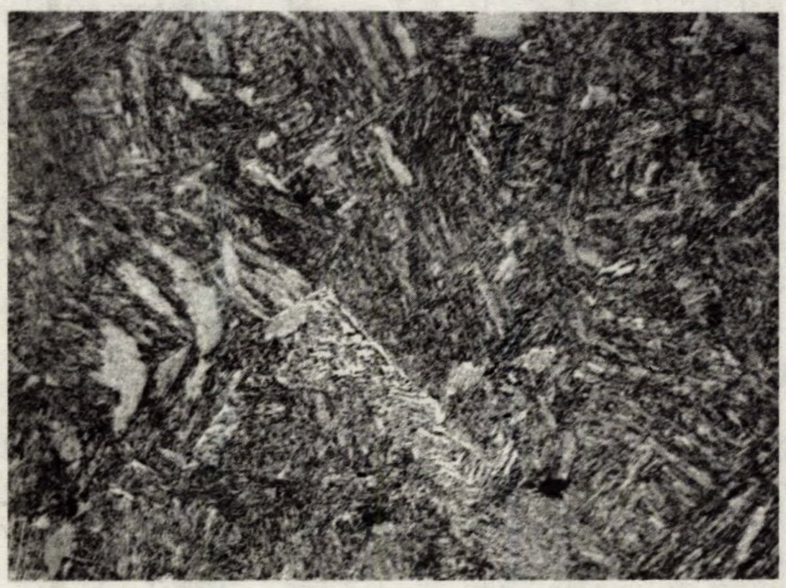

Figure 3. CF-BHW Port Front.
Etched in 2% nitric acid in alcohol. X500.

Figure 4. CF-BHW Port Rear.
Etched in 2% nitric acid in alcohol. X500.

Figure 5. CF-IGG Starboard Front.
Etched in 2% nitric acid in alcohol. X500.

Figure 6. CF-OBN Starboard Front.
Etched in 2% nitric acid in alcohol. X500.

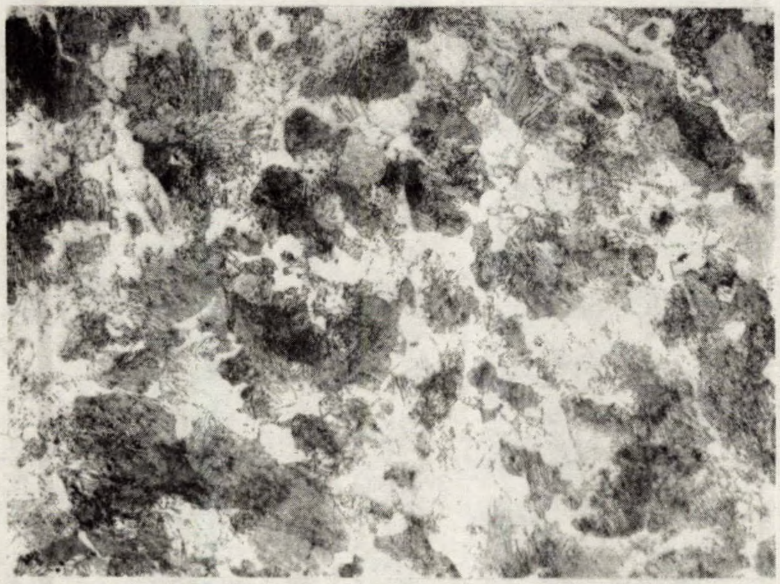

Figure 7. CF-BSJ Starboard Rear.
Etched in 2% nitric acid in alcohol. X500.

DISCUSSION

The metallurgy of the failed sample does not in any way indicate a reason for failure. The fractured unit had been heat-treated to a considerably higher strength than the other samples, but, due to the associated increased notch sensitivity, the overall service strength of the fitting was probably not greatly different from that of the others. It is therefore to be concluded that, despite the different structure and mechanical properties, the metallurgy of the part cannot be considered as a contributing factor to the failure.

The microstructure of the other bolts reflects no more than the expected variations associated with batch production of a part for which rather loose specifications have been established. As a low-strength high-ductility steel is required for this application, many compositions could be used with very little, if any, difference in service performance.

The failed eyebolt is of the earlier design, without an undercut fillet. It is widely accepted that this configuration is structurally inferior to the later design, and for this reason alone it is recommended that no further eyebolts of this design be placed in service. It is also recommended that all such eyebolts already in service be removed at the first aircraft inspection that necessitates removal or loosening of the part. However, both fractured eyebolts responsible for the accidents failed at the first thread in the lock-nut as far as can be ascertained, and, consequently, the absence of an undercut fillet can only be, at most, a minor contributory factor.

Calculations based on established principles show that unloaded multiple threads (7/8 in. - 14 tpi) with a 0.005 in. root radius have a theoretical stress concentration factor of about 4.0 in tension or bending; with decreasing radius, the factor will rise above this value. Thread profiles of various eyebolts were examined on a projection comparator at X75 magnification. In most cases, the threads were of adequate form with root radii of the order of 0.005 in., the failed bolt (CF-BHW port front) being in this group. In certain units, the thread roots were of irregular profile with effective radii much less than this figure.

The estimated fatigue limit of normalized SAE 2330 is about ± 55,000 psi, with full allowance for the stress concentration present; the effective endurance limit in this application will be about ± 14,000 psi. The manufacturer quotes for the eyebolt fitting a resolved design tensile loading under 1G conditions of 4,300 lb, which includes all relevant customary safety factors in the design and does not represent the service load, which will be about one-quarter of this or less. A load of 4,300 lb corresponds to a stress of 12,000 psi across the root area. Full positive-negative G loads are not normally experienced, and the more normal loading will be G ± 1/2 G. With a mean stress at 12,000 psi, the estimated endurance limit would be reduced to ± 12,000 psi. It is thus seen that the fitting is adequate for the design loads and, as only few failures over a period of more than 15 years have been reported, it is reasonable to assume that the stress levels under all normal conditions of operation lie below the estimated fatigue limit.

It should be appreciated that the foregoing calculation is only an approximation. No allowance has been made for the additional effects of thread loading, though the associated strength reduction could be less for the design under consideration than for a normal nut-and-bolt assembly. To some extent, this effect will be offset by the use of the full theoretical stress concentration factor, which would undoubtedly not apply in service. Furthermore, no allowance has been made for the deleterious effect of the cadmium plating on the fatigue strength. The probable reduction for steel with a tensile strength of 110,000 psi would be of the order of 10%, but for 150,000 psi steel it could be as high as 20%.

In the case of the particular eyebolt being investigated, the tensile strength was higher than normal, but the design was of the earlier and inferior type. It is considered unlikely that the fatigue properties of the eyebolt in service could be significantly different from those of the lower strength eyebolts. It is suggested, therefore, that some additional loading must have been superimposed on the normal flight loads.

Some indication of the nature of the additional loading can be obtained from the appearance of the fracture surface (Figure 2). The fatigue cracks in both the present eyebolt and the eyebolt from aircraft CF-BSJ initiated and propagated in a direction transverse to the axis of the wing. Their appearance was consistent with the superimposition of cyclic plane-bending loads. Such loads, parallel to the axis of the aircraft, could have been caused by some unobserved structural defect, e.g., excessive ~~decrease~~ clearance in the wing root fixture, or by transverse flexure of the wing.

It is considered improbable that continuous high stress cycles, resulting from such a defect, both initiated and propagated the crack; it is far more likely that a limited application of high stress cycles occurred during a rough take-off or landing to initiate the crack and, subsequently repeated applications of a lower cyclic stress propagated the crack to failure.

CONCLUSIONS

It is concluded that the port front wing eyebolt from aircraft CF-BHW failed in fatigue due to the application of an unknown cyclic load beyond the design limits of the fitting in a direction parallel to the axis of the aircraft. The structure and properties of the material used were not consistent with the manufacturer's specifications for the part, but this is not considered to be any more than a possible contributory factor and not in any way the cause of the failure.

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