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Failure analysis of a civil aircraft landing gear

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Abstract

This paper describes the analysis and investigation of the causes of the failure of the main landing gear of a Cessna 402B civil aircraft. Optical analysis of the failed elements indicated possible fatigue crack failure initiation. However, further scanning electron microscopy examination ruled out this failure mechanism showing shear failure mode as the cause of fracture.

Keywords: Accident investigation; Aircraft failures; Fractography; Impact; Landing gear

1. Introduction

This study describes the analysis and investigation of the causes of the accident of a Cessna 402B civil aircraft with a weight of approximately 28 kN. At the moment of the accident, the aircraft was landing under normal wind and visibility conditions. On landing, one of the main landing gears failed, following the failure of the remaining one. The objective of this study was to determine whether the accident was caused by defective materials or human error.

2. Background

Fig. 1 shows the main landing gear of the Cessna 402B aircraft. Linkage A locks the landing gear at vertical landing position. This linkage is subject to high loads at landing and high shear stresses are applied

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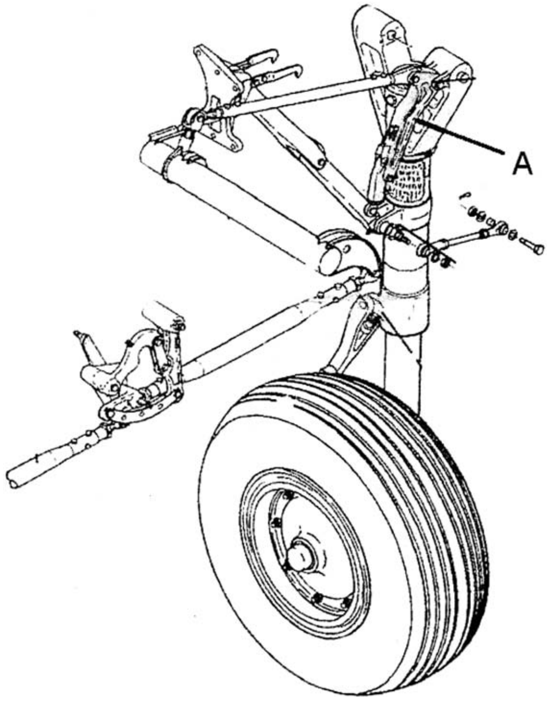

Fig. 1. Schematic showing the Cessna 402 civil aircraft landing gear. Locking linkage A is shown.

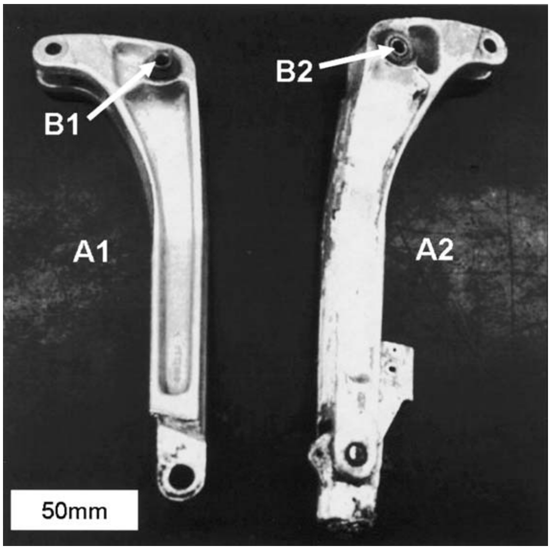

Fig. 2. Landing gear left and right locking linkages A1 and A2, respectively Also shown is the location of the respective failed bolts B1 and B2.

to the clevis bolts. The failure of the landing gear was initiated on these linkages, and no other failed components were found on the landing gear, consequently the analysis was concentrated on these linkages and their respective bolts.

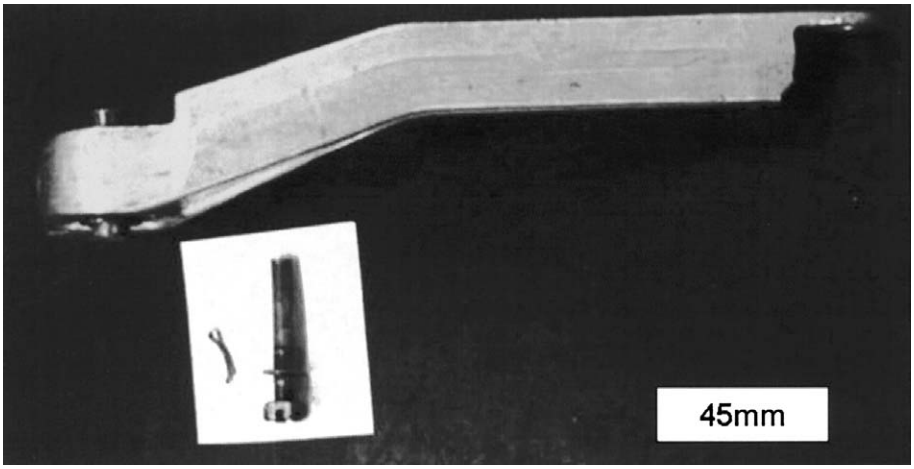

Fig. 3. Linkage A1 and bolt B1. Note the fracture of linkage A1 at the top right corner of the figure.

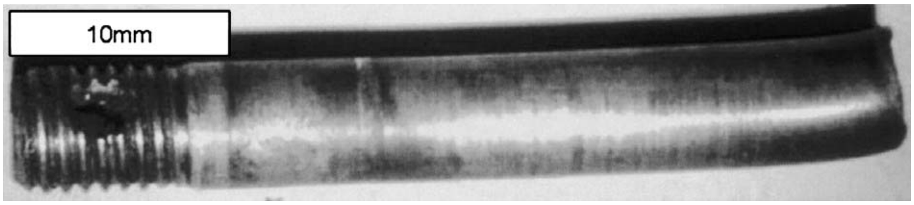

Fig. 4. Bolt B1.

Fig. 2 shows the two linkages as received for analysis after the accident. Linkage A1 shows fracture of the bottom clevis, with bolt B1 fractured at one end (see Figs. 3 and 4). Linkage A2 on the other hand, was received with clevis bolt B2 fractured at both ends (see Figs. 7 and 8).

3. Fractographic analysis

3.1. Linkage A1

The mounting direction of clevis bolt B1 on linkage A1 is shown in Fig. 3. This bolt failed at the right-hand side (Fig. 4). Stereographic examination of the fractured surface reveals a typical mode II or shear loading fracture with the arrow indicating the zone where the fracture began (Fig. 5). Also note the slightly bent tip of the bolt (right-hand side of Fig. 4) which is a feature usually found on shear induced failures.

Fig. 6 shows the fracture surface of the failed clevis of linkage A1 (see also Fig. 3). The fracture surface indicates crack opening mode I loading failure, initiating the crack at the internal surface of the element as indicated by the arrow.

3.2. Linkage A2

Fig. 7 shows linkage A2 and its corresponding clevis bolt B2. The arrows indicating the mounting direction of bolt B2. Fig. 8 is a macroscopic image of bolt B2 with the arrow also indicating the mounting direc-

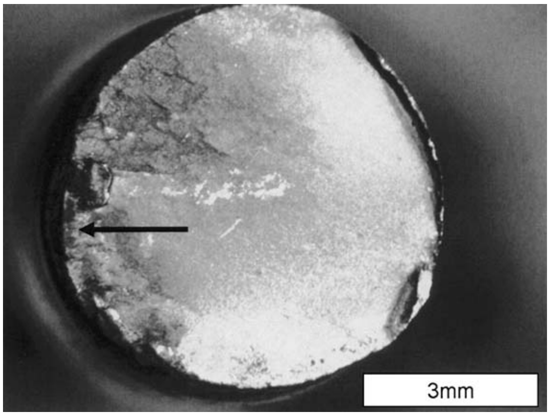

Fig. 5. Stereoscopic micrograph of the fractured surface of bolt B1. The arrow points toward the fracture initiation.

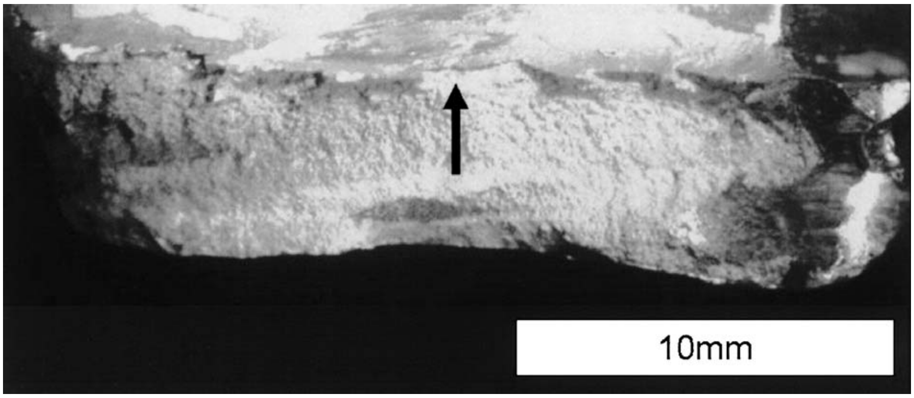

Fig. 6. Stereoscopic micrograph of the fractured surface of the clevis of linkage A1. The arrow points toward the fracture initiation.

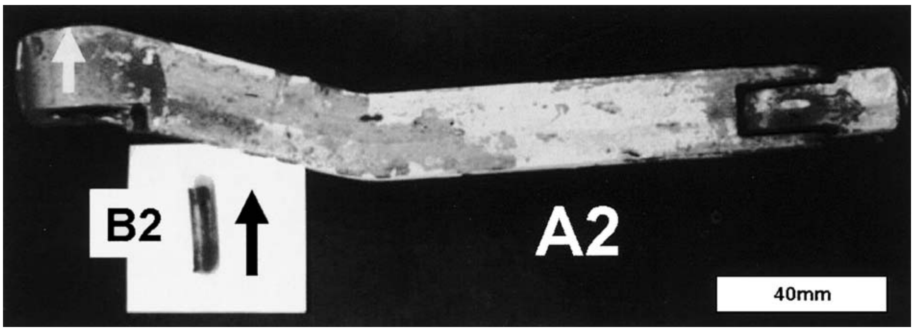

Fig. 7. Locking linkage A2 and bolt B2. Arrows indicate the mounting direction of the bolt.

tion. It is worth noting here the bent left-hand tip of bolt B2 in comparison with the straight right-hand tip in the same figure.

Fig. 9 shows the fractured surface of the left-hand side tip of bolt B2. This surface displays similar characteristics to the fracture surface shown in Fig. 5 for bolt B1, with shear fracture mode prevailing, also

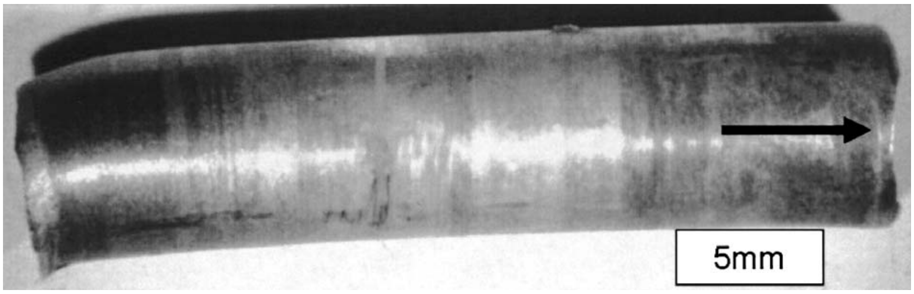

Fig. 8. Bolt B2.

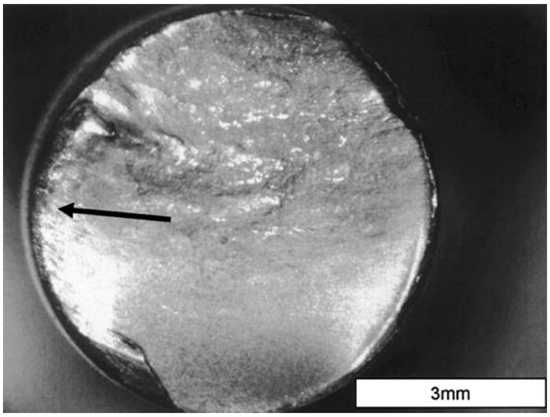

Fig. 9. Stereoscopic micrograph of the fracture surface of the left-hand side of bolt 2 in Fig. 8. The arrow points toward the fracture initiation.

accompanied by bending of the left-hand side tip of the bolt. Fig. 10 on the other hand shows the fracture surface of the right-hand side of bolt B2. This surface exhibits different characteristics when compared with the respective fractured surfaces of the bolts analyzed previously, with a less rough appearance in zone A

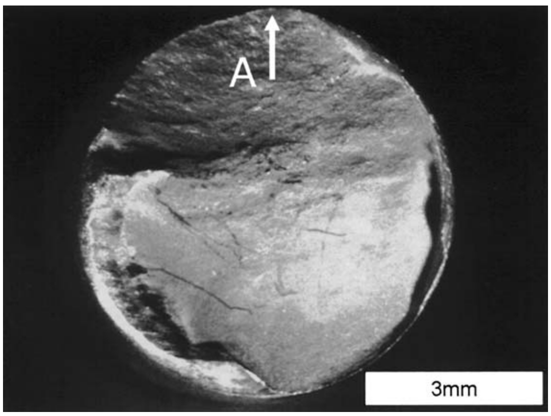

Fig. 10. Optical macrography of the fracture surface of the right-hand side of bolt 2 in Fig. 8.

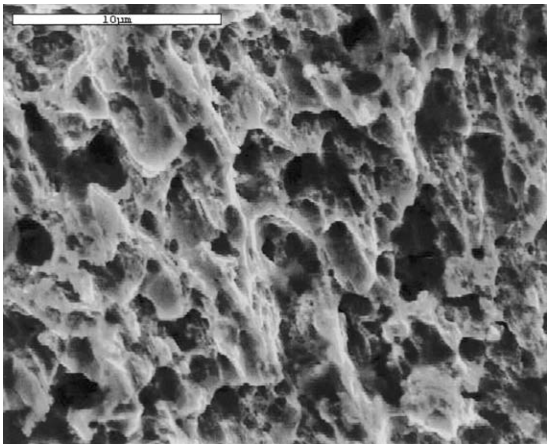

Fig. 11. SEM micrography of zone A in Fig. 10 showing ductile shear fracture.

(see Fig. 10). This zone also displays what appear to be fatigue beach marks, which along with the straight right-hand tip fracture could indicate a pre-existent crack in the bolt. However, higher magnification SEM analysis revealed that the failure was indeed caused by shear loading mode as for the other fractured bolt surfaces and no evidence of fatigue was found, as shown in Fig. 11. This apparent fatigue marks can be misleading and care must be taken in order to assess a realistic failure cause.

4. Estimation of the failure load

As the landing gear failure was caused by shear loading of clevis bolt B2, the load at landing supported by this bolt can be estimated. The ultimate shear stress of the bolt can be approximated from the empirical expression [1]:

$$\tau_u = \frac{\sigma_{TS}}{1.6}, \tag{1}$$

where σ_{TS} is the tensile strength of the material. This tensile strength can in turn be estimated using the empirical correlation [1]

$$\sigma_{TS}\ (\mathrm{MPa}) = 3.2\ \mathrm{HV}, \tag{2}$$

where HV is the Vickers Hardness of the material. The measured Vickers Hardness of clevis bolt B2 was of 349 HV, then from Eqs. (1) and (2) the ultimate shear stress of the bolt is $\tau_u = 698$ MPa. Finally and considering that bolt B2 failed by double shearing, the ultimate load can be calculated as

$$F_u = 2\tau_u \pi r^2 = 39.5\ \mathrm{kN}, \tag{3}$$

with $r = 3$ mm.

It is worth noting that the empirical approximations employed (Eqs. (1) and (2)) were based on quasi-static loading experiments and not on dynamic loading as was the case of the failure being analyzed. It is known however, that dynamic shear resistance is higher than static resistance (see for instance [2]). Therefore, the value of F_u must be taken as a lower approximation to the real load supported by the bolt. With this in mind and recalling that the total weight of the aircraft was of 28 kN approximately, the landing to cause shear fracture of bolt B2 had to be abrupt and heavy.

5. Discussion

After analysing the different fracture surfaces of the landing gear, a conclusion of the causes of the accident can be drawn. The failure was initiated by a sudden impact shear load on bolt B2 causing shear fracture leading to loose of all load bearing capacity of linkage A2 and the corresponding landing gear. As a consequence, all the landing load was displaced to a lateral loading of the left landing gear leading to the shear failure of bolt B1 and subsequently mode I failure of linkage A1 clevis. In order for the failure to occur in that way, the landing had to be abrupt with all the load applied to the right landing gear. Therefore, the accident was due to human error and not to material defects.

6. Conclusion

The failure of the main landing gear was caused by a heavy landing, leading to shear failure of the clevis bolts of the locking linkages. There were no indications that failure was originated by previous material defects. Therefore, it can be concluded that the failure was a consequence of human error and not material defects.

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