

# An investigation on the fracture of linkage connecting wing flap of aircraft

Yanpeng Feng<sup>1</sup>, Haijun Tang, Chun Wang, Ping Shu, Xiaoming Ma, Chunguang Li

Analysis and Appraisal Lab of Civil Aviation Safety, China Academy of Civil Aviation Science & Technology, Beijing, China

E-mail: Fengyp@mail.castc.org.cn

**Abstract.** Linkage that connected wing flap and supports was found broken several times during from 2011 to 2014. Flights data was check, no heavy landing or exceed limiting speed warning were found. To investigate the root cause of the failure process, macroscopic and micrograph of the fracture surface were research with optical micrograph and scanning electron micrograph. Results show that the surface of fracture was dimples and shearing fracture structure which mean transient breaking features. Nearby the fracture, a lot of scratch and paint marks were found, that indicated that the rod may collapsed by impacted with some mechanical components. But the distance to the nearest component is within the tolerance, during ground inspection. Basing on stability analysis of column, the linkage will be bending deflection with elastic deformation, when compress exceed a critical value, which decrease the distance. But it will be recovered, during ground inspection for lower compress. Finite Element methods were used to demonstrate the bending deformation too. Basing on the reports and analysis, enhanced linkages were provided and substituted for older versions, and the relevant incidents were never found.

## 1. Introduction

Trailing-edge flap is the activity component that installed in the tailing edge wing surface, usually close to under the wing surface during level flight. During the approach and take-off process, the flap is gradually extension, the bending of cross-section drawn is increase and the windward area of main wing is increase too, so the lift force of aircraft is improved 85%~95% [1,2]. So it is one of the systems to adjust and control the lift coefficient, the disable and failure of the system is dangerous for passengers and aircrafts [3, 4].

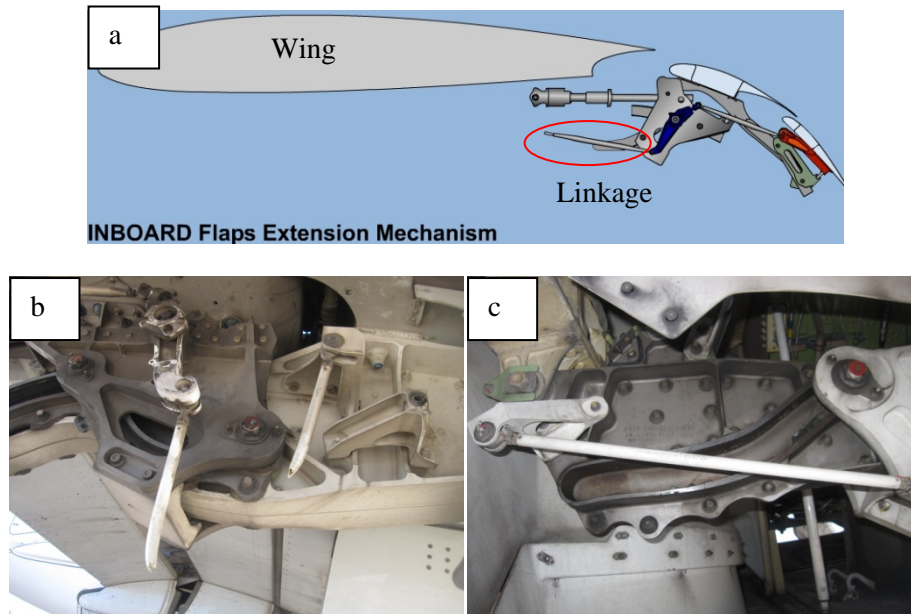
The extension mechanism of flaps is shown in figure 1a, a mechanical component with thread screw fixed at main wing, allowing movement in two directions used in the flap extension and retraction system. The installation location of flap connecting rod is shown in figure 1a with red circle, one side of linkage connected to the body with universal connector by simply supported, the other side connected to slide rail by simply supported too. So the condition of loading is compression stress along axial direction.

The connecting linkage was found broken or bend three times in two years for some aircraft, and no heavy landing signs were found for the failure process. The broken linkage is shown in figure 1b comparing with normal linkage in figure 1c. The bending or broken position close to the middle of the connecting rod and no obstacle components was found during the extension and retraction process.



## 2. Microstructure analysis

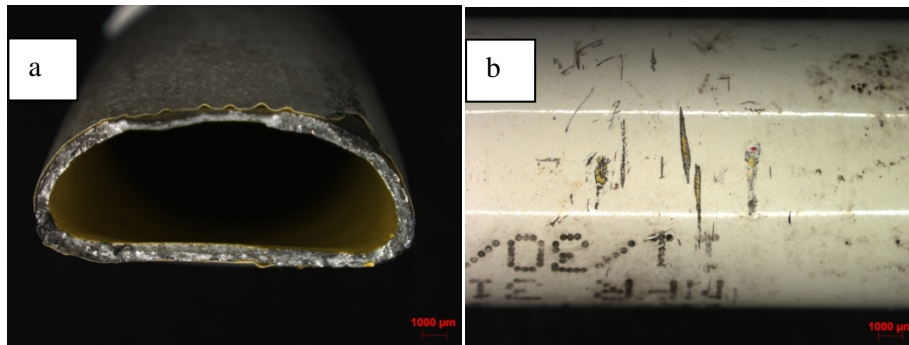
Fractured and bending linkages were shown in figure 2, the rod pipe was fabricated with 2024 aluminium alloy, the surface of pipe was coating with white colour paint, no corrosion products along axial of the connecting rod and no broken at the connected side were found. The angle of bending is about 12 degree for failed rod. A universal connector at the end of each rod in figure 2 is flexible rotation without any jamming condition, and no damage and impacting marks were found on the connector.



**Figure 1.** Assemble sketch map of linkage rod and unfolded mechanism of open the flap



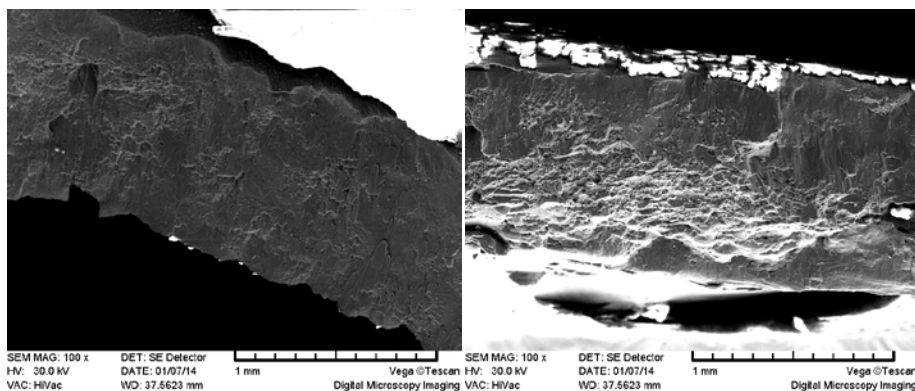
**Figure 2.** Fractured and bending connecting linkage



**Figure 3.** Macroscopic fracture surface and side wall of the broken linkage

Macroscopic fracture surface of broken linkage were shown in figure 3, cross section of normal linkage is circle, but the damaged one is ellipse. Flank wear and impacted marks are show in figure 3 b, surface coating was cut off from the linkage. From the trend of the impacted marks, it may instantly contact with some components. But after inspection in land situation, no object was found alone the travel path of the linkage.

The microstructure of fracture is shown in figure 4, the surface of fracture is type oblique and fluctuation, full of dimples and quasi-cleavage tear ridges without any fatigue lines, which mean that the process of the break is transient behaviour never inoculation process.



**Figure 4.** Scanning electron micrograph of fracture morphology

### 3. Stress analysis

Base the above analysis, the broken of linkage is instantly process, and no objects hinder the track, while the failed is not frequently found for the aircraft. So to clarify that what happy to the linkage, a stress analysis for the linkage is necessary. Basing the installation position and stress situation of the linkage, it is typical compression stability of column [5, 6]. The moment of section inertia for thin-walled circular tube is express as:

$$I = \frac{\pi(D^4 - d^4)}{64} = 4.33 \times 10^{-10} (\text{m}^4) \quad (1)$$

Where D is the outside diameter for the cross section of the tube, which is 12.32 mm in this case, and d is 10.92 mm for the inside diameter. Inertia radius of rod is:

$$i = \sqrt{\frac{I}{A}} = 0.0041 (\text{m}) \quad (2)$$

Where A is the cross-sectional area for the circular tube, the flexibility of the rod is express as:

$$\lambda = \frac{\mu L}{i} = 89.9 \quad (3)$$

Here  $\mu$  is the length coefficient of compressed rod,  $\mu$  is 1 for simply supported beam. And  $L$  is the length of the rod, is 0.37 m. Base the critical stress checking the stability.

$$\lambda_p = \pi \sqrt{\frac{E}{\sigma_p}} = 62.8 \quad (4)$$

$E$  is the elasticity modulus of the aluminium alloy, as 72 GPa. And  $\sigma_p$  is the yield stress, is 180 MPa. Because of  $\lambda > \lambda_p$ , and according to euler formula, the critical stress  $P_{cr}$  to bending the rod is express as follow:

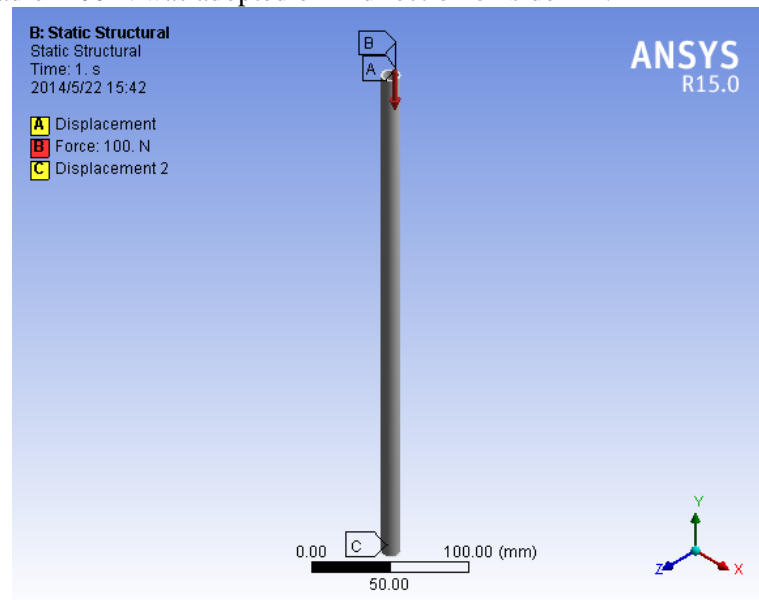
$$P_{cr} = \frac{\pi^2 EI}{(ul)^2} = 2246.9 \quad (5)$$

So, if the load of linkage over 2246.9 N, even the normal stress of it never greater than the yield stress, bending deformation will also come up. And with the increasing of deformation, the middle side of the linkage will experience plastic deformation.

#### 4. Finite element analogy

Software of finite element analysis is adopted with ANSYS 15.0, to simulate the stability of the compressed rod. The geometric dimension of the rod was the above mentioned, and both side of the rod are fixed with simple supported. The compressive stress situation was forced on one side of the rod. The material parameter was adopted with 2024 aluminium alloy, elasticity modulus is 72 GPa, and poisson ratio is 0.3.

Boundary conditions setting as follow, according to the practical situation of flap linkage. 1) Displacement constraint of X, Y, Z directions were adopted on side 'C' (in figure 5), and rotation of three directions were free. 2) Displacement constraint of X and Z directions were adopted on side 'A' (in figure 5). 3) Preload of 100 N was adopted on Y direction on side 'A'.



**Figure 5.** Boundary conditions setting of compressive linkage

Deformation cloud of simulation result is shown in figure 6, bulking deformation in the middle of the linkage. That provides lateral displacement about 1.1 mm, decrease the gap between linkage and objects. The critical load for bulking deformation is 2.2 KN, approach to calculated result.

When unload, the linkage recover in elastic deformation. So maintenance and service engineers never found any objects could impact the linkage. The bulking deformation occurs on release and

retraction flap in the air condition, with air load on the wing flap. In the land condition, without any load bring to the linkage, bulking deformation never emergence.

## 5. Results

The failure module of linkage on wing flap is impacted with objects and shear fracture in the middle side. Because of instability on bulking deformation under compressive load, the middle of the rod move toward perpendicular to the axial direction.

The solution of the problem is increase the strength of linkage, that resistant the bulking deformation. So one selected alternative component of linkage with more strength flexural rigidity is provided, and replaced the previous versions. Failure of linkage never found in the past two years.

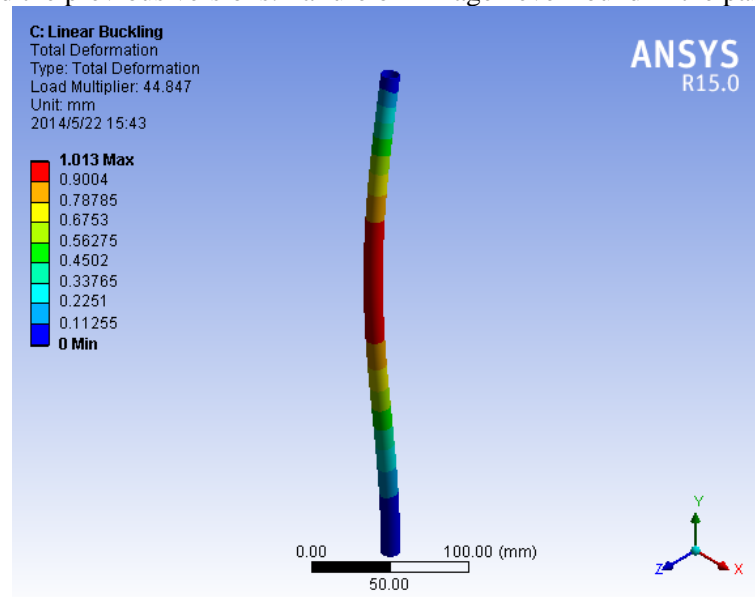


Figure 6. Bulking deformation of compressive linkage

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