Updated 5th April, 2017

Some MH370 Right Flaperon Separation Mechanics

Summary

The design of the flaperon is such that loss of its trailing edge from any cause at high speed will lead to the flaperon remainder separating immediately as a consequence, in overstress. Major contributors are a shift forward of the flaperon centre of lift and increased drag. The effect of these is to reverse the normal compressive loading on flaperon actuators, which will result in a tensile force for which they were not designed. Consequent flaperon deployment will overload its hinges in tension. Subsequent snatch loads on the flaperon's actuator attachments will break them and the flaperon will separate.

This would occur whether the trailing edge failed in fatigue from flutter or in overstress, though the latter is the more likely.

This explanation is inconsistent with the ATSB findings that most likely it and the adjacent outer flap collided when neither was deployed.

Introduction

The right flaperon had five failures, one at its trailing edge, the other four being to its attachments to the wing; two hinges and two hydraulic jack actuators (more formally, PCUs). The French hold the recovered item but have not released any findings about the character of these fractures. The ATSB has observed there are witness marks indicating the flaperon and its adjacent outer flap collided when flaps were up and the flaperon was not appreciably deployed from neutral. Also it believes that the aircraft was in a steep descent before crashing. These are the only contributions by the investigators relevant to the flaperon separation.

Separation hypotheses include:

1. Flaperon flutter during a descent outside the aircraft's speed limits, leading firstly to trailing edge failure in fatigue, followed by flutter of the remainder or of the aircraft's wing, either leading to fatigue of the flaperon attachments. (Flutter is an instability which can come from an aircraft's flight envelope being exceeded, or damage. It is component twisting and flapping at frequencies stimulated by aerodynamic loads, which in turn they can feed back into, leading to fatigue. Fatigue damage occurs under repeated loading beneath ultimate stress limits).
2. Trailing edge separation due to flutter followed by immediate attachment separation in overstress
3. Failure of the trailing edge in overstress in a high speed descent during a spiral or pullup, the attachments then failing also in overstress.
4. Failures similar to 2 but due to water impact on ditching or in a flat descent.
5. Shock at wing breakage in flight in overstress or at high speed water impact.

The first has been advocated by several and analysed by Tom Kenyon.

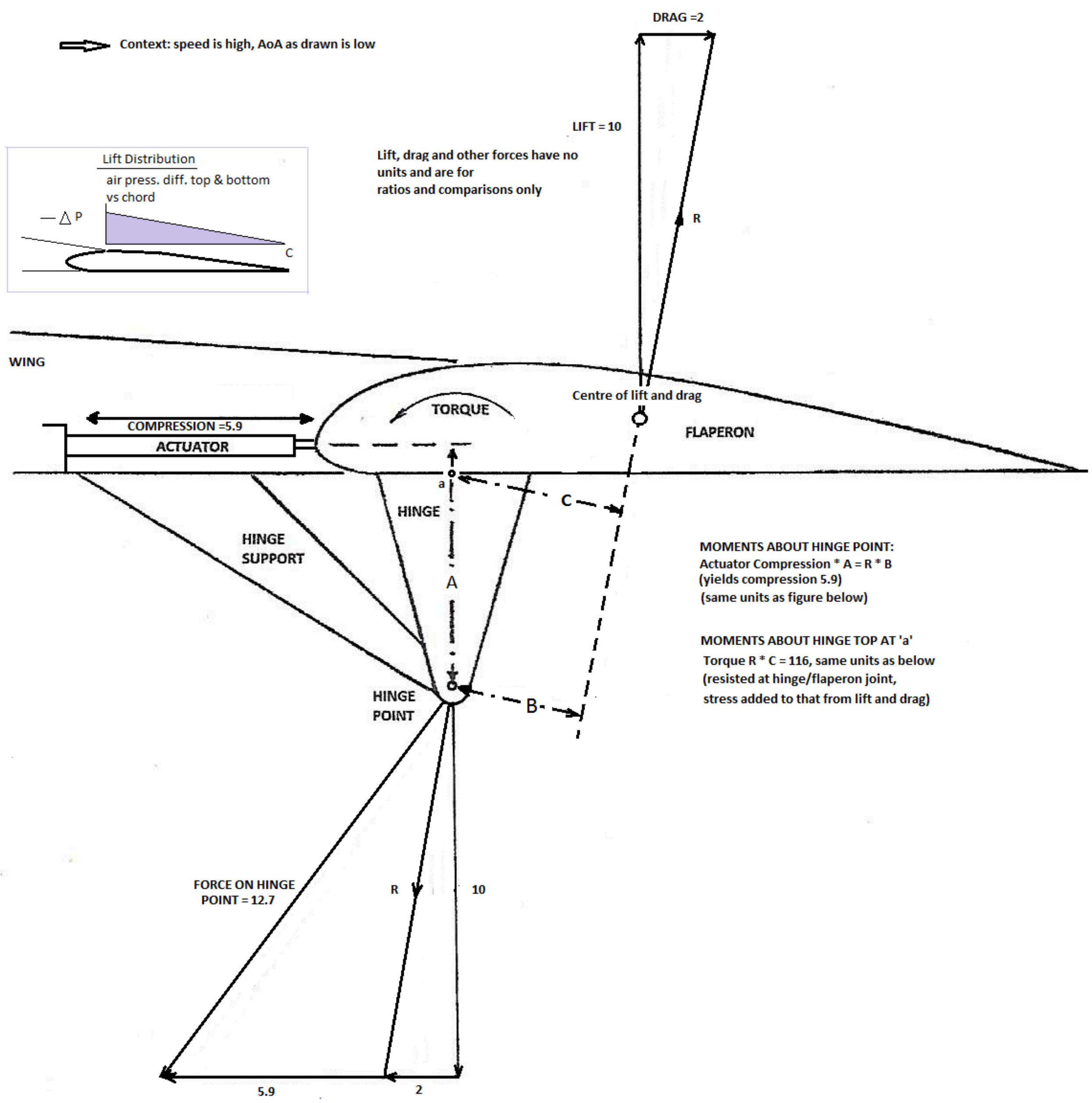
I am not of their opinion, which entails simultaneous fatigue failures. Fatigue initiation depends on stress raisers commonly unique to the manufacture of individual items. Again its rate of fracture progress varies between individual items, whose loading and metallurgy may vary microscopically. In my opinion it is unlikely therefore that there would be simultaneous fatigue weakening. Simultaneous failures are a good deal less probable again.

Furthermore, natural/ resonant frequency alters with configuration and mass distribution. Trailing edge flutter fatigue at one flutter frequency followed by failure of the flaperon attachments at a different frequency is possible but most likely would require two airspeeds.

This appraisal examines hypotheses 2 & 3.

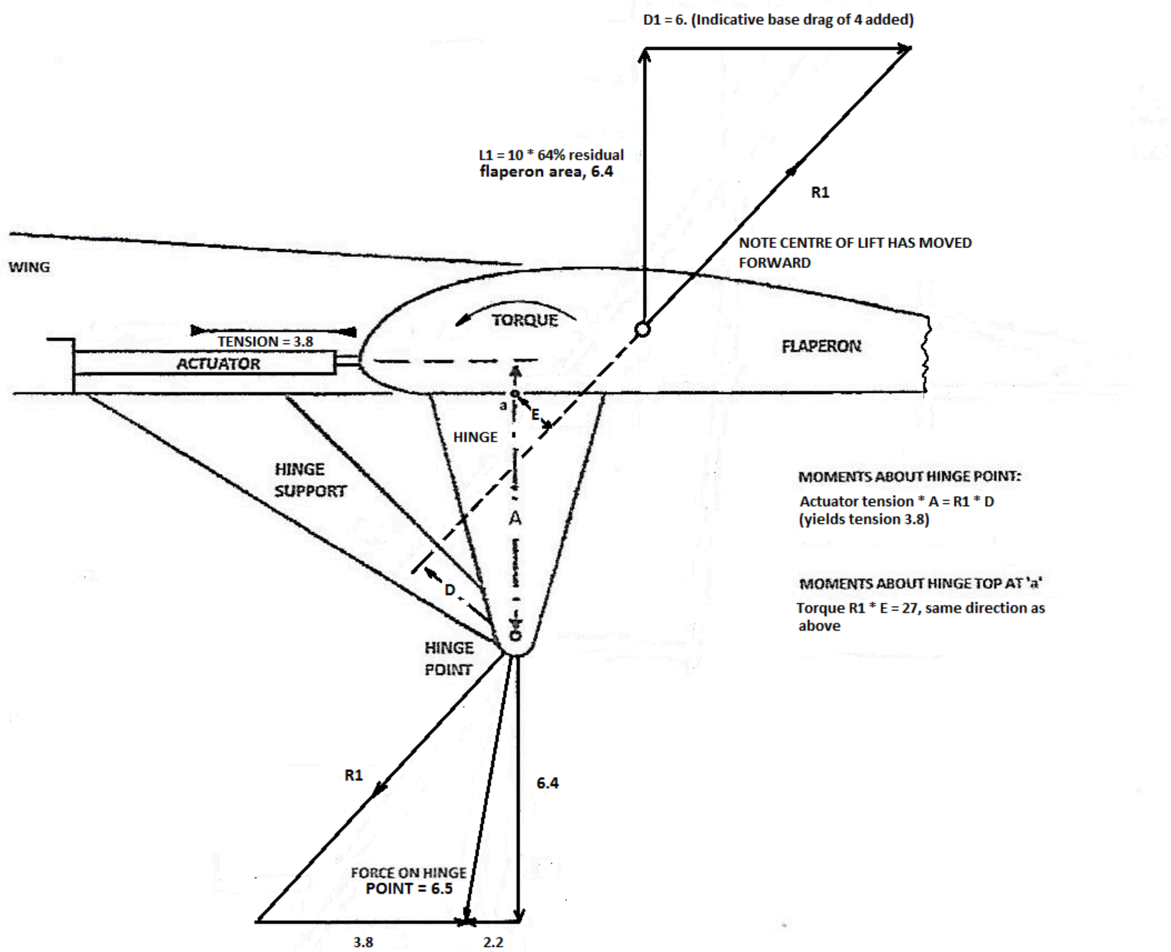
Aerodynamic Loading.

Below is a diagram of the normal loading experienced by a flaperon.



The drawing is intended to be representative of the actual flaperon, inboard end, its principal dimensions having been deduced from various depictions and photographs. The position of the centre of lift supposes (see insert) the lift to be highest where the flaperon is exposed to upper wing airflow towards its front. It is taken to be zero at its trailing edge and linear between the two. That leads to the centre of flaperon lift being almost 0.3 of its exposed length from the lift front.

The second diagram below is of flaperon loading after loss of a representative portion of trailing edge.



The centre of lift has moved forward, remaining at almost 0.3 of the residual exposed length. The lift is reduced proportionately to its smaller area, other parameters being as before. Drag has been multiplied by an indicative three to allow for base drag at the break. The earlier lift drag ratio of an indicative 5 to 1 (high speed, low AoA) has been reduced accordingly.

The two hinge failures, one either side, were close to their attachment to the flaperon. A major contributor to stress there will be the torque illustrated. Aside from these examples indicating the likelihood that loading at the hinge pivot would be lessened by trailing edge failure, the same applies to the torque loading[1]. This would reduce maximum stresses at their attachments, the highest loading most likely being tensile at the hinge brackets' rear.

So why would trailing edge loss lead to flaperon separation?

Actuator Consequences

Please notice that while the force at the actuator has decreased also, it is now in tension.

An actuator like this has unequal piston areas pushing and pulling due to the area taken by the actuator rod. In this instance the difference is striking. See the actuator in this photograph of an inner end of a left flaperon (the original was used by Tom Kenyon at his Exhibit 2, (thanks Tom)).

Notice the diameter of the fescolised actuator rod where it enters the cylinder as compared to the cylinder diameter. The piston pushing and compressing that rod against resistance to its extension will have much greater area exposed to hydraulic pressure than its area on the other side for retraction. Thus the actuator will exert comparatively little retractive force or overcome much resistance. From measurements of photographs and diagrams and my calculations of cylinder wall thickness, the piston area on the extending side, deploying the flaperon, will be around 50 times that of the other. Put another way, for this retraction force to equal the designed compressive force, hydraulic pressure would need a 50 fold increase.

Thence it is reasonable to deduce that the *undamaged* flaperon in the air will impose a compression force spread between its two actuators, one at each end, aerodynamic lift overcoming its own weight. Deployment down might reduce that compressive force, its nose then contributing lift and the lift centre moving forward, but by nature of the design not to the point where the actuator would be in tension.

So reversal in actuator loading as above, even if lessened, will be a non-design condition, most likely leading to blown seals or a ruptured actuator cylinder.

Therefore at trailing edge loss the actuators would extend and the flaperon would deploy, all towards their full extent without real constraint. While this does suppose that aerodynamic force and direction changes would not halt that rapid extension, the continuing effect of high drag on the lift to drag ratio I believe makes this a reasonable assumption.

The result will be that the flaperon drag will exceed the tensile stress limits in the hinges, their failure will lead to snatch loads on the actuator attachments and the flaperon will separate.

The above assessment is independent of the hydraulic supply and whether this was from the RAT or otherwise. The RAT would operate just the outer actuator, the other being in by pass. This would not alter the overall outcome. Bypass would alter just the detail of actuator extension and relief valves likewise, though please note that the flow through a relief valve, depicted, would have little effect on an active actuator; that is, not in bypass. Whereas the bypass arrangement allows for unbalanced flow quantities from one side of the piston to the other, the relief valves do not. On the rod being extended under tension there would be a vacuum created in the “compression” chamber therefore though this could impose a minor extension constraint only. Even should a relief valve reduce the risk of a blown cylinder or seal, that would not prevent the extension and thence flaperon separation.

Trailing Edge Overstress

While the above does not address the cause of the trailing edge failure, I believe it to be more likely that this was in overstress than fatigue since its bottom skin’s failure is straight along much of its line, at the rear spar. The top edge is more ragged. This gives the appearance of the bottom edge bending around the rear spar as a fulcrum, the top having failed in compression. Close examination of the fracture surfaces would be more conclusive. However there has been nothing about that from the French, at least made public.

Reservations

It is most unlikely the flaperon would fly up and strike the outer flap at that point, leaving this explanation inconsistent with the ATSBs that the two collided from a housed position[2]. Also, it contains conjecture and is based on just two “snapshots”, so would need confirmation, as circumstances may warrant.

1. These torque figures do not include the comparatively minor effect of actuator compression and tension. That would decrease the complete flaperon’s from 116 to 103, the flaperon’s without trailing edge increasing from 27 to 35.

2. The analysis above is based on the trailing edge breaking off in flight. Were it in fact to have broken away from the intact flaperon after its separation, the above explanation would be irrelevant.