Accidents Investigation Branch

Department of Transport

Report on the accident to Fokker F27-200 G-BHMZ at Creil Airfield, France on 2 October 1984

Aircraft Accident Report 7/85

Report on the accident to Fokker F27-200 G-BHMZ at Criel Airfield, France on 2 October 1984

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CORRECTIONS

Page 10, 1.16, para 2, line 7	*for* "200 kg" *read* "200 kt".
Page 18, 2.6, para 3, line 3	*for* "licences" *read* "licensee's".

Department of Transport
July 1986
LONDON: HER MAJESTY'S STATIONERY OFFICE

List of Aircraft Accident Reports issued by AIB in 1985/1986

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Department of Transport
Accidents Investigation Branch
Royal Aircraft Establishment
Farnborough
Hants GU14 6TD

4 February 1986

The Rt Honourable Nicholas Ridley
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr K P R Smart, an Inspector of Accidents, on the circumstances of the accident to a Fokker F27–200 G–BHMZ, which occurred at Creil Airfield, France on 2 October 1984

I have the honour to be
Sir
Your obedient Servant

G C WILKINSON
Chief Inspector of Accidents

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Accidents Investigation Branch

Aircraft Accident Report No. EW/A308

Registered Owner:	Air UK Ltd
Operator:	Air UK Ltd
Aircraft Type:	Fokker F27
Model:	F27–200
Nationality:	British
Registration:	G–BHMZ
Place of Accident:	Creil Airfield, France
Date and Time:	2 October 1984 12.50 hrs

Synopsis

The accident occurred during a scheduled passenger service from Leeds/Bradford to Paris/Charles de Gaulle. Shortly after the start of the descent into Paris the crew experienced a sudden severe vibration which culminated in the rudder pedals jamming with full right rudder applied. The co-pilot, who was handling the aircraft at the time, was able to maintain directional control by use of 15-20 degrees of left bank. Some 11 minutes after the rudder had jammed the port engine ran down and the propeller was feathered. The Commander declared an emergency and was cleared to land at Creil military airfield north of Paris where a safe landing was completed during which the aircraft ran off the right side of the runway on to the grass.

The report concludes that a 'flutter' condition occurred in the rudder assembly as a result of a long term reduction in the effective stiffness of the rudder trim tab. This accident was the latest in a series of seventeen comparable cases which have occurred throughout the service life of the F27. The report recommends that a modification similar to that developed by Fairchild Hiller in 1965, which has eliminated this problem on F27 aircraft built under licence in the USA, should be considered for incorporation in all F27 aircraft.

1. Factual Information

1.1 History of the flight

On the morning of 2 October 1984 the aircraft was used on a scheduled flight from Leeds/Bradford to Belfast and return. It was not equipped with an automatic pilot, and the commander on these flights reported that to achieve balanced flight the aircraft required more adjustments than usual to the elevator and rudder trim controls. On the return flight, during the descent he felt a small amount of free movement in the rudder trim control and noticed that, after small displacements to left or right, the control wheel tended to move slowly back to the neutral position. He reported in the aircraft Technical Log that the rudder trim had free play and did not set correctly. The rudder trim screw jack was repacked with grease; the system was then tested and found to be satisfactory.

The aircraft then left Leeds/Bradford with a different crew to operate Air UK scheduled flight UK703 to Paris/Charles de Gaulle. The flight proceeded normally until within 50 nm of Paris; when just after the start of the descent from the cruising altitude of 19000 ft, as the aircraft accelerated at cruise power through a speed between 200 and 220 kt indicated airspeed (IAS), the cabin staff heard a sharp crack followed by a brief period of severe vibration. The vibration was also felt by the two pilots, who found that when it ceased the rudder pedals were jammed with full right rudder applied. The co-pilot, who was handling the aircraft at the time, had to apply approximately ¾ of the available aileron control and 15° to 20° of left bank to maintain the heading of the aircraft. At this stage the commander passed a radio message to Paris Control advising that he had a rudder control problem and requesting a priority landing. During the ensuing radio conversation, as Paris Control attempted to confirm the nature of the problem, the commander used the words "WE'VE GOT LIMITED RUDDER CONTROL ON THE AEROPLANE .... WE DECLARE AN EMERGENCY". Paris Control acknowledged this message and told the commander to expect a "short circuit" for landing on runway 27 at Charles de Gaulle airport, which was then some 42 nm away.

Five minutes later, and approximately 11 minutes after the rudder controls jammed, the port engine ran down. The commander feathered the propeller and took control of the aircraft from the co-pilot. With the port engine shut down, he had a greater margin of control; being able to maintain heading with only ¼ deflection of the ailerons and a much reduced angle of bank. Although he still had to fly the aircraft with crossed controls and a large amount of left skid, he found he had some control available to turn the aircraft slowly against the influence of the rudder. Accordingly, he decided not to attempt to restart the port engine and he transmitted a MAYDAY (distress) message to Paris Control describing his new situation. Paris Control cleared the aircraft to land at Creil, 6 nm to the east, where the commander executed a safe instrument approach and landing with the rudder still jammed fully to the right. During the latter stages of the landing he maintained a speed 15 kt above normal scheduled threshold speed to ensure controllability. After touchdown he selected ground fine pitch on the right engine but despite asymmetric braking, was unable to prevent the aircraft from leaving the runway to the right. When the aircraft came to rest, the right engine was shut down and the passengers were disembarked without injury.

1.2 **Injuries to persons**

	Crew	Passengers	Others
Injuries	–	–	–
Fatal	–	–	–
Serious	–	–	–
Minor/None	4	12	–

1.3 **Damage to aircraft (see Appendix 1)**

The damage to the aircraft was confined to the rudder and rudder trim tab assembly. Severe structural damage had occurred in the vicinity of the rudder top hinge together with skin buckling and distortion at several positions on the rudder and trim tab surfaces.

1.4 **Other damage**

None.

1.5 **Personnel information**

1.5.1 *Commander*

Age: 37	Male
Licence:	Current Airline Transport Pilot's Licence valid to 13 June 1986.
Medical Certificate :	Valid to 31 October 1984.
Aircraft ratings:	DHCl, PA23, Trislander, Twin Otter, F27
Flying experience:	
Total flying hours:	6520
Total hours on type:	3250

1.5.2 *First Officer*

Age: 32	Female
Licence:	Commercial Pilot's Licence valid to 28 September 1991.
Medical certificate:	Valid to 31 August 1985
Aircraft ratings:	PA23, S330, F27
Flying experience:	
Total flying hours:	2200
Total hours on type:	350

1.6 AIRCRAFT INFORMATION

1.6.1 Leading Particulars

Type:	Fokker F 27-200 Friendship
Constructor's No:	10244
Date of construction:	1964 (March)
Certificate of registration:	G–BHMZ/R1 Owner – Air U.K. Ltd
Certificate of airworthiness:	No. 9457/1 Transport Category (Passenger) Valid to 9 September 1985
Certificate of maintenance:	Valid to 24 December 1984 or until 35515 hours aircraft total flying time.
Total airframe hours:	35260 – 27 hours.
Last maintenance check:	A check on 28.9.84 B Check at 34965 hours on 17.8.84
Engines:	2 Rolls Royce Dart 528–7E
Last flight test:	C of A renewal flight test was conducted on 15 September 1984 at 35041.5 aircraft hours. Aircraft assessed satisfactory in all respects.

1.6.2 Technical Log defect on previous flight.

During the previous sector the crew noticed that the rudder trim had returned itself to a neutral setting after having been set to a deflected position by the crew. This was reported, the rudder trim screwjack was repacked with grease and a note put in the Technical Log for crews to report if the defect persisted. The crew on the accident flight did not observe this feature to occur.

1.6.3 Known histories of rudder and trim tab

Neither of these items was required to have a separate history sheet and consequently it was not possible to determine the full history of either. The known component histories since entering Air UK are annotated below.

Trim Tab Serial No. 233
1972 fitted to aircraft No. 10293. Now Air UK G–BAKL
(The tab was fitted to this aircraft at manufacture).

On initial certification onto the UK register the mandatory modification to the tab control arm and its attachments was already embodied. (SB 55–30).

(Note: This modification was incorporated at construction on Aircraft No. 10275 et seq).

On investigation it was found that the wrong specification rivets had been used in the vicinity of the tab drive arm. The archive records at Air UK have not permitted subsequent movements of the tab to be established.

Rudder Serial No. 160.

Originally fitted on this aircraft.

Entry to Air UK on aircraft No. 10201(G–BCDN) 25 April 1974
Removed from G–BCDN and fitted to G–BDVT 30 April 1976.
Removed from G–BDVT due to rudder vibration reports 27 July 1976.

Archive records at Air UK have not revealed movements of this rudder between July 1976 and July 1981 when the rudder was overhauled.

The movement of the rudder after overhaul is similarly unclear.

1.6.4 *Fuel System*

The main fuel tanks for the F27 consist of a single integral tank of 2532 litres capacity in each wing. The fuel flows from these by gravity through two pipes from the base of the inboard tank closing rib into a collector tank in each nacelle. The collector tanks have a capacity of 50 litres each. The fuel is drawn from the collector tanks through two booster pumps with non return valves and is fed via a low pressure shut-off cock to the engine fuel system. It is possible to cross-feed fuel from either collector tank to both engines.

1.6.5 *Service Bulletins applicable to rudder/trim tab*

1.6.5.1 *Fokker Service Bulletins*

a.	SB 55–A10 Dated 26.5.61	Alert Bulletin as a result of a flutter incident in 1961. Called for inspection of tab control arm attachment bolts.
b.	SB 55–11 Dated 8.6.61	Follow up to SB 55–A10 introducing standardized attachment bolts.

NOTE: Both the above bulletins were the result of finding improper securing of the trim tab control arm leading to looseness of the attachment of the control arm to the tab which permitted vibration.

c.	SB 55–25 Dated 15.1.63	Introduced increased size skin stiffeners to prevent rudder skin cracking.
d.	SB 55–A29 Dated 20.1.65	Alert Bulletin as a result of another flutter incident. Called for inspection of trim tab for cracking near to the control arm attachment. Inspections to be repeated at 150–200 hr intervals.

e.	SB 55–30 Dated 28.4.65	Follow up to SB 55–A29 introducing a modified tab control arm together with reinforcement of the tab structure around the control arm attachment. (This is the subject of UK Airworthiness Directive AD 65–4–28). Fokker built aircraft modified to the standard laid down in this Bulletin are accepted by the Federal Aviation Authority and are not subject to F.A.A. Airworthiness Directive 65–05–04 (See 1.6.5.2c).
f.	SB 55–33 Dated 26.6.66	Introduced thicker skins on the lower aft part of the rudder to prevent "oil canning" and rivets becoming loose.
g.	SB 55–51 Dated 29.12.75	Called for inspection of tab hinge fittings on rudder. Later incorporated into Structural Integrity Programme.
h.	SB 27–116 Dated 22.8.80	Introduced steel tab push-pull rod as a result of some light alloy rods being found bent.
i.	SL 329	General warning on loose blind rivets. Pointed out effects of rivet looseness on structural stiffness. Also commented that in combination with play in hinges and drive mechanisms the flutter margins could be eroded.

1.6.5.2 *Fairchild Hiller Service Bulletins*

a.	SB F27–55–8A Dated 29.1.65	Introduced as a result of flutter incidents. Called for inspection of the rudder trim tab structure around the tab control arm attachment with subsequent inspections at 100 hour intervals. It also introduced a reinforcement of the tab structure around the control arm attachment with post modification inspections at 600 hrs and every 150 hrs thereafter. (NOTE: This SB broadly covers Fokker SBs 55–29A and 55–30).
b.	SB F27–27–39A Dated 12.3.65	This introduced a fundamental modification to the rudder and trim tab and was introduced as a result of a re-analysis of the rudder flutter characteristics. Flight trials showed that this modification resulted in maintenance of satisfactory trim control and did not give rise to any adverse handling characteristics.

c.	FAA Airworthiness Directive Dated 25.2.65 Revised 13.5.65	65–05–04 This Directive specified the compliance to the two Fairchild Hiller service bulletins which was required.

1.7 Meteorological information

Weather was not a factor in the accident. At the time of the event the aircraft was at approximately 18000 feet in smooth air, clear of cloud and above 6 oktas of cumulus cloud, base 2000 feet, tops 8000 feet.

1.8 Aids to navigation

Not applicable

1.9 Communications

Very high frequency (VHF) communication was satisfactory and radio telephony frequency (RTF) recording was available on all frequencies used during the flight.

1.10 Aerodrome information

The aircraft landed on runway 25 at Creil, a French military aerodrome equipped with ground controlled approach (GCA) radar. Runway 25 has a landing distance available of 2400 metres, is 56 metres wide and is equipped with a Category 1 instrument landing system (ILS), high intensity approach lighting and visual approach slope indicators (VASIs).

1.11 Flight Recorders

1.11.1 Flight Data Recorder

The aircraft was fitted with a Sundstrand FA542, engraved foil flight data recorder. Four parameters only were recorded and these were:

Airspeed
Altitude
Magnetic Heading
Normal Acceleration

Flap angle was a mandatory parameter at the time of the accident but was not recorded as the operator had been granted a dispensation by the Civil Aviation Authority.

The other mandatory parameters at the time, namely pitch and roll angles and engine power were exempt under the provisions of Scale P in Schedule 5 of the Air Navigation Order 1980, on the grounds that the equipment provided on the aircraft did not allow the recording of these parameters.

The data recorder was retrieved from the aircraft by the French authorities and the foil medium was returned to the UK.

Only normal acceleration had been recording correctly, airspeed and altitude were erroneous due to the pitot and static lines being cross-connected at the flight data recorder isolating valve. Heading was reading 180° in error as a result of crossed wiring at an associated terminal block.

The faults in the data recorder made the readout of speed and altitude difficult, pressures had to be deduced from the raw readings, assuming that the airspeed transducer behaved in the same manner for negative pressures as for positive. Comparison with expected speeds and altitudes indicated that the accuracy of quoted airspeed was probably ± 15 kt and that of altitude ± 500 ft.

The readout of the recorder indicated that the rudder structural failure took place as the aircraft reached an altitude of 17300 feet at a speed of approximately 215 kt, this was some one and a half minutes after start of descent from the cruise conditions of 19000 feet and 185 kt.

1.11.2 Cockpit Voice Recorder

A Fairchild A100 four track Cockpit Voice Recorder was installed in the aircraft. This used plastic based tape as the recording medium and was the normal endless loop type of recording with a duration of thirty minutes. The track allocation was as follows:

Track 1 – P1 headset telephone audio
Track 2 – P1 and P2 'live' microphones
Track 3 – Cockpit area microphone
Track 4 – P2 headset telephone audio

The recorder was recovered from the aircraft and a satisfactory replay was obtained.

1.12. Wreckage and Impact Information

1.12.1 Aircraft examination at Creil military airbase

The aircraft was initially examined at Creil by a representative of the Bureau Enquette D'Accidents (French Accidents Investigation Authority) together with engineers from the operator and manufacturer. The rudder was found to be jammed in the full right rudder position with skin fractures and obvious structural disruption in the area of the rudder top hinge which had resulted in the partial separation of the rudder structure above the hinge (see photographs Appendix 1). Both the rudder and rudder trim tab surfaces exhibited severe skin creasing and buckling which was most evident in the vicinity of the control surface hinges.

The rudder trim tab operating rod was bent and the trim tab skinning in the area of each of the tab hinge positions was torn indicating that the surface had travelled beyond its normal range of movement in both directions. The tab structure showed evidence of loose rivets and reduced structural stiffness which was particularly apparent in the vicinity of the tab control arm. Many rivets had the products of fretting around their heads (black powdery deposits) and in a number of instances these had streamed in the airflow to produce a black streak away from the rivets, (see photograph Appendix 1).

Before removing the damaged rudder/tab assembly, assembly, the rigging of both rudder and tab controls were checked and found to be within limits and there was no apparent play in either the rudder or tab hinges.

A replacement rudder assembly was fitted to the aircraft and it was then flown from Creil to the operator's engineering base at Norwich. Following discussions between the French Bureau Enquettes D'Accidents and the UK Accidents Investigation Branch (AIB) it was decided that the AIB would be responsible for the conduct of the subsequent investigation. The rudder assembly was despatched to Farnborough where a preliminary metallurgical examination was conducted.

1.12.2 *Rudder examination at Farnborough*

A detailed survey of the damage sustained by the rudder assembly was made at Farnborough along with a metallurgical examination of the structural failure in the vicinity of the rudder top hinge. No evidence of any pre-existing defect was found during these examinations and the metallurgists concluded that the failure resulted from a gross overload condition induced by lateral displacement of the rudder. The pattern of damage to the assembly suggested that an aerodynamic flutter condition had occurred. At the conclusion of the examinations the assembly was shipped to Fokker Aircraft, Amsterdam, where further examinations were conducted, monitored by AIB Inspectors.

1.12.3 *Examination at Fokker Aircraft, Amsterdam*

A programme of examinations and tests on the damaged rudder assembly was drawn up during initial meetings between AIB and the manufacturer. The sequence agreed was to initially conduct all those examinations that did not require any structural disturbance and to follow these with those tests and examinations that called for progressive disassembly.

The trim tab damage at all the tab hinge cut-outs showed that the tab had over-travelled repeatedly to 25 degrees either side of the central position. The normal range of movement for the tab is ± 10 degrees. The rudder trim tab system backlash was measured at 0.85 mm, well within the maximum allowance of 1.3 mm.

Examination of the trim tab screwjack actuator showed that although it was free of axial play (the sense in which it operates) it had considerable radial play. It was also noted that it was possible to back drive the actuator when a fluctuating axial load was applied to it.

Tests to establish trim tab torsional stiffness determined that, in relation to a new tab, the damaged tab had suffered a reduction of stiffness of approximately 80% in the area of the tab control arm and approximately 50% away from the tab arm.

Large numbers of loose rivets were identified particularly between tab stations 457.3 and 1477.3 (see Appendix 2) where all the rivets exhibited varying degrees of looseness. The numbers of loose rivets and their looseness reduced with distance from the tab control arm. When the tab skinning was removed, no evidence of fatigue or pre-existing failure was found in the tab structure. The rivets used on the trim tab were all of AGS 2050 (Tucker Pop) type whereas those specified by Fokker Service Bulletin F27/55-30 for the area of the tab control arm attachment were of MS 20600 and MS 20601 type. The numbers and disposition of the rudder mass balance weights within the leading edge of the surface were examined and considered by the manufacturer to be reasonable for that installation. Rudder hinge wear was also determined to be within acceptable limits.

A further structural examination of the rudder conducted by the manufacturer revealed no evidence of long term structural deterioration over and above that damage previously referred to. It was noted that the rudder had undergone a series of extensive repairs at some stage in its service life and discrepancies in several skin panel thicknesses were observed. Some of these repairs were considered unacceptable or inadequate from a structural point of view, but there were no signs of these playing a significant role. Due to their complexity, a possible effect on vibration modes could not be assessed.

1.12.4 *Left Engine Examination*

Examination of the left engine and the fuel system at Creil revealed no evidence of any damage, defect or malfunction. The engine was subsequently ground run and air tested and performed normally.

1.13 Medical and pathological information

There were no injuries.

1.14 Fire

There was no fire.

1.15 Survival aspects

Not applicable.

1.16 Tests and Research

At the initial discussions between AIB, Fokker Aircraft and the Dutch Airworthiness Authorities, the manufacturer undertook a theoretical re-examination of the flutter modes of the various components in the fin and rudder assembly based on the stiffness values recorded during the examination of the components from G–BHMZ.

The results of this work showed that the reduced stiffness noted on the rudder trim tab resulted in a tab torsional frequency of some 27-31 Hz compared with a nominal value for a new tab of 54 Hz. The reduced torsional frequency value was very close to the fin torsional frequency of 35 Hz and indeed at speed of around 100 m/s (200 kt) the frequencies became coincident. The manufacturer concluded that this condition could lead to an unstable oscillatory mode at about 200 kg which would cause the rudder to deflect in lateral 'S' bending, and result in the damage pattern observed on the rudder assembly from G–BHMZ.

The manufacturer then conducted a series of vibration tests on six rudder trim tabs, all in the modification state demanded by SB 55–30 but in varying conditions. The initial test on all tabs showed that the natural torsional frequency lay in the region of about 40 to 47 Hz. Subsequently one tab, in good condition, was selected for research into the effects of rivet looseness (simulated by removal of rivets) on the natural frequency and mode of vibration.

The first test, removing rivets from the skin to front spar joint, did not produce sufficient degradation of torsional stiffness to produce conditions necessary for flutter since the natural frequency was only reduced by about 3Hz. The tab was then restored to its original state.

The rivets were then removed progressively from the skin to control arm support ribs joints (see Appendix 3). It was found that when all 14 of these rivets were removed the natural frequency fell suddenly from an initial value of 41 Hz to 29 Hz, and the mode of vibration changed from almost purely torsional to one which was very nearly totally rotational. Further progressive removal of rivets from the front spar to skin joint on the control arm side of the tab to simulate the as found state of the accident tab produced a further, though smaller, reduction in natural frequency but no change in the mode of vibration.

Using the results of this test, a further flutter analysis was performed comparing the effects of variation of both torsional and rotational frequencies of the tab. This showed that the earliest onset of flutter in the torsional mode could occur at a speed of about 200 kt with a frequency of 37 Hz and in the rotational mode at about 210 kt with a frequency of 32 Hz. It was also confirmed that the flutter using the tab rotational mode would result in torsional oscillation of the fin coupled with lateral bending of the rudder between the upper two hinges.

1.17 Additional Information

1.17.1 During the investigation it was found that, between May 1961 and December 1982, the manufacturer had received 12 reports of severe rudder vibration occurring to Fokker built F27 aircraft. These had resulted in varying degrees of damage to the rudder and trim tab, several involving partial or complete loss of the trim tab and some cases of loss of the upper part of the rudder. (In those where the upper rudder remained attached, damage to the rudder structure around the top hinge was similar to that seen on G–BHMZ.

It was also noted that in most instances the tab control rod was found to be bent.

Apart from some yawing during the period of severe vibration no significant handling problems were reported in any of these earlier cases. The flutter occurrence to G–BHMZ was the first in which a rudder became jammed in a deflected position.

The manufacturers investigations of these earlier occurrences identified two basic causes, namely: loss of stiffness of the tab control mechanism and fatigue cracking of the trim tab hinge fittings on the rudder. Errors in mass balancing of the rudder assembly were found to be significant in some instances.

The first reported flutter incident in 1961 was found to have resulted from looseness of the tab control arm. This arose as a result of the use of incorrect length bolts attaching the arm. The manufacturers then issued two Service Bulletins (see 1.6.5.1 a&b) calling for inspection and modifications to the bolts.

Between December 1964 and March 1965 three flutter incidents were reported, and, in all cases fatigue cracking of the tab structure at the control arm attachment was identified. As a result of these the manufacturer issued two more Service Bulletins (See 1.6.5.1 d&e) calling for inspection of and modification to the control arm attachment. This modification was incorporated in subsequent tab production and provided a greatly improved control arm location. In 1966 a further flutter incident occurred to an aircraft which was believed to be unmodified.

The next flutter incident, in 1971, resulted in three of the tab hinge fittings on the rudder failing, and after a similar occurrence in 1975 the manufacturer issued a Service Bulletin ordering inspections of the tab hinge fittings and their surrounding structure. This Bulletin was subsequently cancelled when the inspection was included into the Structural Integrity Programme, together with modifications similar to those introduced on production rudders as a result of these incidents.

In 1977 another incident occurred in which the tab control rod was bent in an unusual way. This led to the manufacturer becoming concerned about the stiffness of this rod since it had been found to be bent after most reported flutter incidents and on other occasions when no reports of vibration had been received. A modification to fit a steel control rod in place of the light alloy rod was introduced, but not made mandatory as it was believed that bending of the control rod was a consequence rather than a cause of rudder vibration.

From October 1977 to December 1982 a further 5 incidents were reported, and after the G–BHMZ occurrence, a further incident to an aircraft not modified in accordance with SB F27/55–30 was reported.

Apart from the specific inspections and modifications already mentioned the manufacturer also drew attention to the requirement to mass balance the rudder assembly, by amendment of the Structural Repair Manual in 1965 and 1978/9, and by Service Letter (305) in 1978. The manufacturer also issued a Service Letter (329) in 1982 drawing attention to the problems of loose rivets (see 1.6.5.1h).

1.17.2 The Fokker F27 was also built under licence in the United States of America by Fairchild Hiller. In 1964 as a result of four rudder vibration incidents Fairchild Hiller, in conjunction with the Massachusetts Institute of Technology (MIT), investigated the flutter characteristics of the F27 rudder and trim tab assembly. From the flutter analysis conducted, MIT concluded that although the assembly was basically stable the stability margin appeared to be small enough so that deterioration due to service usage could lead to flutter. Fairchild Hiller and MIT considered various solutions based on the flutter analysis. They adopted a modification involving reduction of the trim tab span from 129 inches to 64.5 inches and increased the travel from ± 10 degrees to ± 14 degrees. The effect of this modification was to raise the tab flutter frequency, effectively separating it widely from the rudder bending and fin torsion frequencies. This modification was introduced by an FAA Airworthiness Directive applicable to all existing Fairchild Hiller built F27s. It was incorporated at build on subsequent F27 production and on the FH227 derivative of the type.

Since the introduction of the Fairchild Hiller trim tab modification, no further problems have been reported on Fairchild Hiller built F27's.

1.17.3 The discovery of incorrect specification rivets on the control arm support rib to skin joint during the examination of the trim tab from G–BHMZ led to the issue of Service Bulletin 55–58 calling for a fleet wide inspection of the rivetting of this joint. Information so far returned indicated that several aircraft modified to the standard of SB 55–30 had incorrect type rivets fitted at this joint.

2. Analysis

The accident occurred when a structural failure of the rudder and trim tab followed a short period of severe vibration as the aircraft was accelerating to its initial descent speed of 220 kt. This failure resulted in the rudder becoming jammed fully deflected to the right, seriously affecting the aircraft's flight characteristics. The accident was followed by an incident when the aircraft left the runway on landing but did not sustain additional damage. After a brief consideration of the actions of the flight crew, this analysis considers in detail the circumstances which led to the structural failure of the rudder assembly in flight.

2.1 The conduct of the flight

When the rudder jammed, the aircraft was in the descent phase with the co-pilot handling the controls. The commander's first action was to attempt to free the locked rudder pedals and it might be supposed that when the combined efforts of both pilots failed to free the rudder, the commander should have taken control of the aircraft. However, he was just starting an arrival procedure to Paris/Charles de Gaulle, which required attention to air traffic control procedures and navigation, and, being satisfied that the co-pilot was achieving a stable flight path in the descent, it seems reasonable that he should have concentrated his own efforts on the management of the flight and the emergency.

When the rudder became jammed in the full right position the crew were suddenly confronted with a situation where they required ¾ of the available aileron control to maintain heading. These control positions resulted in an aircraft attitude of 15–20° of left bank with considerable left skid and after approximately 11 minutes of descent in this attitude the left engine ran down and the commander feathered the propeller. The failure of the left engine at this time can be explained by the fact that the fuel demand during the descent would have exhausted the port collector tank in this time, i.e. 11 minutes. The collector tank is gravity fed from the main wing tank and with the aircraft attitude and fuel state pertaining at the time, it is reasonable to conclude that the transfer ports from the wing tank to collector would have been above the main tank fuel level and consequently the collector would not have been replenished in the normal way. Subsequent ground and air tests revealed no faults in the engine or fuel system which tends to support this hypothesis.

With hindsight it can be seen that the run down of the port engine might have been prevented if the crew had used asymmetric power to counteract the yaw. However such a course would have required a significant overall increase in power above the level needed to achieve the rate of descent required for compliance with the arrival procedures. In any case, before the crew had time to experiment with ways of improving the aircraft's controllability, the port engine ran down. By this time the commander had already advised Paris Control of his emergency situation and could expect ATC assistance. He then took over the controls of the aircraft.

To the commander the failure of the port engine was a second and unconnected emergency which did, however, go some way towards counteracting the effect of the jammed rudder and considerably improved his manoeuvre margin. Whilst he might have restarted the engine by crossfeeding fuel from the starboard wing tank, he was not aware that the engine failure had been caused by the excessive yaw and had no reason to suppose that it could be safe or even possible to restart the engine. Moreover, he could not have used power from that engine without again reducing his margin of control.

The subsequent incident in which the aircraft left the runway after touchdown might have been prevented had the pilot used power on the starboard engine to supplement nosewheel steering and asymmetric braking. It is not surprising, however, that, having crossed the landing threshold at 15 kt above normal threshold speed, he should have followed normal deceleration procedure and selected ground idle after touchdown to ensure that he did not overrun the runway.

2.2 Rudder and trim tab failure

The initial examination at Creil showed there was no evidence of collision with any airborne object and the examinations of the main and trim controls to the rudder revealed no evidence of any malfunction or failure. Subsequent detailed examination showed no evidence of failure or significant wear in either the rudder or tab hinges. The rudder structural failure in the vicinity of the top hinge was shown to be the result of a lateral overload. This was consistent with the damage observed on the rudder skins which indicated that the rudder had experienced gross deflections in lateral "S" bending with the rudder hinges acting as nodal points. The damage observed on the rudder was not consistent with any of the normal flutter modes associated with control surfaces i.e., rigid rotation or torsion. The damage sustained by the trim tab however, was typical of that seen in cases of flutter. The damage to the tab skins at the hinge cutouts showed that the tab had over-rotated in both directions in spite of the fact that the control rod mechanism was intact, although crippled, and would have prevented rigid body rotation in one direction. Thus the only modes of deflection capable of causing this damage would be a torsional flutter mode about the control arm or a rigid rotation of the tab permitted by looseness of the tab control arm attachment to the tab. The presence of damage due to over-rotation on all tab hinge cutouts tends to support a predominance of the second mode, although the presence of skin creasing above and below the tab control arm indicates that severe torsional displacements also took place during the vibration period.

2.3 Vertical tail surface flutter analysis

As a result of the manufacturer's re-examination of the flutter characteristics of the vertical tail surfaces it was established that if all components maintained their design stiffness then all flutter modes were satisfactorily damped. However, if a substantial reduction in trim tab torsional or rotational stiffness were to occur then a point would be reached when a cross coupling of trim tab and fin torsion frequencies resulted in an undamped oscillation of the fin and trim tab which would induce sympathetic lateral "S" bending of the rudder. In effect this is the conclusion arrived at by Fairchild Hiller and MIT following their flutter analysis in 1965, which resulted in the reduction of span of the trim tab on American manufactured F27's and FH227's.

The torsional stiffness tests of the rudder trim tab from G–BHMZ showed that there was a general reduction in stiffness of the order of 50% which would have resulted in a torsional flutter frequency considerably lower than that necessary to initiate this undamped oscillation. There is no doubt that during the period of severe vibration the torsional stiffness of the trim tab would reduce as a result of the violent forces imposed on it. Therefore it is reasonable to suppose that immediately before the onset of vibration the effective stiffness of the tab was already sufficiently low for the unstable condition to occur. The presence of a large number of loose rivets radiating from the area of the tab control arm, many of which showed clear evidence of long term fretting, suggests that the tab stiffness had been deteriorating over a considerable period.

During their researches into the effects of rivet looseness on the torsional stiffness of the tab the manufacturer found that it was possible to tolerate a very large number of loose rivets in areas remote from the tab control arm without a significant degradation of torsional stiffness. However, looseness of rivets attaching and in the immediate vicinity of the control arm resulted in a marked decrease in the effective torsional stiffness and this could lead to the conditions necessary for flutter.

It is considered that a combination of the two effects is most likely to have resulted from natural in-service deterioration, with looseness at the control arm attachment playing a more significant part. The presence of incorrect specification rivets attaching the tab control arm can only have increased the rate at which the structure approached the required flexibility for flutter to occur.

The trim tab was originally supplied on aircraft No. 10293 and as such should have complied with Service Bulletin 55–30 on leaving the manufacturer. Although examination showed evidence of repairs on the trim tab end ribs and trailing edge skin, there was no evidence of repairs in the area of the control arm attachment. It should however be noted that if it had been necessary to replace the tab control arm fairing attachment bracket, the rivets of the skin to rib attachment would have to be removed and replaced. In the absence of a component history card it cannot be established whether or not this occurred.

It should be recognised that the most serious damage in terms of hazarding the safety of the aircraft was that which occurred to the rudder as a result of its gross deflections in sympathetic "S" bending. The flutter and vibration analysis performed by both Fokker and Fairchild Hiller/MIT showed that the tab torsional frequency was higher than, but fairly close to, that of the rudder bending frequency. Thus it can be seen that loss of rotational/torsional rigidity of the tab with the attendant reduction in its natural frequency would lead to the condition necessary for the rudder to bend in sympathy with the driving vibration from the tab should it flutter. The Fokker analysis also shows that the natural fin torsion frequency exacerbates this situation.

It would thus appear that to markedly reduce the possibility of this combination of effects occurring it would be desirable to separate the natural frequencies of trim tab rotation/torsion and rudder bending. The Fairchild Hiller modification to the rudder and trim tab was formulated to achieve this whilst maintaining sufficient trim tab power.

2.4 Design considerations

With the original design standard of rudder and trim tab, rudder flutter incidents occurred to aircraft of both Fokker and Fairchild Hiller manufacture. In 1964, Fairchild Hiller initiated an examination of the stability of the trim tab and rudder, and concluded that, although the system was stable as manufactured, relatively little in-service wear could erode the stability margin and permit flutter. They therefore designed an easily retrofitted, fundamental modification that separated the natural frequencies of the components of the system and would thus be more tolerant of in-service deterioration. The fact that since application of this modification throughout the Fairchild Hiller manufactured fleet no further rudder flutter incidents have been reported, suggests that this approach was sound.

By contrast, Fokker, the original designers, have incorporated several less radical improvements to the original design, in an attempt to maintain the intended stiffnesses of the system. Whilst formulating the action to be taken as a result of the early flutter incidents, reduction of the tab span was one option considered. However, since early flight tests had indicated that this might lead to some undesirable flight characteristics, most importantly the feature known as "rudder walking", this approach was discarded in favour of improving the basic stiffness of the control arm to tab attachment as described in Service Bulletin 55–30. It was implicit in this approach that rigorous maintenance of the tab stiffness would be necessary. Despite this however, there has been a continuing pattern of rudder flutter incidents occurring to Fokker built aircraft.

2.5 Maintenance considerations

It is clear from the external appearance of the trim tab after the incident that a number of rivets had been loose for some time and that this was apparent from streaking of fretting products from those rivets. The manufacturer would have expected the operator to have treated the visibly loose rivets as a matter of considerable concern and to have effected repairs at the earliest opportunity. It would appear, since this expectation was not realised, that the manufacturer ascribed to the operator, whose approach to maintenance is generally responsible and conscientious, a greater understanding of the causes and significance of loose rivets than was actually the case. In April of 1982 the manufacturers issued a Service Letter (SL 329) entitled "Stabilizers" which referred generally to loose blind rivets in flight control surfaces and referred specifically to reports of loose rivets on elevator tabs. This Service Letter drew the operator's attention to the potential effects of loose rivets, in combination with play in hinges and drive mechanisms, on structural integrity and flutter margins. It detailed the characteristic evidence of rivet looseness and highlighted areas where this problem was most likely to arise. Since loose rivets in aircraft structures are a very common problem and such inspections are standard maintenance practice, the Service Letter, by coupling the effect of loose rivets to play in hinges and drive mechanisms, effectively reduced the significance of loose rivets in isolation, as was the case on G–BHMZ. It is surprising that, as the manufacturer was clearly concerned about the structural stiffness of flight control surfaces that they did not see fit to issue a Service Bulletin or Alert Service Bulletin which would have had significantly more impact on the operators' maintenance staff.

2.6 Airworthiness implications

The Fokker F27 was first granted a UK type certificate in 1967 some 2 years after Fairchild Hiller had introduced their modification to the rudder and trim tab. In accordance with their normal practice the CAA conducted the UK certification in conjunction with the primary certificating authority (in this case the Dutch Authority RLD).

It is natural that RLD knowledge would reflect the experience and philosophy of Fokker, the designers of the aircraft. It would appear that although both RLD and Fokker were aware that Fairchild had produced a fundamentally different solution to the rudder flutter problem, neither had knowledge of the background work nor the involvement of MIT in the formulation of that solution. Consequently neither appears to have fully appreciated the rational behind it in separating widely the natural frequencies of the vertical tail surfaces.

Licence building of aircraft is not uncommon, and is likely to increase as technologically emerging nations acquire aircraft industries of their own. It is quite possible that licences may, as in this case, formulate a different approach to problems than that of the design originators and, with the national Airworthiness Authorities agreement, introduce changes with which the originators do not concur. In this case, had the United Kingdom Civil Aviation Authority approached the Federal Aviation Administration or Fairchild Hiller as licencees, they would have found that the licence built aircraft were subject to an Airworthiness Directive (AD) relating to the rudder and trim tab of the F27, and this might well have influenced their requirements for granting a type certificate. It would therefore seem reasonable that, in order to eliminate these communications problems, that Authorities (the CAA in the UK case) who are examining the suitability of an aircraft to be granted a national type certificate should establish, when licence built variants of a type exist, whether there are any additional requirements or information in the possession of the licensee or their national authority which may be relevant.

When considering the Fokker built F27 aircraft, the global fleet is, and will continue to be, relatively numerous. The historical evidence suggests that although improvements to the existing rudder trim tab may reduce the rate of flutter incidents, the potential for such occurrences remains so long as the original design is retained. There is a clear case for modifying the trim tabs on these aircraft in line with the modifications incorporated on the Fairchild Hiller licence built aircraft.

3. Conclusions

(a) *Findings*

(i) The crew were properly licenced and adequately experienced to conduct the flight.

(ii) The aircraft had been maintained in accordance with an approved maintenance schedule and the Certificates of Maintenance and Airworthiness were valid at the time of the accident.

(iii) A partial loss of directional control occurred during the initial descent to Paris (Charles de Gaulle) as a result of the rudder becoming jammed and deflected fully to the right.

(iv) The left engine ran down as a result of fuel starvation caused by the aircraft attitude which was adopted in order to maintain heading with the rudder deflected.

(v) Structural damage to the rudder assembly occurred as a result of "flutter" of the rudder trim tab.

(vi) The stiffness of the rudder trim tab had degraded to the point where it was susceptible to flutter.

(vii) The rudder trim tab natural frequency had reduced sufficiently to excite the fin torsion/rudder bending mode and induce undamped vibrations of the rudder assembly resulting in the structural failure of the rudder.

(viii) The rivets in the tab control arm attachment were not of the type specified.

(ix) The loss of effective stiffness of the rudder trim tab resulted from the progressive loosening of rivets in its structure, particularly in the attachment of the tab control arm.

(x) Loose rivets in the rudder trim tab, which had been manifest for some time, were not rectified during scheduled maintenance or during the investigation of the rudder trim tab malfunction reported on the previous flight.

(xi) This was the 13th recorded rudder trim tab flutter occurrence to Fokker built F27 aircraft.

(xii) A modification to separate the natural frequencies of the rudder and trim tab has been in existence since 1965 but had been applied only to F27 aircraft constructed under licence by Fairchild Hiller.

(b) *Cause*

The accident was caused by flutter of the rudder trim tab which resulted in structural failure of the rudder at the top hinge bracket.

A contributory factor was the small separation between the natural frequencies of components of the vertical tail surfaces.

4. Safety Recommendations

4.1 The manufacturer should consider applying a modification similar to the existing Fairchild Hiller rudder trim tab modification to all F27 aircraft.

4.2 The CAA should take account of differences in requirements and modifications incorporated on licence built aircraft when considering the issue of a UK Type Approval Certificate.

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