Fletcher FU24 Fin Engineering Review

Summary Report – Final

Table of Contents

1. Introduction

In November 2005 an FU24-950 ZK-DZG was involved in an accident near Whangarei with the loss of two lives. This aircraft had been previously converted to turbine power in accordance with CAA STC number 98/21E/15 as a Walter Fletcher. After a period of investigation the CAA Safety Investigation Unit (SIU) attributed the accident to the in-flight separation of the vertical fin [1].

Following the accident to DZG, an Action (6A2359 [2]) was agreed with the SIU. The Aircraft Certification Unit (ACU) was to carry out an engineering review to establish the airworthiness of the Fletcher aircraft vertical fin from a damage tolerance, structural design and fatigue strength perspective.

2. Terms of Reference

The ACU engineering review:

i) Addresses action 6A2359 on the ACU, "The Manager ACU is to carry out an engineering review to establish the airworthiness of the Fletcher aircraft vertical fin from a damage tolerance, structural design and fatigue strength perspective". [2]

ii) Investigates the effect of the STC conversion on Fletcher Aircraft, including:

- Measurement and analysis of Fletcher fin loads for both piston and Walter turbine powered aircraft.
- Review of Fletcher and Cresco fin defect and accident history.
- Review of Fletcher certification and STC fin structural reports.
- Recommendations for improvements to the STC process, Continuing Airworthiness process, and the SIU safety investigation.

iii) Makes recommendations to improve the airworthiness of the Fletcher fin structure.

It is not the aim of this review to investigate the DZG accident.

3. Fletcher FU24 Fin Engineering Review

The engineering review of the Fletcher fin can be divided into two main areas of work. The first was a practical static and in-flight load testing program on the Fletcher vertical fin. This was accomplished with the assistance of the STC Holder. In addition a finite-element analysis of the FU24 fin was commissioned from an engineering consultant.

The second part of the review involved the ACU carrying out a desk-top review of design requirements and certification compliance documents, as follows:

1. Review the original certification report for the FU24-950 Series regarding the fin substantiation.
2. Relate this original substantiation against the fin testing carried out at Super Air Ltd in March 2006.
3. Produce a spreadsheet to analyse the effect of aircraft speed, engine power and propeller diameter on the vertical fin loads.
4. Review the measured loads obtained from the flight testing above, and relate these back to the original substantiation.
5. Review the reports on the previous FU24 turbine conversions to see what changes were made to their vertical fin, if any, and whether the design load cases were changed due to the turbine engine conversion.

If at any time during the engineering review an unsafe condition was discovered, safety action would be taken immediately to correct it.

In February 2008 a workshop with interested parties was hosted by the ACU to share the information gathered up to that time. It was also an opportunity for comment and discussion on the review findings to date.

4. Background Information

4.1 FU24 Aircraft Development History

The Fletcher FU24 has been the backbone of the New Zealand agricultural aviation industry since the late 1950s. It has been subject to a continuous development process to improve its cost-effectiveness and utilisation. This history is quite important in order to understand the technical development of the fin and the knowledge of the FU24 Series aircraft and its structure which had built up within the CAA and in industry.

The first FU24 aircraft flew in 1954 fitted with a 225 hp Continental O-470 engine and with a 3500 lb maximum takeoff weight. It was imported in large numbers, initially in kitset form, until ownership of design and production rights were transferred to New Zealand in the early 1960s. Subsequent modifications were developed to include installation of other piston engines up to 300 hp. In this period there were also three early turbine conversions to the FU24:

1. The first was the FU1060, which installed a 500 shp PT6A-20. The aircraft had a re-designed forward fuselage and engine mount, dual-wheel landing gear, strengthened wing and rear fuselage, including vertical fin. Technical substantiation was carried out by Air New Zealand and the model was type certificated by the CAA.

   Service History: FU1060 ZK-CTZ s/n 1001 was first registered in July 1967, and was withdrawn from service and de-registered in December 1980. (Lou Forhecz in his book on the history of the FU24 states the aircraft had flown 5325 hours.)

2. A second version, the FU1160, was essentially the same except a 530 shp Garrett TPE331 engine was fitted.

   Service History: FU1160 ZK-BHQ s/n 2001 (previously FU24 s/n 19) was converted to turbine power in May 1967. The aircraft crashed fatally on 13 August 1968 after 376 hours in service, possibly from a partial power loss due to fuel starvation. (See Aircraft Accident Report No.1837 [6])

3. The third was the FU1284, which installed a 665 shp Garrett TPE331 turbine engine. This aircraft had major changes from the standard FU24 airframe. However, the vertical fin was the same part number. (It is reported that after a failure during testing, some doublers were added to the fin front attachment bulkhead. This change was subsequently retrofitted to all FU24 aircraft.)

   Service History: FU1284 ZK-CYY s/n 2002 was first registered in November 1969, and was de-registered in March 1977. (No information is available on its time in service.) No further examples were produced, because the Type Certificate holder at the time, Airparts (NZ) Ltd, decided to proceed with a new turbine aircraft development which eventually became the 08-600 Cresco.

The next major development in the early 1970s was the introduction of the FU24-950 Series, using the 400 hp Lycoming IO-720 engine. (This engine change was first carried out and approved in Australia by Pays Air Service, using Space Development drawing number 5090.) The MAUW was also increased for the FU24-950 variant to 4860 lbs in accordance with Air Parts Service Bulletin AP55 (Parts A, B and C). Because the calculated fin loads were less than that for the FU1060, the vertical fin and rudder from the

FU1060 were adopted without any testing being required. This variant was very successful and became the standard production aircraft. In addition most existing FU24 aircraft were upgraded to this configuration under Supplemental Certificate of Type Approval Number SA-3 and re-designated FU24-950M.

In the early 1990s the cost of overhaul of the IO-720 engine led operators to look for an alternative. The first proposals involved the use of automotive-derived V8 engines. In 1993 Super Air Ltd was the first applicant and established the principle that the CAA would accept a significant increase in power (37%) for the take-off condition with a 5 minute limitation, with no changes required to the aircraft flight envelope. A similar project was undertaken by Fieldair Ltd using a different V8 engine. Only the Super Air V8 prototype flew, but neither project was taken forward to the certification phase.

The first modern turbine conversion of the FU24-950 was the Australian “Stallion” conversion using the Garrett TPE331, which was approved in New Zealand under CAA STC 98/21E/13. This conversion used the standard FU24-950 vertical fin but with the addition of a dorsal fin. As part of the CAA approval the design substantiation was reviewed. The designer of the Stallion, Auto Avia Design, stated that “The dorsal fin was solely to improve directional stability – with the longer nose for the turbine engine, the weathercock stability was lacking.” It is noted that compliance with FAR §23.572 Fatigue Evaluation was not part of the certification basis of the Australian STC, not even sub-paragraph §23.572(b)(3).

The first modern New Zealand turbine conversion was by Super Air Ltd as the Walter Fletcher, using the Czech Walter M601D-11NZ engine. This first flew in 1998 and some 23 conversions have since been completed. The standard FU24-950 vertical fin is used. Super Air then produced a Pratt and Whitney Canada PT6 powered version with a stretched fuselage, which resulted in a configuration externally very similar to the Cresco. Again there was no change to the vertical fin. A very similar stretched PT6 turbine conversion was produced by Flightcare Limited in 2005, as the FU24-550 Crusader. This aircraft also used the standard FU24-950 vertical fin, but with the addition of a dorsal fin.

In summary, all re-powered conversions of the FU24-950 have continued to use the standard FU24-950 vertical fin Part Number 240340, with no changes other than in some cases the addition of a dorsal fin. This fin was originally approved for the FU1060, which had a similar engine power to the modern turbine conversions. Two of the three original turbine conversions using the Part Number 242341 vertical fin had successful service lives of up to thirteen years, with no reported structural problems.

4.2 FU24 Fin Structural Description

The Fletcher FU24 has a unique type of vertical fin construction. It is made up of strips of vertical sections with integral edge-stiffeners. There is a substantial rear spar, which the whole fin structure effectively cantilevers off. The front fin attachment is a single pin-joint. In the original FU24 fin design there was one internal rib. When the aircraft was first converted to turbine power as the FU1060, with increased speeds and operating weights (and hence design loads), the vertical fin had to be strengthened. This was done by fitting additional internal ribs and associated external straps. This fin design was carried over to the FU24-950, with some minor detail changes. (The top rib was deleted.) When the design was upgraded to the Cresco the same basic vertical fin was used. The fin was strengthened with the addition of a metal closing strip to the front vertical strip. In addition after static tests of the forward-biased case some doublers were added to the bottom rib.

As with all the other parts of the structure the vertical fin had to be shown during type certification to meet the design load cases called up in the applicable airworthiness requirements, which are detailed below.

4.3 CAR 3 / FAR 23 Design Load Cases

The applicable airworthiness design standard for the FU24 was CAR Part 3, and the paragraph applicable to the vertical fin is §3.219:

§ 3.219 Manoeuvring loads. At all speeds up to Va:

(a) With the airplane in unaccelerated flight at zero yaw, a sudden displacement of the rudder control to the maximum deflection as limited by the control stops or pilot effort, whichever is critical, shall be assumed. Note: The average loading of Figure 3-3 and the distribution of Figure 3-8 may be used.

(b) The airplane shall be assumed to be yawed to a sideslip angle of 15 degrees while the rudder control is maintained at full deflection (except as limited by pilot effort) in the direction tending to increase the sideslip. Note: The average loading of Figure 3-3 and the distribution of Figure 3-7 may be used.

(c) The airplane shall be assumed to be yawed to a sideslip angle of 15 degrees while the rudder control is maintained in the neutral position (except as limited by pilot effort). The assumed sideslip angles may be reduced if it is shown that the value chosen for a particular speed cannot be exceeded in the cases of steady slips, uncoordinated rolls from a steep bank, and sudden failure of the critical engine with delayed corrective action. Note: The average loading of Figure 3-3 and the distribution of Figure 3-9 may be used.

There are thus three design cases to consider, which can be summarised as Case (a) full rudder deflection at V_A (maximum manoeuvring speed), Case (b) full rudder deflection in a sideslip, and Case (c) neutral rudder in a sideslip. Case (a) assumes a middle load distribution in Figure 3-8 due to the high camber of the deflected surface, while the latter two cases (b and c) assume a forward-biased load distribution per Figures 3-7 and 3-9, as reproduced below. CAR 3 also provided for a simplified method of determination of the average loading (of the tail surfaces, including the vertical fin), using a table which was effectively proportional to the aircraft weight.

Case (b) Case (a) Case (c)

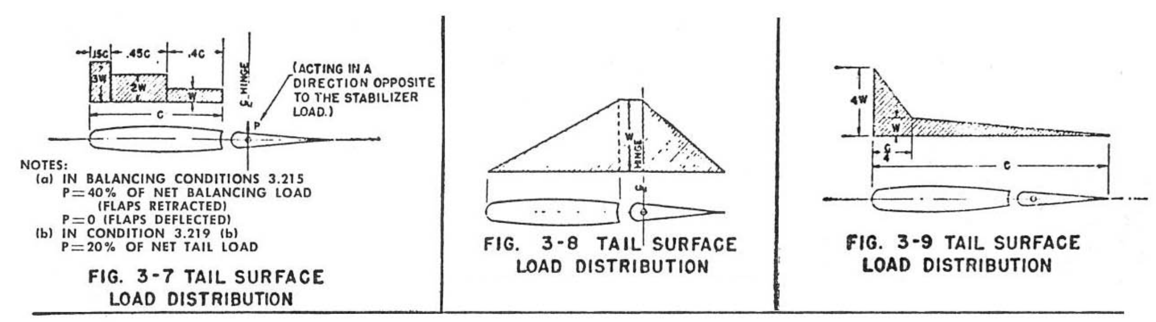

FIG. 3-7 TAIL SURFACE LOAD DISTRIBUTION

FIG. 3-8 TAIL SURFACE LOAD DISTRIBUTION

FIG. 3-9 TAIL SURFACE LOAD DISTRIBUTION

In practice, Case (b) is usually the same as or less than Case (c) so that only (a) and (c) need be considered. Case (a) is also usually numerically higher, but Case (c) more severe because of the forward loading. These requirements are virtually unchanged under the later FAR 23 design standard in paragraph §23.441, as used for the Cresco. (There are small changes in the wording.) However from Amendment 23-42 dated 2/4/91 the option to use the simplified average loading and load distributions are removed.

5. Engineering Investigations

5.1 Review of Fin Substantiation/Tests

The first strengthened FU24 vertical fin was fitted to the FU1060 version, and load tests were carried out by Air New Zealand and passed successfully. Higher loads were tested for the FU1284 fin, because that version had an increased all-up weight. (Some reports state that the fin was modified for this version, but the Drawing List calls up the same part number.) The FU1060 fin was subsequently used on the FU24-950 Series, which became the standard piston-powered FU24 version. Because the calculated loads for the FU24-950 were less than for the FU1060 no additional testing of the fin was required. (The part number of the FU24-950 fin is different to the FU1060, but a comparison of the drawings shows they are essentially similar with only minor detail changes. They were accepted as structurally equivalent by the CAA at the time, as noted in Report FL87.) The same Part Number 242340 FU24-950 vertical fin has been used on all subsequent turbine conversions, sometimes with the addition of a dorsal fin.

The fin load calculations carried out initially by Fletcher Aviation, and later by Air New Zealand, used the simplified average loading permitted by CAR 3. Because for a specified wing loading the fin load is directly proportional to the weight, this is why the fin load increased progressively for the first three versions in Table 1. For the FU24-950 the vertical fin loads analysis in CAA Report FL87 was carried out theoretically using the aerodynamic capability of the fin. This resulted in lower fin loads, especially for Case (c). (This would not be unexpected, as simplified formula usually require some assumptions to be made which must be conservative in order to have a wider applicability.) Similar results to FL87 have been obtained for all subsequent manual calculations by other Design Organisations.

Following the accident to ZK-DZG the STC holder carried out some static load tests on a standard FU24-950 fin to confirm it was capable of withstanding basic design loads. The first was a simple pull test on the fin centred at 25% chord lengthwise and at the point up the fin where the chord is the average length. The fin supported a pull load up to 1050 lbs, at which point it failed due to buckling of the forward lower skin. This load would correspond to a Case (c) limit load of 700 lb. A more comprehensive series of tests was later carried out on another fin, using load figures re-calculated by Super Air using FAR 23 requirements. These values were actually higher than the FU1284 for Case (a), and the FU1060 for Case (c). The fin, which was a used example taken out of store, passed both tests successfully. On the Case (c) forward-loaded test the fin deformed at approximately 125% limit, again by buckling across the forward lower skin area. After the fin deformed the load was re-applied and the fin went on to withstand ultimate load. Under the standard airworthiness design rules the test could be classed as a pass provided the deformation was classified as non-detrimental. The only reason the deformation would be detrimental was if it changed the fin angle-of-incidence, and thus the fin load, significantly. In this case it was assessed by the CAA that the fin load would not have been increased enough by the deformation to invalidate the test. [4] Note the test load was well above that calculated by CAA Report FL87.

The development history of the vertical fin and its use on various FU24 versions is summarised in Table 1. The Calculated Fin loads column shows the actual calculated test loads for the particular design case, with the documented report reference alongside.

Table 1– FU24 Model Development and Vertical Fin Design and Testing

Model:	Approval Date:	TC:	Engine:	Power:	V_{NE}:	MAUW:	Fin Part No.:	Calculated Fin Loads:	Compliance Report:
FU24	22-7-55	FAA 4A12 NZCAA A-3	O-470-E O-470-M*[2] O-470-D GIO-470-A*[3] IO-470-G*[4] IO-520-A/F*[5]	225 hp 240 hp 260 hp 310 hp 250 hp 285 hp	V_{NE} 143 KIAS V_A 116 KIAS	3500 lb 4000 lb*[1]	Part No. 242301	Case (a): 490 lb. Case (c): 490 lb.	Fletcher Corp. Report 24.7001
					Notes: 1. When modified in accordance with Drawing List No. 24.7003A 2. Installed per Fletcher Aviation Corp. Drawing 248142 and FAC EOs. 3. Installed per Sergeant Fletcher Corp. Drawing 248165. 4. Installed per Aero Engine Services Modification AES/11. 5. Installed per Air Parts (NZ) Ltd Modification AP/9 or AP/11.				
FU1060	6-7-69	NZCAA A-5	PT6A-20	500 eshp	V_{NE} 167 KIAS V_A 114 KIAS	4860 lb (Std) 5430 lb (Ag)	Part No. 242341	Case (a): 655 lb. Case (c): 655 lb.	AIR NZ Report ANZ 2471005
FU1160	Not Issued	NZCAA A-6	TPE331	530 shp	V_{NE} 167 KIAS V_A 114 KIAS	4860 lb (Std) 5430 lb (Ag)	Part No. 242341	No Change	
FU1284	10-6-71	NZCAA A-9	TPE331-1-101L	665 shp	V_{NE} 181 KIAS V_A 122 KIAS	5800 lb (Normal) 6500 lb (Special)	Part No. 242341	Case (a): 830 lb. Case (c): 830 lb.	AIR NZ Report ANZ 24.71064
FU24-950	11-12-70	A-3 Part 2	IO-720-A	400 hp	V_{NE} 143 KIAS V_A 116 KIAS	4860 lb (Std) 5430 lb (Ag)	Part No. 242340	Case (a): 573 lb. Case (c): 471 lb.	CAA Report FL87
"Stallion"	23-3-98	STC 98/21E/13	TPE331-6-252	600 shp	No Change	No Change	P/N 242340 (Dorsal Fin)	No Change	
"Walter Fletcher"	9-8-2000	STC 98/21E/15	M601D-11NZ	550 shp (T/O) *[6] 440 shp (Cont.)	No Change	No Change	Part No. 242340	Case (a): 893 lb. Case (c): 685 lb.	Superair Static Test VR 03-05
"Falcon"	21-2-2001	STC 99/21E/3	LTP101-700A	537 shp (T/O) *[6] 392 shp (Cont.)	No Change	No Change	P/N 242340 (Dorsal Fin)	No Change	
FU24-PT6	4-6-2004	STC 3/21E/1	PT6A-11AG	550 shp (T/O) *[6] 430 shp (Cont.)	No Change	No Change	Part No. 242340	No Change	
FU24-550	6-10-2006	STC 6/21E/1	PT6A-15AG	550 shp (T/O) *[6] 392 shp (Cont.)	No Change	No Change	P/N 242340 (Dorsal Fin)	No Change	
08-600 Cresco	9.4.84 13.4.93	NZCAA A-11	LTP101-700A PT6A-34AG	599 shp (T/O) 750 eshp	V_{NE} 176 KIAS V_A 124 KIAS	6200 lb	Part No. 08-32001-2	Case (a): 550 lb. Case (c): 713 lb.	NZAI Report 08-30

*[6] Take-off power is limited to 5 minutes operation.

5.2 Defect and Accident History

5.2.1 Fletcher FU24 Vertical Fin

According to CAA records, there have been eight in-flight vertical fin failures on Fletcher FU24 series aircraft since 1973. Investigations of the first six failures (1973, 1975, 1976, 1982, 1995 and 2001) concluded that these failures were caused by corrosion and resulting subsequent fatigue of the forward attachment fitting. The CAA produced Airworthiness Directive (AD) DCA/FU24/161 to introduce repetitive inspections of this fitting, and finally DCA/FU24/172 in October 2001which replaced the aluminium fitting with a steel item. There have been no reported forward attachment fitting failures since then.

The seventh in flight failure occurred on 18 April 2002 near Masterton (ZK-EGO). This accident was the first fin failure with fatal consequences, although the previous accidents had resulted in one serious injury and varying degrees of aircraft loss of control. The 2002 accident was attributed to fatigue of the vertical fin leading edge skin which had initiated from scribe marks left during the application of a leading edge protective strip. AD number DCA/FU24/173 was released on 26 April 2002 requiring the temporary removal of any protective coverings and a detailed examination of the fin leading edge lower portion. As a result of the AD inspection at least four further aircraft were found to have sustained scribe marks during application of the rubber but none had yet developed into cracks. The fatigue crack on ZK-EGO had grown to extend almost completely across the port side of the fin leading edge and a quarter way down the starboard side of the fin, before it had failed. (See MPT Report 11387.01)

The accident to ZK-EGO and the subsequent ADs raised the awareness of the significance of damage to the fin structural components and between 2002 and 2005 a further 3 reports were made to the CAA of cracking and corrosion of the fin leading edge and/or internal ribs. Unfortunately the database records of these indicate only a superficial level of investigation. Further review where possible by the ACU (usually only by examination of photographs) has found that these fatigue cracks could often be seen to have developed from a stress raiser, such as a rivet hole or section discontinuity. None of the cracks appeared longer than one inch in length.

After the accident to ZK-DZG in November 2005 the CAA issued AD number DCA/FU24/176 (A/B/C), the revisions of which progressively increased the inspection area to include the entire fin leading edge and reduced the inspection intervals to align with the original manufacturer's recommendations. Since then a further four defects have been reported to the CAA. One instance was of cracked ribs (all three internal ribs substantially cracked, leading to loss of the fin end-fairing in flight), which was attributed to a poorly fitting rib. The other three reports were of cracking in the leading edge skin although not in the same location as the damage on either ZK-DZG or ZK-EGO. Nonetheless the variety and prevalence of damage to this component, given its structural significance, was of concern to the CAA.

ZK-DZG was the first fin failure recorded on a turbine powered FU24. However turbine powered FU24 variants did not see significant service in New Zealand until the late 1990's. In 2008 nearly half of the 70 FU24s flying in New Zealand are turbine powered.

A summary of FU24 Series vertical fin defects and failures are presented in Table 2:

Table 2 - FU24 Vertical Fin Defects and Failures

Occurence No:	Type:	Severity:	Date:	Rego:	Location:	Description:	Model:	ACU Comment:
72/78	ACC	MA	22/08/1972	**BIH**	Rere-whakaaitu	During a sowing run the fin of the aircraft collided with a 12-gauge steel wire suspended 150 ft above a gully and carrying power to an electric fence in an adjoining paddock. The aircraft remained controllable and was flown back to the strip.	Fletcher FU24	
73/70	ACC	MA	8/05/1973	**CMK**	Marybank	In flight separation of the fin and rudder occurred during a ferry flight to base. Severe corrosion had weakened the vertical spar to an extent that it failed during a left-hand turn. The aircraft then entered a left-hand spiral dive but recovery was made with sufficient height to enable an emergency landing to be made.	NZ Aerospace FU24A-950M	Corrosion of rear spar and Fwd fitting.
75/123	ACC	MA	17/11/1975	**CZA**	Tahora	At end of sowing run pilot initiated a climb to make another run but found elevator jammed in forward position. Forced landing made. Aircraft touched down heavily on a small flat area on otherwise rugged terrain. Investigation revealed that forward attachment of fin had failed due to progressive corrosion. Fin and rudder had then folded backwards across the tailplane.	NZ Aerospace FU24-950M	Fwd Fitting, likely fatigue from corrosion pits
76/125	ACC	MA	4/11/1976	**BSM**	Pirongia	Failure of the forward fin attachment fitting due to severe corrosion caused the fin and rudder to separate in flight. Control difficulties resulting in the aircraft being forced to land on inhospitable terrain and slide over a bank.	NZ Aerospace FU24-950M	Fwd fitting, corroded (likely fatigue)
			16/11/1976	Airworthiness Directive DCA/FU24/161 issued for inspection of forward fin attachment. Corrosion to be removed/protected.				
			11/03/1977	Airworthiness Directive DCA/FU24/163 issued for modification of forward fin attachment per SB/FU/028				
82/34	ACC	MA	30/03/1982	**EGH**	Maunga-karamea	The fin forward attachment fitting failed in normal cruising flight. The pilot executed an emergency landing without further incident. A fatigue fracture had initiated from the heavily corroded surface of the fin fitting which had finally failed in tensile overload.	NZ Aerospace FU24-950	Corrosion
83/102	ACC	MA	16/11/1983	**BIX**	Wharenui Stn	At the completion of a sowing run the pilot flew the aircraft in a steep turn to position for a further run on the reciprocal track. During the turn he heard a 'bang' from the rear fuselage area and decided to jettison the remaining load and land the aircraft. Inspection of the aircraft after landing revealed that its rudder had folded a fore and aft crack.	NZ Aerospace FU24-950M	Fin Fitting fractured in fatigue from heavily corroded surface.
92/3231	ACC	CR	9/10/1992	**BDS**	Wainui	Hit wire, damaged fin	FU24-950M	Wirestrike
92/3810	ACC	MA	13/11/1992	**BOF**	Orini	Encountered severe downdraft, hit wires	Fletcher FU24	Wirestrike
95/317	ACC	CR	16/02/1995	**BPY**	Ngatea	FIN FOUND 500M FROM CRASH SITE. VERTICAL STABILISER. PILOT ATTEMPTED TO LAND, LOST CONTROL = CRASHED. W/R 95/SAI/194 - Fin Fitting failed due to fatigue from very small corrosion pit, only visible under SEM at IRL. Fatigue surface partially obscured by subsequent fretting. Control of the aircraft was lost at low altitude while spreading insect bait, pilot sustained severe injuries during crash as forward fuselage disintegrated.	NZ Aerospace FU24-950M	Fwd Fin fitting Fatigue
			29/09/1995	Airworthiness Directive DCA/FU24/161A edited to inspect for cracks as well as corrosion.				
			29/09/1995	Airworthiness Directive DCA/FU24/163A edited to require modification of forward fin attachment.				

Occurence No:	Type:	Severity:	Date:	Rego:	Location:	Description:	Model:	ACU Comment:
01/3269	DEF	MA	20/09/2001	**EGV**	Dargaville	The pilot reported that the rudder pedal suddenly locked into a fully deflected position. He managed to land safely at Dargaville where he discovered that the whole tailfin had rotated through 180 degrees on its remaining bracket and was hanging off. Failure was due to a crack originating from a corrosion pit which was hidden from view when installed on aircraft. Discussions with PAC suggest that Fatigue margin of original design may have been reduced by anodising, which was introduced to counter the corrosion problems that were experienced. Cad plated steel item is made to same dimensions so has higher static and fatigue strength margins, as well as good corrosion resistance. Existing DCA/FU24/163 directed that -1 (al) OR -3 (steel) fittings be installed. This AD cancelled and replaced by DCA/FU24/172 which directs that -3 fittings are to be installed and inspected at 12 month intervals.	NZ Aerospace FU24-950	Corrosion
			25/10/2001	Airworthiness Directive DCA/FU24/172 issued for replacement of forward attachment fitting and inspection of fin leading edge.				
02/1578	DEF	MI	16/04/2002	**EGS**	Feilding	Investigation of fin IAW DCA/FU24/173 found scratches and scoring around skin.	FU24-950	LE Skin damaged during modification
02/1167	ACC	CR	18/04/2002	**EGO**	6 SSE Masterton	The tail fin separated in flight; the aircraft struck a ridge and caught fire. The pilot was killed and the aircraft destroyed.	NZ Aerospace FU24-950	Fatigue in LE skin initiated by modification.
			26/04/2002	Airworthiness Directive DCA/FU24/173 issued for inspection of forward fin structure. Any cracks must be repaired before further flight.				
03/1899	DEF	MI	29/06/2003	**EMN**	Gore	The 'flutes' between the elevator hinge P/N 242235 and fitting P/N 242237 were found cracked.	FU24-954	
03/1964	DEF	MI	2/07/2003	**DUJ**	Masterton	Several cracks were found in leading edge and central rib of the tail fin of a Walter powered Fletcher when it was removed for painting. *Not fully investigated*	NZ Aerospace FU24-950 “Walter”	Fatigue and /or overload cracks
03/2967	DEF	MI	26/09/2003	**EUH**	Wanganui	Bad corrosion was found on the vertical fin leading edge skin, in the area of the front mount bulkhead, during the aircraft's first 100 hour inspection.	NZ Aerospace FU24-954	Corrosion
03/3295	DEF	MI	13/11/2003	**DUJ**	Masterton	Multiple cracks were found in the skin and internal ribs of the airframe. This is a Walter Fletcher. *Not fully investigated ,note previous occurrence on this aircraft*	FU24-950 “Walter”	Further fin structural cracking
05/3727	ACC	CR	22/11/2005	**DZG**	Whangarei	RCCNZ reported that the aircraft was carrying out a transit flight from Kaikohe to Whangarei and was reported to be missing. After an extensive search the aircraft was found destroyed in Pukenui Forest.	NZ Aerospace FU24-950 “Walter”	Likely LE Skin Fatigue
06/556	DEF	MA	8/02/2006	**JLU**	Masterton	The internal ribs of the Walter Fletcher vertical stabiliser were found to be broken and cracked. *Not fully investigated*	FU24-950 “Walter”	Fatigue and /or overload cracks
			1/06/2006	Airworthiness Directive DCA/FU24/176 issued for inspection of the leading edge of the vertical fin, including removing all protective coatings and adhesive.				

Occurence No:	Type:	Severity:	Date:	Rego:	Location:	Description:	Model:	ACU Comment:
06/2830	DEF	MI	14/07/2006	**CML**	Hamilton	A crack was found on the fin leading edge skin starboard side between the l. e. and middle rib doubler P/N 242337R. The crack was on the doubler centre line in a horizontal direction about a half inch long. *Not fully investigated.*	Fletcher FU24-950M "PT6"	LE Skin likely fatigue, initiated by poorly formed Rib Similar to 06/3537.
06/3094	DEF	MI	15/08/2006	**DJE**	Nelson	While the aircraft was in for a scheduled 100 hour inspection a large number of 'working rivets' were noticed on the stabilator.	NZ Aerospace FU24-950 "Walter"	
06/3537	DEF	MI	7/09/2006	**EMT**	Palmerston North	Whilst complying with DCA/FU24/ 176 cracks were found on the leading edge skin from working rivets. Chafe marks made by the dorsal fairing were also evident. *Not fully investigated. But LE supplied to CAA*	NZ Aerospace FU24-954 "Stallion"	Widespread structural cracks, likely fatigue, Different position and orientation from DZG or EGO
06/3543	DEF	MI	20/09/2006	**EGI**	Gore	It was reported that the aircraft was undergoing a four yearly inspection when the leading edge fin was found to have a crack in it.	NZ Aerospace FU24-950	LE Skin likely fatigue, similar to Cresco occurrences
			31/05/2007	Airworthiness Directive DCA/FU24/176A issued to change the inspection interval to align with the manufacturer's maintenance program.				
			28/06/2007	Airworthiness Directive DCA/FU24/176B edited to clarify the intent of the above and amend the inspection interval.				
			27/09/2007	Airworthiness Directive DCA/FU24/176C edited to clarify the intent of the above and amend the inspection interval.				

Notes:
1. The Pink highlighting indicates those reported occurrences where there was a structural issue with the vertical fin.
2. The details in the table above have been taken directly as recorded in the CAA Safety Database.
3. The details in red are comments added by the ACU after reviewing what details are available on file.
4. It is noted under "model" whether the aircraft is turbine powered. (This does not show in the aircraft designation on the database.)

5.2.2 Cresco Vertical Fin

The Cresco is a turbine development of the FU24, and is similar in appearance although in most cases the parts are different. The Cresco has a 750 shp PT6A-34AG engine and a MAUW of 6200 lb with increased operating speeds. Two cracked vertical fin leading edges, very similar to that thought to be on ZK-DZG, have been found on PAC 08-600 Cresco aircraft. The Cresco vertical fin is strengthened over the FU24 in this area, with a closed front section. It also has a dorsal fin, for aerodynamic reasons. These were the first known occurrences of significant cracks in the vertical fin front skin in the FU24/Cresco family without a directly attributable cause.

5.2.3 ZK-DZG Vertical Fin

All evidence suggests that the accident to ZK-DZG was caused by the failure of the vertical fin at the front section, which allowed the fin to fold sideways and impair the function of the horizontal tailplane. This caused the aircraft to enter an uncontrollable dive from which there was no chance of recovery. What is undetermined is what initiated the fatigue crack that lead to the fin failure.

Following the accident to ZK-DZG when it became apparent that there was some question over the integrity of the vertical fin, the largest Walter Fletcher operator (and STC holder) carried out a detailed inspection of all vertical fins in their FU24-950 fleet. No significant cracks or defects were found, including on aircraft with higher operating hours than ZK-DZG. (One crack was found a few months later on an aircraft in their fleet, which was attributed to a poorly fitting part.) As recorded earlier in this report the STC holder also performed a series of static load tests on the fin to confirm that the fin could withstand basic design loads. Full details can be found in CAA Visit Report 03-05 [4].

5.3 Effect of the Turbine Conversion

Following the accident, questions were raised about the possible effects of the turbine conversion on the fin and the possibility that this may have been a causative factor in the accident. Accordingly, the STC holder was requested by CAA to carry out some engineering investigations to determine if the installation of the Walter engine had any detrimental effect on fin loads. Flight testing was performed on a standard Fletcher FU24-950 Series aircraft and on a Walter turbine-powered Fletcher to determine if there were any increased loads or other detrimental effects on the vertical fin of the converted aircraft, due to either slipstream, vibration or other causes. The Walter Fletcher was used for this purpose because it was the focus of investigations following the accident, and it was thought the results could be read across to other turbine conversions.

5.3.1 Fin Loads Survey

The testing was carried out by Mr Rod Mackey of Optimech. His final report “Fletcher Fin Load Measurements – July 2007” [5] states in its conclusions “The largest loads on the front fitting... are effectively the same on both aircraft” and “On the Fletcher 400 rear spar, in almost every case the stresses, and therefore the associated loads, are either equal to or significantly higher than those on the Walter.” Mr Mackey stated he could find no significant difference in the loads on the vertical fin between the standard piston-powered aircraft and the Walter turbine conversion over the full range of manoeuvres carried out during the measurement exercise. (These included all the manoeuvres called up in FAA

AC 23-8A, the FAR 23 Flight Test Guide, which are effectively all the manoeuvres the aircraft would be expected to carry out in service. Any agricultural operations would involve a combination of some or all of these basic manoeuvres.)

The Optimech study also measured the stresses in the leading-edge skin of the vertical fin, in the area where the failure occurred on ZK-DZG. The alternating stresses were largest for full rudder deflection, and were around 6000 psi. This is well below the strength capability of the material. (MIL-HDBK-5C gives an allowable compressive yield stress of 39000 psi for 2024-T3 thin sheet.) However structural testing has shown that this area does yield locally due to instability well below the theoretical capability of the material, which is typical for compression failures.

5.3.2 Fatigue Life

In terms of fatigue the principle structural element for the fin is the rear spar. The mean measured alternating stress levels in this were quite low, of the order of 5500 psi. When plotted against the Table A2-1 curves in Appendix 1 of AC23-13 this indicates the vertical fin rear spar would be expected to have an indefinite fatigue life. (4-5 million cycles.) This is typical for vertical fins, which are not highly loaded compared to horizontal lifting surfaces. Under FAR 23 for small aircraft the requirement to analyse for fatigue was only introduced at Amendment 23-7 in 1969, and then it only applied to the main wing. It was only extended to the empennage and other lifting surfaces under Amendment 23-38 in 1989. (It did not apply to the Cresco, for instance.) As a practical example, the 750XL vertical tail was analysed for fatigue and a life of 507,000 hours calculated. This compares to a calculated safe life of 44,600 hours for the horizontal tail surfaces. (See PAC Report 11-1023 [7].) Despite this there has been some localised cracking in the 750XL vertical fin skin, which is thought to be caused by acoustic fatigue. This shows that even a fatigue analysis cannot predict all types of possible structural problems, and the best protection for an aircraft is a sound inspection program.

5.3.3 Failed Fin Metallurgical Analysis

The metallurgical analysis by MPT Solutions [8] of the broken pieces from the vertical fin from ZK-DZG concluded that, while it was difficult to determine with any certainty due to mechanical damage from the two sides rubbing together, there was evidence of possible fatigue action on the failure surface. The report does not mention the length of the crack, but subsequent email correspondence with the metallurgist indicated their estimate that the initial crack length may have been of the order of centimetres in length.

A separate metallurgy analysis was carried out by the Defence Technology Agency [9], at the request of the Transport Accident Investigation Commission. Their report also found that there was some evidence of fatigue at the fracture surface, over a series of cracks. This report estimates the crack may have been of the order of 110 mm in length prior to the final failure. (This would be similar in magnitude to the crack on ZK-EGO before the fin failed on that aircraft.) However, crucially, the DTA report also stated there was evidence the fin leading edge may have been affected by either foreign-object-damage (FOD) or a past overload event prior to the formation of the fractures.

5.3.4 Fin Finite Element Analysis

The CAA commissioned a finite element analysis (FEA) of the FU24-950 vertical fin to get some stress data to be used for a fatigue analysis. This was carried out by an engineering consultant, who modelled the two design load cases calculated in CAA Report FL87. Due to constraints of time and resources some simplifications were made to the geometrical model, but it still provided a close structural representation of the fin.

The results were published in Report TA0809FU24 [12], and found that stresses in the fin were generally low. The highest stresses occur in and around the main spar, which is expected because the spar is the only structural element resisting fin bending. The stress in the fin leading edge, where the failure occurred in ZK-DZG, is low and of the order of 6250 psi. (This result correlates fairly well with the measured results from the Optimech strain gauge survey.) The rear spar stress levels were calculated to be much higher at up to 33,000 psi in the critical area.

6. Walter Fletcher STC Review

6.1 STC Certification Basis

Following the accident, questions were raised about the the certification basis of the Walter Fletcher turbine conversion. In fact the certification basis of the Walter Fletcher STC was FAR Part 23 at the latest Amendment status (Amendment 23-52 dated 27.03.1996) as at the date of application, *for those areas changed by the STC*. (That means that any change to the aircraft introduced by the STC had to be substantiated to the very latest airworthiness design standard.) The STC introduced a complete new engine package forward of the firewall, comprising engine and accessories, engine mount, cowling, and propeller. The only changes aft of the firewall were the instruments and controls in the cockpit, and a completely new fuel system. Crucially the weight and balance limitations and the flight envelope (aircraft speeds) were unchanged, which means the design loads on the vertical fin were unchanged. (Fin loads using CAR 3 average loading is directly proportional to aircraft weight. For an unchanged geometry the main effect on calculated theoretical fin loads as derived in CAA Report FL87 for the FU24-950 come from aircraft speed, with some variation due to slipstream from engine thrust. However the latter is not significant. For example sample calculations show that an 80% increase in thrust will result in a 7% increase in the load on the fin. As another example of the relative unimportance of thrust the Manual associated with CAR 3 provides under Section 3.19-1 that the power of an engine may be increased on an aircraft <u>without any substantiation</u> provided there is no increase in gross weight or in placard speeds.)

Note: Fin effects due to the agricultural overload provisions of CAR 137 Appendix B were not considered as part of the STC, because this was part of the original flight envelope of the FU24-950 and was unchanged by the turbine conversion.

Therefore because an increase in power alone does not have a big effect on fin loads, there was only the question of vortex impingement and slipstream effects as called up under FAR §23.572(b)(3) to consider during the approval of the STC. In this case no obvious vibration of the vertical fin was observed during ground running or in flight test, and no feedback through the control system reported by the pilots. Coupled with the past knowledge and experience of previous turbine conversions, the ACU considered that the standard vertical fin was satisfactory for the Walter Fletcher and any possible long-term effects could be handled by an inspection program. Damage Tolerance Analysis

6.2 Damage Tolerance Analysis

It has been suggested that a Damage Tolerance Analysis (DTA) could have been required as part of the STC, which would have predicted the fin weakness and possibly prevented the accident. In actual fact damage tolerance under FAR §23.573 is just one of several options for fatigue control of light aircraft. Damage Tolerance is the ability of a structure to withstand cracks and other damage for a specified period of unsupervised usage without catastrophic failure. It is a specific engineering process which involves the examination of a structure to predict where cracks will occur and an analysis of the behaviour of the structure after the onset of such fatigue cracks. It also involves analysis of a structure with some assumed initial flaws, due to material or manufacturing and processing operations. It is a relatively new technique having only been introduced into FAR 23 at Amendment 23-45 dated 28 July 1993. It was initially intended (and is mandatory) for composite construction where, because of the nature of the material, production and in-service defects are difficult to detect. It is a complicated and more expensive process and has not generally been used for light aircraft. When fatigue is a concern, the usual and cost-effective solution in the past has been to place a life limit on the part. In this case a DTA was not even considered because at that time there had never been any evidence of fatigue cracking of any kind occurring in the FU24 vertical fin.

6.3 Fatigue Analysis

The FU24, which first flew in 1954, is from the era of aircraft where lower-strength but less-fatigue-susceptible materials were used, and less precise analysis methods led to more conservative safety margins. At that time there was no requirement in the Design Standards to analyse for fatigue. (There is only a general statement under CAR §3.307 that the structure should be designed to avoid points of stress concentration where variable stresses above the fatigue limit are likely to occur in normal service. This was carried over into FAR 23.627, which was part of the certification basis of the Walter Fletcher.) Any fatigue issues are dealt with as they arise, because they are generally slow-growth cracks. (It is accepted that aluminium does not have a distinct endurance limit like steel, where if stresses are kept below a certain level fatigue will not occur. However in practice for lower stresses any fatigue action is likely to occur at cycle counts well beyond the life of an aeroplane. For example, one British light aeroplane was certified on the basis of keeping stresses below a specified figure with no fatigue evaluation and the fleet leader was at 90,000 cycles some years ago.) The majority of light aircraft in use around the world were designed under CAR 3 with no fatigue requirements, and are still flying safely with an average age of over 35 years old. However, this type of fatigue management does rely on good inspection regimes, and on any defects being reported and investigated.

As an example of a fatigue calculation for the FU24 vertical fin, the methodology in CAA Engineering Instruction EI-16 for calculating the fatigue of wings on aircraft used for agricultural operations was applied. Using an average 1-g stress level of 5000 psi, which would be extremely conservative given this is the highest stress level measured during the strain gauge program, results in a factored fatigue life of 4460 hours. If a more realistic average 1-g stress level of 2000 psi was used, the predicted fatigue life would rise to 153,000 hours. These calculations are very conservative and a new fatigue analysis of the fin was subsequently carried out using the latest FAA ACE-100-01 report methodology. Using a figure of 6250 psi stress for the fin front skin would lead to a predicted fatigue life of 58,000 hours. This is clearly well beyond the life of any FU24 aircraft. Using a stress level of 34,600 psi for the rear spar leads to a predicted fatigue life of 9434 hours. Many FU24 aircraft have exceeded this value, and to date no fatigue cracks in the rear spar have been reported. This could be due to a number of factors, ranging from the inherent variability associated with fatigue calculations through to the regular rebuilds of agricultural aircraft meaning no individual parts ever reached that life. The actual reason is most likely to be that the stress levels used were too high. The stress levels were based on early results of the FEA analysis. These early results predicted much lower displacements (fin bending) than actually found during tests. The FEA model was therefore altered slightly to allow some more flexibility in the fore-aft direction. This reduced rear spar stress loads down to 16,500 psi. This figure is closer to the even lower values recorded during the strain gauge survey. Reducing the stress level by 50% is likely to increase the predicted fin fatigue life by a factor of 2 or more, probably to a minimum of 20,000 hours.

6.4 Effect of Power Increase

The detailed certification basis for the Walter Fletcher was developed using the FAA Advisory Circular 23-14, "*Certification Basis for Conversion from Reciprocating Engine to Turbine-Powered Part 23 Airplanes*". One of the assumptions used in developing this AC was that any power increase from the conversion was small. The SIU report also questions the validity of using the AC when the Walter Fletcher had a 33% power increase. In fact this power increase on the Walter Fletcher is only a take-off rating, and the maximum continuous increase is only 10%, which the ACU considered would come under the definition of small. The larger power increase for take-off and climb does not invalidate the assumptions of the AC because these operating regimes are essentially low-speed ones. The primary determinant of load on the vertical fin is the aircraft speed. The difference between agricultural and non-agricultural turbine conversions is that the main purpose of non-agricultural conversions is to get improved performance, particularly cruise speed. In that case the simplified certification basis in AC 23-14 would not be applicable in isolation, and it would be important to consider increased loads on the whole aircraft structure. (AC23-14 also states that installations that involve changes to power increases which affect high speed characteristics or airplane handling qualities may require additional substantiation and/or additional certification basis requirements.) The most important point for the turbine conversion with respect to flight loads is that the original flight envelope was unchanged. The FU24 was designed using V_H (maximum level speed at maximum continuous power (MCP)) to define the flight speed envelope. With a turbine conversion the applicant had to show that V_H had not increased. Table 1 shows that MCP for two of the turbine conversions had to be restricted to less than the 400 hp of the original FU24-950 for this reason. (The Walter Fletcher is limited to 370 shp maximum continuous power when operating in the Standard Category as the high drag agricultural role equipment is not fitted.)

7. Discussion

The Fletcher vertical fin has remained essentially unchanged since the P/N 242340 design was adopted for the first 500 shp FU1060 turbine conversion in 1969. (The Walter Fletcher is the 4th turbine conversion of the FU24, and the three previous ones used a very similar vertical fin.) The fin has seen close to forty years of operation with a wide range of engine types. Apart from the one case with ZK-EGO, traced to a specific isolated source, there had been no reported instances of significant fatigue in the vertical fin skin on the FU24-950 until the accident to ZK-DZG. In the case of ZK-EGO the fatigue crack had grown to be over 50% in length of the free surface area before it failed. (See MPT Report 11387.01)

There were six failures of the vertical fin in the period 1970-1990, although there were no resulting fatalities. All these instances were due to failure of the front attachment fitting, and the causes have been addressed by a number of Airworthiness Directives [10].

The Instrumented Engineering Review undertaken by Optimech [5] has shown there is very little effect on the FU24 vertical fin due to the installation of a Walter turbine engine. This conclusion is supported by the physical evidence in terms of reported defects, and the fact that all other FU24 turbine conversions over a period of forty years have made no change to the vertical fin, other than the addition of a dorsal fin for aerodynamic reasons.

The vertical fin design case is maximum rudder deflection at V_A, and hence manoeuvring speed is the major factor in determining the load on the fin. Calculations [11] show that an increase in engine power, propeller diameter or thrust have a small effect on vertical fin loadings, while an increase in aircraft speed results in a proportionately far greater increase in fin loads. Where there is no change to the flight envelope there is no change to the vertical fin design loads. (Neglecting secondary effects like vibration, although the testing found this was actually higher in some areas on the piston-powered FU24-950.)

The results of the Optimech testing have shown that measured fin loads correlate very well with the calculated design loads. The FU24-950 vertical fin has been tested and shown to satisfactorily withstand design loads without failure, including the required 50% safety factor. One of the design cases requires the loads to be biased towards the front of the fin, due to the high angle of attack of the aerofoil at maximum sideslip. This is the area which has shown to be critical on the FU24-950 fin during load testing.

Except for the specific case of ZK-EGO caused by deep scribe marks, the reported fatigue crack in the main central skin area of the fin of ZK-DZG has not been found on any other examples of an FU24-950. (Although similar cracks have been found in two 08-600 Cresco aircraft.) The draft accident report [1] did not state how many hours ZK-DZG had flown since the turbine conversion. It has now been found that the fin was completely rebuilt some 2963 hours before the accident, and had a detailed inspection under DCA/FU24/173 some 2070 hours before the accident.

In summary there is no doubt that the vertical fin is strong enough to meet the basic design loads, as shown in numerous static tests. The design loads have been independently calculated several times with similar answers, and have been verified during the Optimech load measurements as noted above. A finite-element analysis of the FU24 fin has also confirmed that stress levels in the fin are low. The basic strength of the fin can also be shown by the accidents to both ZK-EGO and ZK-DZG, when the fin only failed after the fatigue cracks grew to be of significant size, in the case of ZK-EGO half of the free surface length.

Given the negligible effect of the power increase and no measureable increase in fin load due to vibration or slipstream, the other possible effect on the FU24-950 caused by a turbine conversion would be due to the improved take-off and climb performance, and hence higher aircraft usage and therefore the acceleration of any type of wear.

However ZK-DZG was nowhere near the fleet leader in terms of time in service (It was the thirteenth Walter Fletcher conversion, in February 2001). Therefore the more likely explanation is that there was some pre-existing damage, possibly due to some type of impact, which had acted as a fatigue initiator. This possibility is suggested by the DTA metallurgy report [9].

The design of the FU24 vertical fin has no redundancy at the front, so that any failure of the front attachment or the front structure will result in complete failure of the fin. However lack of redundancy is typical of light aircraft design practices of the time, and some other aircraft have very similar vertical fin designs. For example the Piper PA-28 Cherokee Series and the Robin R2000 Series both use a single attachment bolt at the front of the vertical fin.

Given the history of fin failures on the FU24 and the recent fatal accident to ZK-EGO which resulted in increased inspections of the vertical fin, the question is, if there was a large existing crack on the fin of ZK-DZG why was it not discovered?

Agricultural aircraft operate in a very harsh environment in terms of frequent operations from very rough ground, using corrosive chemicals. The operators are fighting a continual battle against the effects of these conditions and materials which can damage the aircraft structure. The two main forms of protection used are some form of covering on the airframe, and regular inspections of the airframe to find any damage and repair it. Clearly there is some conflict here between access for inspection and protective covering. The empennage at the rear of the aircraft is particularly susceptible to damage, because it is in the slipstream of the propeller and in the downstream trajectory for items being thrown up by the undercarriage. FU24 operators over the years had evolved the practice of fitting a rubber protective layer on the leading edge of the vertical fin. This would hide any cracks developing in this area. (And also any impact damage.) Modification JA/FU24/M258 for leading edge abrasion strips was approved by the CAA in December 1975, although photographs show rubber leading edge coverings in use well before this. Airworthiness Directive DCA/FU24/176 now requires any non-transparent protective coatings and their adhesive to be removed for inspections. The AD requires a daily visual inspection by the pilot and a detailed inspection by an engineer at 50-hour intervals.

The second question is why a fatigue analysis was not required as part of the STC approval process, and if it was would it have prevented the accident? As noted above the fin is not a highly loaded structure, and a fatigue analysis would be expected to return a high life. (Well above the 2070 hours time-in-service of the fin on ZK-DZG.) For exactly the same reason a damage tolerance analysis (DTA) would find the same result. A DTA is required to consider the effect of pre-existing damage due to manufacturing or material defects, or even in-service difficulties. However this sort of defect is usually a mis-shaped hole or a small tear in the metal, which might be induced during production and gone unnoticed.

With hindsight the leading edge of the fin can be seen to be vulnerable. However even after the failure of the fin on ZK-EGO it was not thought justified to require more than a single one-off fin inspection in the resulting Airworthiness Directive. It was considered all weaknesses had now shown up and been addressed, and another failure in that area due to a different cause was simply not expected given the 50 year service history of the fin.

A fatigue analysis of the aircraft under FAR §23.572 was not part of the certification basis of the Walter Fletcher STC because the STC did not change any of the basic loads on the aircraft, or any of the materials of construction of the main structural elements. The original Fletcher FU24-950 Series was not subject to any fatigue requirements. It would be unreasonable to expect an STC holder to take responsibility for the fatigue management of an aircraft which had already been in service for 44 years and for which they were making no changes to the structure or basic loads. CASA came to the same conclusion when they approved the Stallion turbine conversion.

A fundamental principle of certification is that an STC only has to show compliance for those aspects changed by the STC. It is not the responsibility of the STC holder to correct aspects of the original design over which they have no control. (Similar conflict exists with the TC holder who does not want to be responsible for any changes caused by a modifier.)

The Rules under §21.123(a)(2) provide for the CAA to require an STC applicant to provide evidence of appropriate liaison with the TC holder. In principle it is beneficial for a TC holder to know is being done to their aircraft. In practice however this liaison almost never occurs. There are a number of reasons for this, the major ones being commercial sensitivity and product liability. The original manufacturer does not want to assist a competitor to make their own product better, for obvious reasons, and the modifier does not want to tell the original manufacturer what they are doing because they want to introduce a new idea onto the market. The original manufacturer also wants to distance themselves from the modified aircraft so they can minimise their exposure to liability in the event of an accident. For a modification as extensive as the Walter Fletcher STC there is a grey area with respect to continuing airworthiness responsibilities in trying to decide whether the turbine conversion had any effect on the basic airframe.

Rule §21.123(a)(2) requires liaison between the TC holder and an STC applicant when the STC applicant is using the TC holder’s data and the CAA needs to determine that the data is still current and valid. If an STC holder does not have any liaison with the TC holder then they must substantiate themselves all aspects of any changes they have made to an aircraft. This is in line with international practice.

The review revealed no evidence that the fatigue failure of ZK-DZG’s fin was caused by increased loads due to slipstream or any other effects from the turbine conversion. It is much more likely that the fatigue was initiated from an existing defect, such as from a stone impact. There is a suggestion of this by the fact that a piece of metal is missing from the fin leading edge, indicating that the pre-damage area may not have been just a crack but a larger area. The DTA report also states there is evidence of either possible impact or overload damage on the edge of the failed area. The resulting fatigue crack(s) weakened the fin such that it was unable to withstand the loading experienced when the aircraft was operated near the maximum manoeuvring speed in gusty conditions. i.e. in higher than normal fin load conditions, but still below the maximum design limit load.

8. Findings

8.1 The Walter Fletcher STC was the fourth turbine conversion of the FU24 airframe. The same fin has been used on all FU24-950 conversions, sometimes with the addition of a dorsal fin. The vertical fin has been substantiated to higher design loads, for the FU1060 variant, than is actually required for the FU24-950 Series.

8.2 The comparison between Fletcher fin loads for both piston and Walter powered aircraft by a strain gauge measurement program has not found any measurable effect of the Walter turbine conversion on the FU24 aircraft, due to either slipstream effects or vibration.

8.3 The measured stress in the front skin of the FU24 vertical fin is very low, of the order of a maximum of 6500 psi. This low value of stress would be very unlikely to cause a fatigue crack to initiate. (The fin does fail when tested at a low stress for the front skin, because the failure mechanism is by compressive instability which occurs well below the strength capability of the material. However compressive loads do not lead to fatigue.)

8.4 A fatigue analysis of the FU24-950 fin has been carried out which predicts a minimum fatigue life of 9,400 hours for the fin, using very conservative stress values. This is based on loads on the rear spar, which has never shown a failure. Calculations based on the low measured stress levels in the leading edge skin lead to a very long predicted fatigue life. It is therefore highly likely the fatigue crack in the vertical fin front skin in ZK-DZG was initiated by a stress concentration due to FOD impact or an overload event.

8.5 A Damage Tolerance Analysis has not been carried out, as firstly it is a technique not usually used for small all-metal light aircraft, and secondly because the low stress in the fin front skin would not have predicted the accident failure mechanism in this area. (The skin only failed when 50% of the original supporting area had been lost due to a crack.)

8.6 After reviewing the defect and accident history of the aircraft, no other examples of similar fatigue cracks (or series of cracks) in the vertical fin have been found on any other turbine-converted FU24 aircraft [10]. (Although similar cracks have been found in Cresco aircraft, which uses a similar fin with some strengthening in the front skin area.)

8.7 This review has shown that the CAA needs to have a close working arrangement with the holders of type certificates and major STCs. This is to ensure that continuing airworthiness issues are dealt with in the wider context of service and fleet experience.

8.8 The review concludes that the fin failure is the result of the susceptibility of the FU24-950 vertical fin to damage and the catastrophic effect of failure, coupled with the conflicting requirements for protection and inspection. The susceptibility of the FU24-950 vertical fin to damage is irrespective of the type of powerplant.

9. Conclusions

9.1 This review has found that the vertical fin on the Fletcher FU24-950 Series meets the structural requirements of the applicable airworthiness design standard, CAR Part 3. This was demonstrated by load tests at the time, and has been confirmed by repeated structural testing more recently.

9.2 It was not the purpose of this review to investigate the DZG accident. However, as a result of work completed during the review, it seems likely that the vertical fin failure on ZK-DZG was caused by a large fatigue crack which would have greatly reduced the fin's capacity to withstand design loads. It is likely that this crack was growing for a considerable period of time [9] but was not detected because it was covered by the protective covering on the fin leading edge.

9.3 There is no conclusive evidence as to what actually initiated the fatigue crack which led to the failure of the vertical fin on ZK-DZG. Because measured and calculated stress levels in the fin are low, especially in the fin leading edge, the DTA metallurgical report [9] suggesting evidence of damage due to impact or overload is the most logical explanation.

9.4 By design, the FU24-950 vertical fin has no structural redundancy and is therefore vulnerable to potentially catastrophic failure if the front skin is damaged in a way which weakens it significantly.

10. Recommendations

10.1 Because of the susceptibility of the FU24-950 vertical fin to damage and the catastrophic effect of failure, coupled with the conflicting requirements for protection and inspection, it is recommended that the CAA require operators to fit a vertical fin of new design to all FU24-950 Series aircraft, irrespective of the type of powerplant. The design features for the new fin are listed in Appendix 2.

10.2 It is recommended that the CAA defect investigation process be made more robust and thorough, particularly with respect to correlation to determine if there are other reported defects that could be an indicator of a wider problem. The ACU should assist with the investigation of defects involving New Zealand Type Certificates or STCs as the ACU is the technical unit of the responsible State-of-Design National Airworthiness Authority, and as such has the appropriate engineering data and expertise to undertake this job.

Geoff Connor
Manager
Aircraft Certification Unit

David Gill
Team Leader Airworthiness
Aircraft Certification Unit

10 March 2009

File Ref: A540-F02

11. References

[1] Aircraft Accident Report (draft) Occurrence Number 05/3727 ZK-DZG – Safety Investigation Unit Report by Manager Richard White – undated

[2] Action 6A2359 on the ACU, "The Manager ACU is to carry out an engineering review to establish the airworthiness of the Fletcher aircraft vertical fin from a damage tolerance, structural design and fatigue strength perspective."

[3] Review of the Certification Basis used for STC No. 98/21E/15 – Safety Investigation Unit Report by Safety Investigator Peter Kirker – 17 April 2007

[4] Super Air Ltd Visit Report VR03-05 – File no: A540-F01 – Witness of structural load testing on the Fletcher FU24-950 fin – by David Gill – 24 July 2006

[5] Optimech Report – Fletcher Fin Load Measurements – July 2007

[6] Aircraft Accident Report No.1837, FU1060, ZK-CTZ – 13 August 1968

[7] PAC Report 11-1023 – Main Plane – 750XL Empennage – Fatigue Evaluation

[8] MPT Solutions Report 20226.02 – Failed Fin from Fletcher Aircraft ZK-DZG – May 2006

[9] Defence Technology Agency Technical Memorandum C1087 – Failure of Fin Leading Edge – FU24-950 ZK-DZG – by Investigator P C Connor – 27 March 2008

[10] FU24 and Cresco Fin Failures and Occurrences Summary – ACU Report – 17 March 2008

[11] Vertical Fin Engineering Workshop.ppt – by Beth Coughlan – 5 Feb 2008

[12] TA0809FU24 – A Finite Element Based Stress Assessment of the Fletcher FU24 Vertical Stabiliser – Aero Design – 30/9/08

Appendix 1

FU-24-950 SERIES VERTICAL TAIL FATIGUE EVALUATION

The vertical tail section is assumed to be only subject to flight loads, comprised of gust and manouvre Occurrences, and not ground-air-ground (GAG) effects or taxi loads or landing impact loads. The reason for this is because the latter loads are horizontal in application and will not affect the vertical tail.

The FU24-950 is to be assessed against "General" usage spectra.

1. FLIGHT LOAD SPECTRA

1.1 GUST LOAD SPECTRA

Table below calculates vertical tail surface loads due to gusts. A constant speed equal to Vc is assumed. (This method is copied from PAC Rpt 11-1023 - 750XL Empennage Fatigue Evaluation with data changed to FU24-950) - This corresponds to Method B per ACE-100-01

FAA Report AFS-120-73-2				Vc =	113.84	kts
GUST Load Spectrum				AnLLF =	2.02	G
N/nm	An/AnLLF(hi)	An/AnLLF(lo)	N/hrs	Mean Δg	gust velocity	ΔHTS load
1.00E-06	0.96	-0.99	1.14E-04	1.97	29.26	343.9
2.00E-06	0.90	-0.90	2.28E-04	1.82	27.01	317.5
5.00E-06	0.82	-0.79	5.69E-04	1.63	24.15	284.0
1.00E-05	0.76	-0.72	1.14E-03	1.50	22.20	261.0
2.00E-05	0.70	-0.65	2.28E-03	1.36	20.25	238.1
5.00E-05	0.62	-0.57	5.69E-03	1.20	17.85	209.9
1.00E-04	0.56	-0.52	1.14E-02	1.09	16.20	190.5
2.00E-04	0.52	-0.47	2.28E-02	1.00	14.85	174.6
5.00E-04	0.45	-0.41	5.69E-02	0.87	12.90	151.7
1.00E-03	0.40	-0.37	1.14E-01	0.78	11.55	135.8
2.00E-03	0.36	-0.34	2.28E-01	0.71	10.50	123.5
5.00E-03	0.32	-0.30	5.69E-01	0.63	9.30	109.4
1.00E-02	0.28	-0.26	1.14E+00	0.55	8.10	95.2
2.00E-02	0.25	-0.24	2.28E+00	0.50	7.35	86.4
5.00E-02	0.22	-0.20	5.69E+00	0.42	6.30	74.1
1.00E-01	0.18	-0.17	1.14E+01	0.35	5.25	61.7
2.00E-01	0.15	-0.14	2.28E+01	0.29	4.35	51.2
5.00E-01	0.10	-0.10	5.69E+01	0.20	3.00	35.3
1.00E+00	0.07	-0.07	1.14E+02	0.14	2.10	24.7

Columns 1-4 taken from 11-1023, which in turn were taken from 11-1022 main wing report. That data was derived from Fig.1 of AFS-120-73-2

Column 5 is the gust acceleration calculated from the mean value of An/AnLLF in columns 2 and 3 times AnLLF

Column 6 is the gust velocity calculated by Δg = KUVm/498(W/S)

Column 7 is the incremental tail load due to gust velocities Lt = [$K_g U_{de} V a_1 S_e$]/498 x [1-(d*/d*)]

(XL values ware: V=140.67 kts; AnLLF=1.52; m=4.075; W=7500; S=305; K=1.088; K_g=0.707; a_1=3.287; s_e=61.02; d*/d*=0.600)

FU24 values are: V=113.84 kts; AnLLF=2.02; m=4.53; W=6366; S=294; K=1.075; K_g=0.707; a_1=3.63; s_e=26.51; d*/d*=0.600)

Report 11-023 uses fin vertical loads derived from the gust velocity on the basis gust loads are proportional to gust velocities. In this case the gust response for the Fu24-950 is not know. HTS load is used, because the HTS tail load and the load proportional to gust were very similar for the 750XL.

1.2 MANOUVRE LOAD
SPECTRA

ACE-100-1 (page 11, para 2) states that an acceptable simulation of a manouvre spectrum is to assume each gust load is matched by a zero sideslip rudder induced load of equal magnitude.
The manouvre spectrum is therefore taken as the reverse of the gust spectrum.

COMBINED GUST-MANOUVRE LOADS CALCULATION:

Stress on Rear Spar for Max. Load of 460 lb =			34598	psi
n	Sm	Sa	N/hrs	n/N
1.14E-04	0.00	25869.36	1.90E+03	5.99E-08
2.28E-04	0.00	23879.41	2.80E+03	8.13E-08
5.69E-04	0.00	21358.80	5.20E+03	1.09E-07
1.14E-03	0.00	19634.18	8.40E+03	1.36E-07
2.28E-03	0.00	17909.55	1.20E+04	1.90E-07
5.69E-03	0.00	15786.94	2.20E+04	2.59E-07
1.14E-02	0.00	14327.64	3.20E+04	3.56E-07
2.28E-02	0.00	13133.67	4.80E+04	4.74E-07
5.69E-02	0.00	11409.05	9.50E+04	5.99E-07
1.14E-01	0.00	10215.08	1.60E+05	7.11E-07
2.28E-01	0.00	9286.44	2.70E+05	8.43E-07
5.69E-01	0.00	8225.13	4.40E+05	1.29E-06
1.14E+00	0.00	7163.82	8.50E+05	1.34E-06
2.28E+00	0.00	6500.50	1.50E+06	1.52E-06
5.69E+00	0.00	5571.86	3.50E+06	1.63E-06
1.14E+01	0.00	4643.22	7.50E+06	1.52E-06
2.28E+01	0.00	3847.24	1.70E+07	1.34E-06
5.69E+01	0.00	2653.27	1.00E+08	5.69E-07
1.14E+02	0.00	1857.29	5.00E+08	2.28E-07

	∑	0.000013
Fatigue Life =	75475.60	
Scatter factor =	8	
Factored Fatigue Life =	9434	Hours

COMBINED GUST-MANOUVRE LOADS CALCULATION:

FEA Stress on Front Fin Skin for Load of 575 lb =			6250	psi
n	Sm	Sa	N/hrs	n/N
1.14E-04	0.00	3738.52	1.00E+08	1.14E-12
2.28E-04	0.00	3450.94	1.00E+08	2.28E-12
5.69E-04	0.00	3086.68	1.00E+08	5.69E-12
1.14E-03	0.00	2837.44	1.00E+08	1.14E-11
2.28E-03	0.00	2588.21	1.00E+08	2.28E-11
5.69E-03	0.00	2281.46	1.00E+08	5.69E-11
1.14E-02	0.00	2070.57	1.00E+08	1.14E-10
2.28E-02	0.00	1898.02	1.00E+08	2.28E-10
5.69E-02	0.00	1648.78	1.00E+08	5.69E-10
1.14E-01	0.00	1476.24	1.00E+08	1.14E-09
2.28E-01	0.00	1342.03	1.00E+08	2.28E-09
5.69E-01	0.00	1188.66	1.00E+08	5.69E-09
1.14E+00	0.00	1035.28	1.00E+08	1.14E-08
2.28E+00	0.00	939.42	1.00E+08	2.28E-08
5.69E+00	0.00	805.22	1.00E+08	5.69E-08
1.14E+01	0.00	671.02	1.00E+08	1.14E-07
2.28E+01	0.00	555.99	1.00E+08	2.28E-07
5.69E+01	0.00	383.44	1.00E+08	5.69E-07
1.14E+02	0.00	268.41	1.00E+08	1.14E-06

	∑	0.000002
Fatigue Life =	465066.23	
Scatter factor =	8	
Factored Fatigue Life =	58133	Hours

Appendix 2

Fletcher Redesigned Fin

All of the information from reviews and safety investigations is to be utilised to enhance the airworthiness of the new fin design. A list of design features (see below) for the new fin design will ensure it will take advantage of all of these lessons learnt and address any likely safety recommendations in the final DZG accident report. PAC has agreed with the list of design features and they have revised their original redesigned fin. Following the issue of a new/revised manufacturer's Service Bulletin, the process for the issue of an AD will commence immediately.

The redesigned fin should provide the following features:

1. The redesigned fin structure, must comply with Federal Aviation Regulations Part 23 including amendments 23-0 though 23-48.
2. Specifically the redesigned fin must comply with either FAR Part 23.572(a) paragraph (2) or (3). For the FU24 where a flight load spectrum is difficult to establish it is expected that either FAR Part 23.572(a)(2) or 23.572(a)(3) be used. The provision of structural design redundancy at the forward attachment points is required.
3. Inspection of the principal structural members must be possible without removal of the fin from the aircraft. An inspection procedure must be defined in accordance with FAR Part 23.575 and must be shown to provide consistent results with respect to initial detectability commensurate with the analysis provided under FAR Part 23.573
4. The redesigned fin must demonstrate compliance with FAR Part 23.305 by test. Structural tests must be shown to be conservative when the change in distribution of loads due to deflection is taken into account in accordance with FAR Part 23.101(c).
5. The principal structural members must be protected from impact damage, erosion and corrosion with consideration to the aircrafts intended roles of dispensing agricultural products.

Interim Safety Measures

Pending the modification of Fletcher aircraft with a new designed fin, the CAA is satisfied with the frequent repetitive fin inspections required by the existing AD to ensure the continuing airworthiness of the Fletcher fleet. This is however considered interim action until each aircraft is fitted with the new designed fin.