THE AERO COMMANDER CHRONICLE

S.J. Swift[1]

The service history of the Aero Commander light twins teaches a hard lesson in the theory and practice of fatigue control.

INTRODUCTION

In June 1991, seventeen senior engineers met in Seattle to discuss the safety of Aero Commanders after the twenty-third in-flight wing failure. Lawyers watched carefully over their shoulders. The meeting had been called by the United States Federal Aviation Administration (FAA) to discuss ‘wing loads, flutter, corrosion, cracking, and possible corrective action.’ How was it that such fundamental structural problems were still unresolved after forty years?

The Aero Commander typifies the practicalities of controlling fatigue in small commuter aircraft. The purpose of this paper is not to criticise Aero Commanders or those involved, but to draw lessons for the future - for designers, operators, regulators and all who have an interest in structural durability.

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[1] Principal Fatigue Engineer, Civil Aviation Authority (CAA), Australia. This paper was originally presented at ICAF 95, Melbourne, Australia, in May 1995. The Proceedings are published by EMAS UK. The CAA is now CASA, the Civil Aviation Safety Authority.

THE AEROPLANE

Development

In 1944, two ex-Douglas engineers set up the Aero Design and Engineering Company [2] to design a family of light twins. One was Ted Smith, later of Aerostar fame. The aeroplane they produced was a fast high wing six seat cabin monoplane, all metal, weighing 4600 pounds and powered by two 190 horsepower piston engines. This prototype, known as the L-3805, first flew on 23 April 1948.

Over the next thirty-seven years the design was extensively developed to produce a range of 29 models. Some had piston engines; others turbines. The original six seat fuselage was stretched to seat eleven; some were pressurised. About 2000 Aero Commanders had been built by the time production ceased in 1985. A list of the characteristics of each of the Aero Commander models is at Appendix A.

L-3085 The Aero Commander prototype

Courtesy of Jane's Information Group

[2] The company changed hands several times: Rockwell bought it in 1958; merged with North American in 1967; bought by Gulfstream in 1981; and Twin Commander in 1989. For convenience, this paper always refers to the company as 'Aero Commander' and the aeroplanes as 'Aero Commanders'.

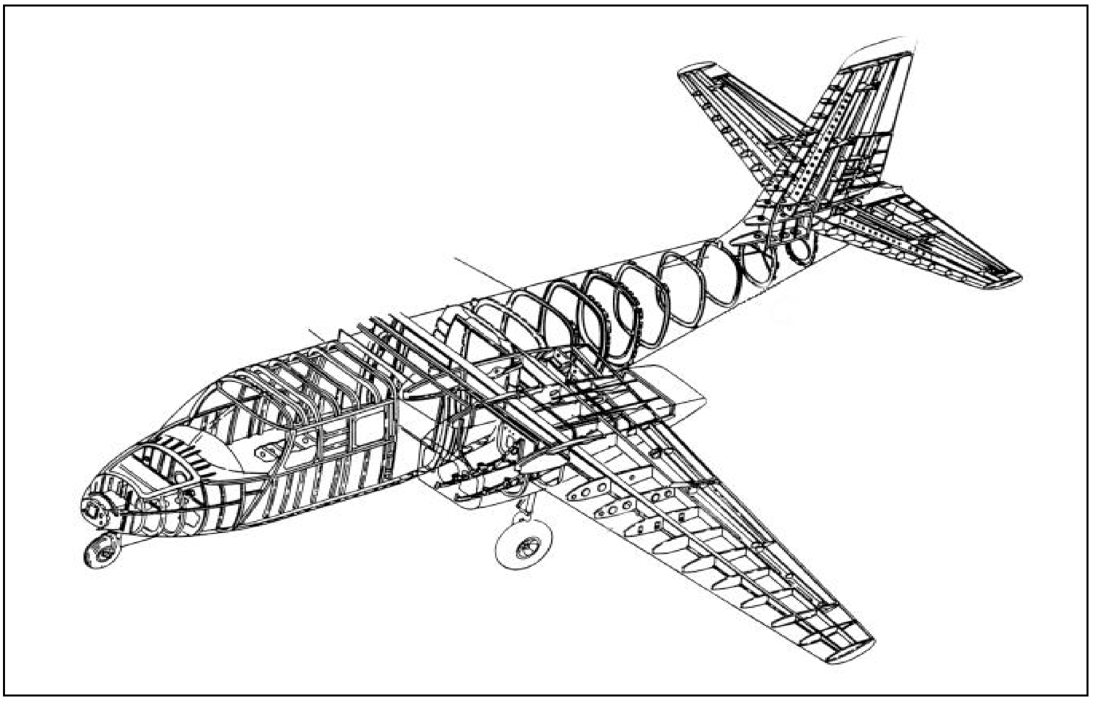
Aero Commander 695B, the last production model

All were big aeroplanes for the job. The airframe has been described as ‘massive’ and ‘heavier and structurally stronger than most’. American pilot, Bob Hoover, became famous for flying aerobatics in Aero Commanders and strength became legendary.

Aero Commanders have been used for a multitude of roles around the world: regular public transport, military transport, cargo, passenger charter, coastal patrol, air ambulance, mineral survey, calibration of airways navigation aids - even V.I.P. transport for the US President and the Australian Prime Minister.

The Wing

Aero Commander wings come in several variations on the basic design, including three lengths. All have a main spar at 35 % chord and a rear spar at 67 % chord. Instead of wing joints, an unusual feature is that the spars are continuous from tip to tip. On each side of the fuselage the main spar is bent up 5° for dihedral and 5° forward for sweep. The spar is an aluminium alloy I-section made up of tee extrusions (known as caps) joined by a sheet web. The 2014-T6 alloy caps are bent cold in the fully heat treated condition.



Aero Commander structure

WING HISTORY

Things are not always what they seem. Despite the robust appearance, at last count 24 Aero Commanders had lost wings in flight, 35 spars had been found cracked on the ground, and hundreds of other spars had defects caused by:

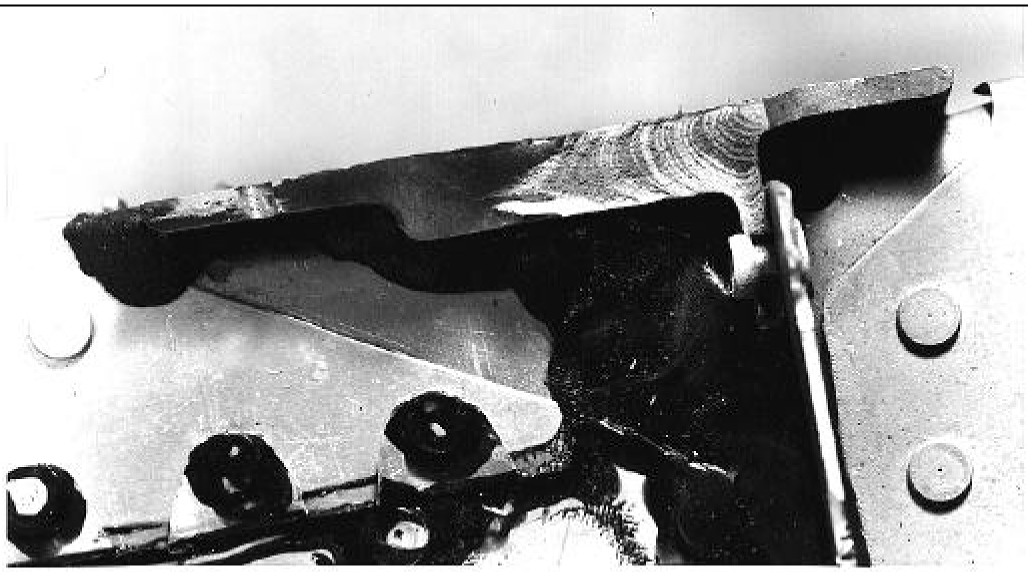
- fatigue
- corrosion
- stress corrosion
- static overload

A detailed chronology of the Aero Commander wing is at Appendix B and a list of the spar failures is at Appendix C.

Most of the problems have centred on the bend in the main spar lower cap, where the highest flight stresses coincide with high residual stresses and a geometric discontinuity - at wing station (WS) 24 for short wings and WS 39 for long wings.

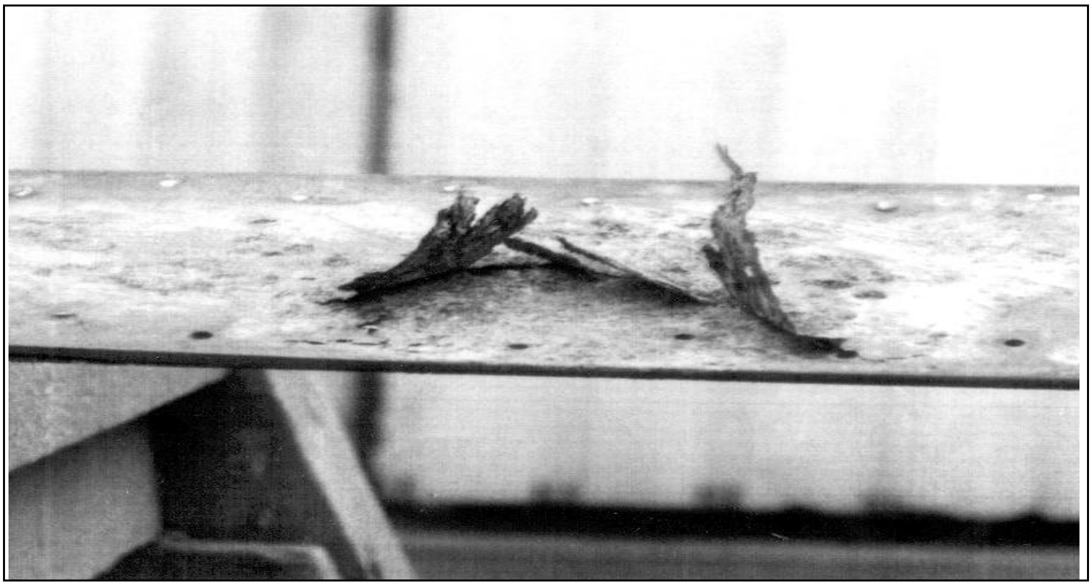
A fatal wing separation in New Zealand in 1961, another in Canada in 1964, and numerous other reported cracks, forced Aero Commander in 1964 to design reinforcing straps for the spar bend. The first were external retrofits, soon added to production. By 1968 the straps were internal and more elegant. The spar caps still cracked, but the cracks grew more slowly to give time for inspections.

Wing separation, New Zealand 1961



Main spar lower cap at Wing Station 24 failure site

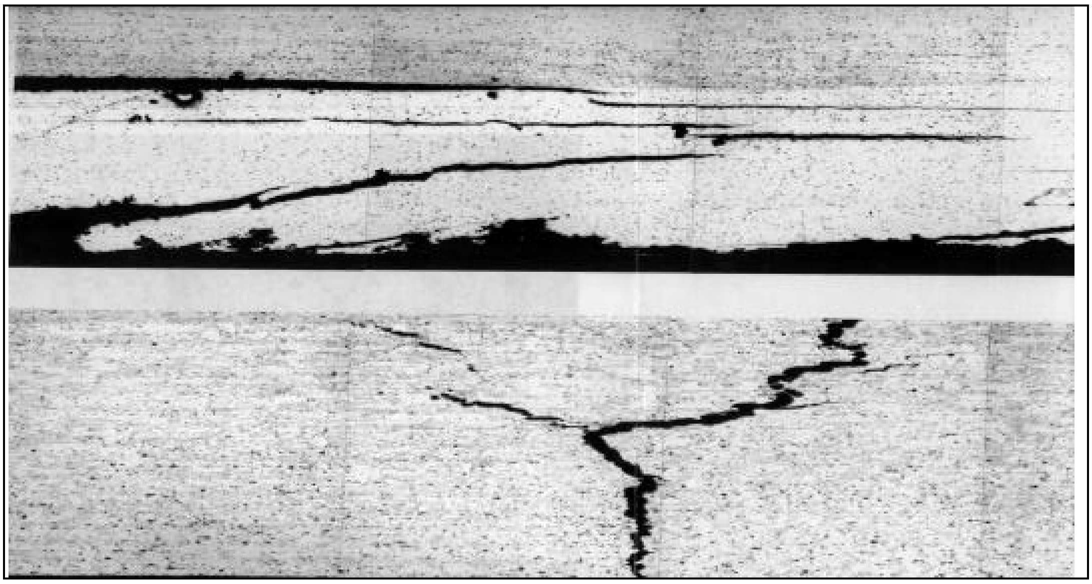
But the straps introduced new problems. The external straps, which only extended fourteen inches outboard of the spar bend, created another fatigue-critical site at the end fasteners. The internal straps were much longer and better for fatigue, but being stainless steel they galvanically corroded the aluminium alloy spar cap.



Exfoliation corrosion in main spar lower cap

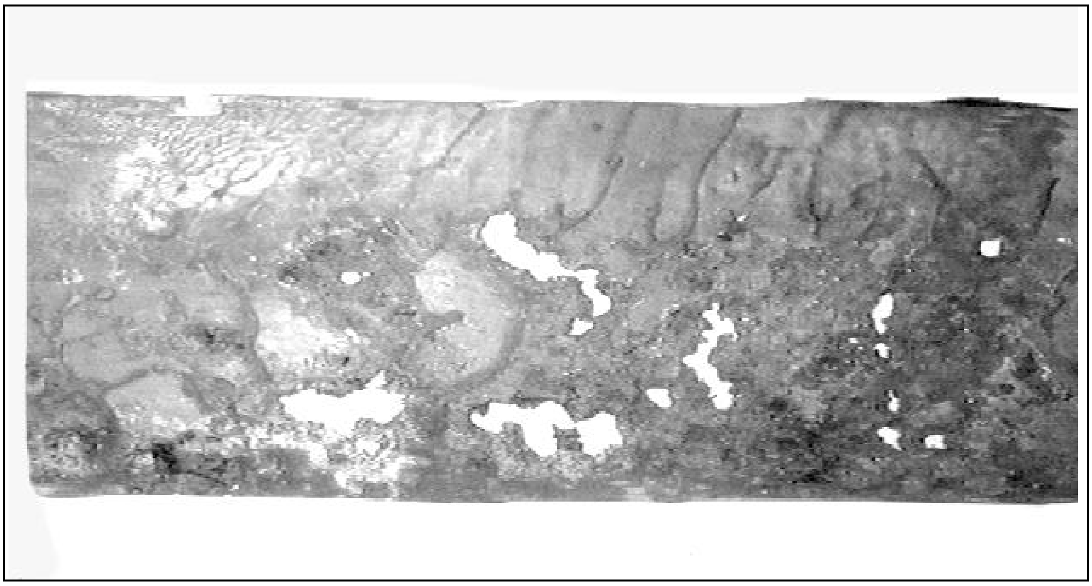
Corrosion was first reported in Australia in 1985 and later in the United States. Most Aero Commanders with the stainless steel strap have by now had spar corrosion. Many owners have had to replace the spar cap at great expense. Normally the corrosion has exfoliated, causing a slow loss of spar area. Corroded spar caps have to be inspected more frequently until the corrosion depth exceeds allowable limits.

In another twist, in 1991, inspectors looking for corrosion found massive cracks almost right through the spar cap in a couple of aeroplanes. Metallurgical investigation found that the cracks were caused, not by fatigue in this case, but by stress corrosion of a type not normally found in extrusions. The extrusions were faulty in that they had an unusually fine, equi-axed and re-crystallised grain structure. This problem required another set of spar inspections to identify and remove from service all faulty extrusions. A complication was what to do with extrusions which had an intermediate grain structure - there seemed to be little information available to assist those having to make decisions with important safety and financial consequences.



Intergranular corrosion. Upper: exfoliation in a normal extrusion. Lower: stress corrosion in equi-axed grain structure.

At about the same time another few aeroplanes were found in which the spar caps were intact, but corrosion had eaten large holes in the internal reinforcing straps which were, for some reason, not made from stainless steel. Perhaps there was a supply shortage.



Corroded 4130 steel internal strap

Some Aero Commander wings failed by static overload. It has been postulated that the forward sweep and the relatively aft position of the main spar cause the wings to twist when loaded, further increasing the load. One estimate has suggested that this effect may double the loads in some cases.

Other wing problems have been fatigue from badly drilled holes, fatigue from fretting of the engine firewall on the spar, cracked ribs at the spar bend, and cracked skins. In 1994 the US FAA issued five Airworthiness Directives on the wing.

The problems have been so widespread and so expensive to fix that an owner's association has been formed for the specific purpose of filing a class action lawsuit against the companies which built the Aero Commander, as well as their aluminium supplier.

THE LESSONS

What went wrong?

Concentrating on the wing of the Aero Commander and its history in the United States, there are lessons from all four phases of airworthiness.

The Design Standard

In contemplating the design and approval of a new aeroplane, one would expect that all the rules of the current design standard had been applied. But that is not always what happens.

If the new aeroplane is not entirely new, but a derivative of an already approved type, FAA rules allow the ‘new’ model broadly to keep the old design standard.[3] This practice is called ‘grandfathering’. Choosing the point at which the design changes become extensive enough to require a complete re-approval of the aeroplane to current standards is the prerogative of the FAA. However, in practice it is a matter of negotiation with an often powerful industry.

Twenty-seven Aero Commander models were grandfathered on to just two models which were first approved in 1950 and 1955. Consequently the design standard lagged behind the rules of the day, a regulatory concession which later cost air travellers and the company dearly.

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[3] See FAR 21.101 and CAR 3.11

But back to the beginning. When the first Aero Commander was designed in the late 1940s, there were no fatigue rules in the United States design code for small aeroplanes, Civil Air Regulation 3 (CAR 3). At that time aeronautical fatigue was certainly known, but could have been said to be in its infancy. The first fatigue tests on complete aeroplane wings had only recently been completed. Analysis had only just become possible by Milton Miner's cumulative damage hypothesis in 1945. ICAF of course did not start until 1951.

Notwithstanding the aviation community's earlier knowledge of the problems, the need to prevent fatigue first appeared in CAR 3 in 1956:

> ‘3.307 Fatigue Strength. The structure shall be designed, insofar as practicable, to avoid points of stress concentration where variable stresses above the fatigue limit are likely to occur in normal service.’

We now know that the ‘fatigue limit’ is an experimental property rarely seen in practice. Stress concentrations cannot be avoided; local stresses exceed the fatigue limit; forming and assembly stresses are built in; smooth surfaces fret and corrode[4]. The first Aero Commander required to comply with CAR 3.307 was the 1960 model 500A. The 500A and its successors have not escaped fatigue in service.

In 1956 two other interesting rules were added to CAR 3:

> ‘3.291 General. The suitability of all questionable design details or parts having an important bearing on safety in operations shall be established by tests.
>
> 3.292 Materials and workmanship. The suitability and durability of all materials in the airplane structure shall be established on the basis of experience or tests.’

With their emphasis on testing, those paragraphs could have been much better fatigue rules than 3.307. But they were not interpreted as such - at least not for the Aero Commander. Durability meant the ability to withstand the weather, but not flight loads. The spar cap, which is cold bent in two directions but not stress-relieved, was perhaps not regarded as a ‘questionable detail’.

In 1957, fatigue evaluation was added to CAR 3, but only for pressurised cabins (CAR 3.270). Although the emphasis of this paper is wings, it is worth noting that Aero Commander fatigue tested examples of all pressure cabins, but the controls devised from the results have not yet been promulgated in the United States.

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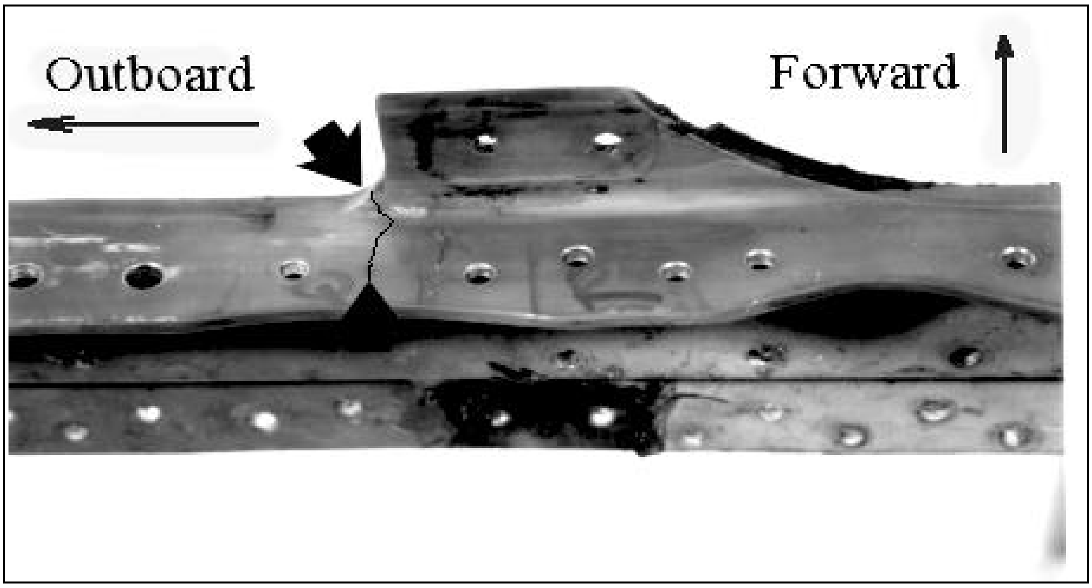
[4] Despite the now widely acknowledged weaknesses of CAR 3.307, similar rules persist. One is BCAR S 627.

The requirement to demonstrate the ability of a wing to withstand the repeated loads of variable magnitude expected in service was introduced by Amendment 7 to Federal Aviation Regulation 23 (FAR 23) in 1969. FAR 23 was the successor to CAR 3.

Aero Commander completed an extensive fatigue evaluation of the wing in 1974 in response to the service failures. The fatigue evaluation was quite thorough and would have satisfied FAR 23.572. The Aero Commander report of that fatigue evaluation recommended life limits for the wings of all models. However, for reasons which are not clear, it seems the FAA did not demand the submission called for by FAR 23.572. No measures to control fatigue were promulgated.



Wing Station 24 - typical crack

Despite vital fatigue safety limits being available since 1974, the FAA did not enforce them for any of the 27 models approved before 1981. CAR 3 was still the design standard for a major re-design [5] of the Aero Commander wing as recently as 1992.

'Grandfathering' against design standards for fatigue evaluation is neither necessary nor appropriate. Firstly, compliance can be achieved without change to existing hardware. Secondly, fatigue cannot be avoided. If evaluation is not part of the design standard, it will have to be faced later - often tragically.

[5] Supplemental Type Certificate SA5740NM

The Aero Commander is not the only type which has been grandfathered. One of many others is the Cessna range of twins. In the United States, a wing retirement life (13 000 hours) has been promulgated for the model 425, but not for the earlier models of the same type: 401, 402, 411, 414 and 421. The FAA's Aging Commuter Airplane Program is an attempt to redress the shortcomings of grandfathering, but does not include the Aero Commander, as although it is a commuter airliner in Australia and elsewhere, it is not in the United States.

The Design Process

Durability is an important design objective for civil aircraft - for safety and for sales. Yet testing - even analysis - to prove durability is often done only under compulsion. In that respect small aeroplane design has yet to reach maturity.

Consider performance and flight handling. Both can be estimated by comparatively robust analysis, but the value of expensive and repetitive flight tests is accepted. Flight tests repeatedly highlight faults not predicted by analysis.

Fatigue is no different. Analysis without testing is even more uncertain and can be just as fatal.

There are two reasons why aeroplane companies resist fatigue testing: over-confident designers and short-sighted accountants.

Over-confidence about fatigue is common among designers, especially the inexperienced. For some it's just ignorance. Few see the failures. It's easy to be duped by textbook talk about endurance limits or 'no growth' strain values. The vagaries of scatter must not be ignored; and the precision of fatigue analysis computer software can too easily instil a false confidence which belies the uncertainty in the input data and the crude hypotheses on which the algorithms are based.

Over-confidence is hard to shake. Not deterred by their inability to predict cracks in the original design, designers confidently market 'terminating modifications' - repairs advertised as permanent fixes. Many crack again because the repair suffers from the same errors of analysis that caused the original design to crack. To their credit, Aero Commander fatigue tested the spar reinforcing straps so operators knew when and where to look. Reinforced spars have cracked as expected.

Design and certification costs are a major hurdle at the start of any aeroplane project. However, a good fatigue test saves money in the long run. It is cheaper to fix a design fault earlier rather than later. ATR's fatigue test of the ATR 42 identified a design fault early enough to confine the cost of wing replacement to the first 70 aeroplanes. Aero Commander might have avoided a potentially crippling lawsuit had the durability of the bent spar been tested earlier.

Fatigue testing has its limitations. One is the difficulty of simulating the interaction with the other arch enemy of durability - corrosion. However, fatigue testing remains unquestionably the designers best aid to preventing structural catastrophes in service. Aero Commander's tests confirmed that, contrary to an earlier analysis, the bends in the spar were not very durable. The tests came too late to improve all but the last few models, but were useful to calibrate cumulative damage and crack growth analyses to keep the old designs safe.

As an aside, a long-running controversy has been the relative merits of Miner's rule and fracture mechanics. It must be remembered that uncalibrated analysis by either method can be wrong, by easily an order of magnitude. Both methods suffer from an incomplete representation of the fatigue process because of our lack of fundamental understanding. Each method has its strengths. The most important issue is not which is best, but whichever method is used must be calibrated by tests[6].

Lastly, the designer should keep records. Not just because of the rules, but because it is good practice. Aero Commander were unable to find records for the substitution of 4130 steel for stainless steel in production of the internal reinforcing straps. That meant that every aeroplane had to be checked when the problem of corroded 4130 steel straps arose in service.

The Design Audit

The regulatory process known as type certification is meant to be an independent check that the aeroplane complies with the design standard; in other words, a design audit. But in the United States the enormity of the task means that much of the auditing is entrusted to Designated Engineering Representatives (DERs) - employees of the company who act on behalf of the FAA. Apart from the conflict of interest, even the most principled DER is not independent of faulty company doctrine.

The use of stainless steel in the reinforcing straps seems to be a case in point. The only plausible explanation seems to be that the DER who approved the design for corrosion protection[7] was misled by the same Aero Commander process specification which misled the designer [8]. Both thought that the stainless steel reinforcing straps would be galvanically safe against the aluminium alloy spar.

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[6] Emmerson, A.J., ‘Airworthiness Control in the Face of Structural Fatigue’, Aging Commuter Aircraft Conference, Canberra 1992.

[7] CAR 3.295, ‘Protection’, was the applicable rule.

[8] It is not exactly clear what happened, but not long after the first stainless steel straps were designed, Aero Commander Process Specification 90.1, Galvanic Corrosion Protection, was amended in December 1970 to show aluminium and stainless steel as galvanically compatible.

That one design error, which once threatened fleet safety, now threatens the survival of the company.

Doubts about the static strength of the Aero Commander wing were raised in 1991 by two engineering consultants investigating some unexplained wing failures. As already noted, one consultant suggested that actual wing loads might be double those calculated for original certification. This led to the FAA's initiating the first independent audit of the wing static loads, to see whether wing flexibility had been considered as required by CAR 3.171(b).

Someone once said that ‘an aeroplane is ten million human judgements - none of them foolish - none infallible’. Even after the regulator in the home country has issued a type certificate, there is still a good case for design audits[9] by the regulators of importing countries.

As well as the obvious benefit of a second check on the original processes, the importing country learns about the aeroplane - it's design, it's manufacture and support, it's maintenance requirements and what data are available for the maintenance of continuing airworthiness. The Australian Civil Aviation Authority has found that sort of information invaluable, not only in it's airworthiness control of the Australian fleet of Aero Commanders, but also in its contributions to Aero Commander safety internationally[10].

The Design in Service

Keeping the aeroplane safe in service, so called ‘continuing airworthiness’, starts with the fatigue control measures approved at type certification. These sometimes have to be adjusted along the way; even the best design and testing and the most thorough design audit won't eliminate all surprises. Obviously, if fatigue evaluation were not part of certification, there would be more of the unexpected and less information with which to respond.

Continuing airworthiness requires observation, interpretation, and action. It is a team effort between manufacturer, operator and regulator. Unfortunately, continuing airworthiness is not always done well for small aeroplanes.

In the United States, reporting of defects found in service is not mandatory for small aeroplanes, except those flying scheduled services. Investigations into the airworthiness causes of accidents to small aeroplanes are often inconclusive. The truth is that government safety agencies must concentrate their energy on the larger airliners.

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[9] A design audit, not full type certification. Full type certification can only be done coincidentally with the design of the aeroplane.

[10] The Australian Civil Aviation Authority was the only international participant in the Seattle meeting mentioned in the Introduction. The CAA was able to contribute knowledge that would not have been available but for the design audit when the Aero Commander was first imported into Australia.

The first signs of fatigue or corrosion problems in the fleet are often misinterpreted as isolated occurrences. As the lawyers say, 'Absence of evidence is not evidence of absence'. The psychologists would add that structural fatigue and corrosion are fertile soil for cognitive dissonance, the mental conflict that occurs when beliefs or assumptions are contradicted by new information. Only the expert skilled in airworthiness control as well as the science of fatigue can avoid common errors.

It has been observed that 'some manufacturers have been most reluctant to acknowledge that defects occurring in Australia are pervasive design or manufacturing faults - even when the evidence is squarely before them'.[11] That is also true of regulators.

The corrosion of the Aero Commander wing spars cannot be found by routine maintenance. Naturally one would not expect any reports to come from routine maintenance. Was the absence of US reports one reason why Aero Commander did not act for four years, and the FAA for five years, after the first Australian warnings?

There is a tendency to treat fatigue and corrosion as two separate disciplines. The present Aero Commander Service Bulletin and the FAA Airworthiness Directive do not deal with the possible interaction between the new corrosion problem and the old fatigue problems. Allowable corrosion limits consider static strength, but not fatigue. In some aircraft the corrosion growth has slowed and material loss remains within an allowable depth after several years. It would seem highly likely that the gross loss of structural cross section could combine with the stress concentrating pits to promote fatigue cracks.

Since fatigue and corrosion are technically complex and hard to control, what happens when the design ownership and the attendant responsibility are transferred to a company inexperienced in design or airworthiness control? Such aeroplanes are sometimes called 'orphans', because their 'parents' have 'died', and that is what happened to the Aero Commander. A heavier burden must inevitably rest with the regulators, who sometimes themselves are being down-sized and de-skilled.

But even when the signs of a problem are correctly observed and interpreted to find a technical solution, implementation can be delayed or blocked for other reasons. For example, industry groups petitioned the FAA to postpone compliance of the Aero Commander corrosion inspections.

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[11] Emmerson, A.J., 'Airworthiness Control in the Face of Structural Fatigue', Aging Commuter Aircraft Conference, Canberra 1992.

It seems that there are attributes of fatigue and corrosion - scatter is one - which mean that engineers must work very hard to convince their managers in the face of commercial and political pressures. Fatigue engineers need more than technical skills.

CONCLUSION

The Aero Commander highlights the difficulty of putting theory into practice. The wealth of research into structural fatigue did not help. As in other fields of science and engineering, the greatest challenges facing the fatigue practitioner are not technical; they are legal, psychological and political.

The proposition that prevention is better than cure is not yet accepted as axiomatic.

In hindsight, what happened with the Aero Commander seems all so obvious. But a paradox of fatigue is that the obvious so often goes unnoticed.

Appendix A

AERO COMMANDER MODEL CHARACTERISTICS

Models on Type Certificate 6A1 Revision 45

Model	Year	MTOW (lb)	Seats
520	1952	5700	5
560	1954	6000	7
560A	1955	6000	7
560E	1957	6500	7
500	1958	6000	7
500A	1960	6250	7
500B	1960	6750	7
500U	1964	6750	7
500S	1968	6750	7

Models on Type Certificate 2A4 Revision 45

Model	Year	MTOW (lbs)	Seats	Pressurised	Turboprop
680	1955	7000	7		
680E	1958	7500	7		
720	1958	7500	6	Y	
680F	1960	8000	7		
680F(P)	1962	8000	7	Y	
560F	1961	7500	7		
680FL	1963	8500	11		
680FL P	1964	8500	11	Y	
680T	1965	8950	11	Y	
680V	1967	9400	11	Y	Y
680W	1968	9400	11	Y	Y
681	1969	9400	11	Y	Y
690	1971	10250	11	Y	Y
685	1971	9000	9	Y	
690A	1973	10250	11	Y	Y
690B	1976	10325	10	Y	Y
690C	1979	10325	11	Y	Y
695	1979	10325	11	Y	Y
695A	1981	11200	11	Y	Y
690D	1981	10700	11	Y	Y
695B	1984	11750	11	Y	Y

Appendix B

CHRONOLOGICAL HISTORY OF AERO COMMANDER WING

April 1948	First flight of prototype, the L-3805.
June 1950	The L-3805 was issued Type Certificate No. 6A1 by the United States Federal Aviation Administration (FAA).
January 1952	The first production model, the 520, was added to Type Certificate No. 6A1. The design standard was Civil Air Regulation Part 3 (CAR 3), which did not require a fatigue evaluation of the wing. Over the next 16 years eight other models were approved.
October 1955	FAA issued Type Certificate 2A4 for the model 680. Again, the design standard was Civil Air Regulation Part 3, and again, over the next 29 years nineteen other models were approved.
November 1961	Aero Commander 680 ZK-BWA crashed in New Zealand. The wing main spar lower cap failed by fatigue at wing station (WS) 24 after 5040 flight hours.
January 1962	Australia required regular inspections of WS 24 (AD/AC/21).
September 1962	Australia cancelled the inspections, thinking that the New Zealand accident was a 'one off'.
April 1964	Aero Commander 680E CF-JOK lost a wing and crashed in Canada after 5949 hours. Fatigue at WS 24.
May 1964	Australia re-instituted inspections of WS 24 (Special Inspection AC/64/1) for all aeroplanes with more than 2000 hours.
July 1964	Above inspection made mandatory for all aeroplanes (AD/AC/31).
	First crack found at WS24 by inspection rather than accident.
September 1964	Aero Commander started selling external reinforcement kits for WS 24 (Service Change 81), which were later incorporated into production.

December 1964	Australia made the reinforcement kits mandatory for Aero Commanders flying a severe role (AD/AC/31A). Reinforced aeroplanes were exempted from further inspection.
February 1965	A crack at WS 24 was found in Australian Aero Commander 560E VH-CAW after 2877 flight hours.
March 1965	The U.S. FAA (AD 65-06-01) and Australia (AD/AC/31B) made reinforcement of WS 24 mandatory for all Aero Commanders.
October 1965	Aero Commander's first fatigue analysis. Report S16-022 was incomplete and contained serious errors.
June 1966	Aero Commander 560E, S/No 562, with an external reinforcing strap, was found by inspection to be cracked at WS24.
September 1966	Australia mandated radiographic inspection of WS 38 at the end of the external strap (AD/AC/33).
March 1967	Aero Commander redesigned the spar reinforcement from external straps to a wider and longer internal stainless steel strap. No special precautions were taken to protect against galvanic corrosion.
August 1967	Aero Commander produced a second fatigue report, No. S16-026.
September 1967	Aero Commander 560E N3831C crashed after losing a wing in Texas, USA A fatigue crack had started at a double-drilled hole in the spar lower cap at WS 81 after 6780 hours.
	Later that month Aero Commander issued Service Bulletin (SB) 92 which specified regular inspections. In October, FAA and Australian CAA followed with Airworthiness Directives 67-28-01 and AD/AC/36 respectively.
August 1969	The FAA issued Amendment 7 to FAR 23, which added paragraph 23.572, the requirement to demonstrate the ability of a wing to withstand the repeated loads of variable magnitude expected in service.
March 1970	Aero Commander issued SB 90B requiring regular inspection of WS24 for reinforced spars.
	Aero Commander produced a third fatigue report, S16-043, the first to recognise that cold bending of the spar cap was a major contributor to the short fatigue life.

May 1970	Australia mandated SB 90B inspections (AD/AC/42).
December 1970	Aero Commander amended Process Specification 90.1 Galvanic Corrosion Protection (Corrosion Between Dissimilar Metals). The amended PS could be misread to condone the use of stainless steel and aluminium together without special corrosion protection.
August 1974	Aero Commander published the results of a comprehensive review of the fatigue characteristics of the bent spar cap, both strapped and unstrapped, in Aero Commander Report No. S16-046: strain gauge data from flight test; several load spectra compared; 23 specimens same as production (heat treatment, cold bend, machining quality); constant amplitude; recorded time to first observable crack and final rupture; retirement lives calculated using Miner's rule method and a scatter factor of 5. The review concluded with tables of 'safe lives' for critical points on the spar caps of all models for several strap configurations and for normal and survey flying. Australia required inspections beyond the safe lives for inspectable points (AD/AC/42), and retirement of the spar cap at the safe life of uninspectable points (AD/AC/66). Retirement lives had not been promulgated by Aero Commander or FAA as at February 1995.
April 1981	The FAA approved the addition of the model 695A to Type Certificate 2A4. The 695A was the first of the 'grand-fathered' models required by the FAA to have a wing fatigue evaluation under FAR 23.572, even though the rule had been in force since 1969. Aero Commander issued Report No S16-053 on the fatigue test of the 690D/695A.
October 1982	A crack at WS 24 was found in Australian Aero Commander 680E VH-CAY after 10286 flight hours.

August 1984	A crack at WS 24 was found in Australian Aero Commander 500S VH-EXS, fitted with the internal production strap, after 13196 flight hours.
January 1985	Production of Aero Commander aeroplanes ceased.
September 1985	Severe exfoliation corrosion was found by chance in the spar cap of Australian Aero Commander 500S VH-MEH. The corrosion was caused by galvanic action between the aluminium spar cap and the stainless steel reinforcing strap. Since the corrosion is not normally visible until it has advanced to the stage where it causes skin bulging - when the wing strength has already been compromised - the Australian CAA developed radiographic, then ultrasonic methods.
February 1986	An even more severe case of corrosion was found in the spar cap of Australian Aero Commander 500S VH-EXY.
June 1986	The Australian CAA notified Aero Commander and the US FAA, enclosing copies of the inspection method.
July 1986	The FAA acknowledged receipt of the information, but decided not to act because they 'had not received any (US) reports of corrosion'.
November 1986	A crack at WS 24 was found in Australian Aero Commander 500S VH-TWS (now VH-UJI) after 9058 flight hours.
September 1987	After further prompting from Australia, FAA asked for more information on the spar corrosion.
June 1990	Aero Commander issued SB 208, based on the Australian-developed corrosion inspections.
July 1990	Aero Commander 680E, SE-FTP, crashed at Hassela, Sweden, after losing the right wing. The investigation by the Swedish Board of Investigation concluded that a fatigue crack started and propagated to failure in the main spar lower cap at WS 98, inside the engine nacelle. The aeroplane had flown 8346 hours. The Board noted the following contributors to the cracking: severe low-level, terrain-following flying; a geometric discontinuity in the spar cap; a 0.15 mm deep corrosion pit; and fretting of the engine firewall on the spar. Sweden advised Aero Commander and the FAA.

December 1990	FAA issued a Notice of Proposed Rulemaking (NPRM) which foreshadowed mandatory compliance with Aero Commander SB 208 on spar corrosion.
May 1991	FAA issued AD 91-08-09 making compliance with Aero Commander SB 208 mandatory within 90 days. Aero Commander petitioned the FAA to extend compliance to one year.
June 1991	Seventeen engineers from Aero Commander, FAA and the Australian CAA met in Seattle USA to review fatigue and corrosion in the Aero Commander wing - there had been 18 in-flight wing failures on the official NTSB records, with another 5 known to Aero Commander. At the meeting, in the face of Australian and other evidence, Aero Commander withdrew its petition. There seemed to be general agreement on the actions necessary to prevent further wing failures: that the FAA firmly enforce wing spar inspections for corrosion in accordance with AD 91-08-09; that Aero Commander develop a reliable inspection program for each of the known fatigue-critical locations on the wing spar or impose a retirement life for uninspectable structure; that Aero Commander develop an inspection program for fatigue cracks that might initiate from corroded areas of the wing spar.
July 1991	While cleaning the spar cap in preparation for AD 91-08-09, inspectors in the US found massive cracks in the bend areas on both left and right wings of Aero Commander 690B N32BW S/N 11545. A piece of the left hand spar was sent to Australia for metallurgical analysis by the CAA. Several more similarly cracked aeroplanes were soon found in the same way.
September 1991	Aero Commander reported that out of 242 corrosion inspections completed in accordance with FAA AD 91-08-09, 43% had found corrosion - similar to Australia.
January 1992	The Australian CAA concluded its investigation of the piece of spar from Aero Commander 690B S/N 11545. In Specialist Report No. X1-92, metallurgist Dr Arjen Romeyn noted that the cracking was a form of stress corrosion not normally found in extrusions because of the highly elongated grains. The grains in this extrusion were unusually fine and equi-axed (re-crystallised) which allowed stress corrosion cracks to traverse easily through the spar cap instead of being deflected to produce exfoliation.

Twin Commander and its consultant metallurgist agreed with Dr Romeyn's observation and hypothesis.

Since neither Aero Commander nor the aluminium company were able to determine which aeroplanes might have a faulty extrusion, all aeroplanes had to be checked. By etching an easily accessible part of the spar cap, the Australian CAA inspected the grain structure of all 75 Australian Aero Commanders by May 1992. Of those, 7 had fine grains like S/N 11545 or something intermediate. Those aircraft were either grounded until the defective spar caps were replaced, or sold overseas. There was little information to help determine the susceptibility of the intermediate grain structure to stress corrosion cracking, so one aeroplane was allowed to operate for a limited time with frequent inspections for cracks. Although analytical methods are available for stress corrosion cracking, an attempt to show that safety could be maintained by inspection in the long term proved impractical in the face of too little data and too many uncertainties. When the spar cap was removed from another aeroplane, 500S VH-LTP, it had cracks 90% through the caps in both wings.

January 1992

An alert Australian maintenance organisation found the 'stainless steel' internal reinforcing strap in a 500S VH-UJP corroded right through in places. It was not stainless steel, but (unprotected) 4130. Aero Commander could not find records to identify which aeroplanes had which steel, so all aeroplanes had to be checked - with a magnet held up under the lower wing skin. More than a quarter had 4130. Aero Commander and FAA were advised, but by February 1995 had not acted. The fatigue strength of the wing depends on the integrity of the reinforcing strap.

March 1992

A crack at WS 24 was found in Australian Aero Commander 500S VH-FGS after 6763 flight hours on its second spar cap.

March 1992

Aero Commander followed Australia's lead and issued SB 215, 'Coupon Removal - Wing Main Spar Lower Cap', to find which US aircraft had faulty extrusions.

May 1992

Aero Commander issued SB 211, 'Lower Main Spar Inspection and 39 Rib Modification', to look for cracks in the wing spar lower cap in long wing models where the spar bend is at WS 39.

July 1992	FAA issued STC No. SA5740NM to Aviadesign Inc. for a newly designed spar cap and reinforcement. The 'Saunders Superspar' promised a material more resistant to fatigue and less susceptible to stress corrosion cracking, an improved bending process, no dissimilar metals, better corrosion protection, and improved inspectability. Available for models 690, 690A and 690B, the design standard was still CAR 3, which does not require a fatigue evaluation.
1992	The Twin Commander Owners Association was formed in the USA to recover the costs of corrosion inspections and spar cap replacements by a class action lawsuit.
February 1993	Aero Commander wrote to owners offering free replacement spar caps, worth about US$10,000 each.
May 1993	A crack at WS24 was found in Australian Aero Commander 500S VH-KAC S/No 3185 after 6000 flight hours.
April 1994	FAA issued:
	AD 94-04-11 to mandate Aero Commander SB 215 Coupon Removal, Wing Main Spar Lower Cap
	AD 94-04-12 to mandate Aero Commander SB 211, Lower Main Spar Inspection and 39 Rib Modification.
	AD 94-04-13 to mandate Aero Commander SB 90C, Inspection of Front Spar Lower Cap at WS24
	AD 94-04-14 to mandate Aero Commander SB 208A Inspection for Wing Main Spar Corrosion
	AD 94-04-15 to mandate Aero Commander SB 212 Main Spar Lower Cap Forward Flange Inspection at WS96
July 1994	Aero Commander issued SB 213 which requires inspection and modification of the 690C and 695 wings, based on cracking found on the fatigue test.
February 1995	FAA proposed an AD which would mandate SB 213.

Appendix C

AERO COMMANDER WING SPAR FAILURES

This is a list of Aero Commander twins which have lost the ability to carry statutory design loads. There may have been further failures in flight and additional aeroplanes which cracked severely but by chance did not fail in flight. Most failures have been caused by fatigue, corrosion, and stress corrosion.

Model	Wing Separation in Flight	Spar Found Cracked on Ground
500	1	-
500A	-	1
500B	1	-
500S	-	4
500U	-	-
520	-	-
560	1 (a)	-
560A	-	3
560E	2	10
560F	-	1
680	1	5
680E	2 (a)	3
680F	1	1
680FL	2	-
680FLP	1	-
680FP	1	-
680T	-	-
680V	-	-
680W	-	-
681	-	-
685	-	-
690	2	-
690A	4	-
690B	1	7
690C	2	-
690D	-	-
695	1	-
695A	-	-
695B	-	-
720	-	-
840	1	-
TOTAL	24	35

(a) Suspect wing stressed beyond design requirements