RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

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Shortly after 7.30am on Friday June 2 1994, crew members of a Chinook helicopter, airframe registration number ZD576, had their last breakfast.

They ate cereals; one had poached eggs as well, and another had a full fried breakfast. Then the crew collected their weapons, ready for the day's duties, which were mostly around Northern Ireland.

The aircraft's crew flew some undemanding sorties around the province in the morning and arrived back at RAF Aldergrove, in good time to prepare for their next flight to Fort George, Inverness, Scotland.

A few minutes after 5 o'clock that afternoon the two pilots, Flight Lieutenants Jonathan Tapper and Rick Cook joined two crew and 25 passengers on board ZD576.

The passenger list was shredded on take-off. The 25 names included key military intelligence personnel, including army intelligence officers, agents of the MI5 counter-terrorist agency, and special branch police officers.

Soon after 5.42pm, the Chinook was seen on a low-level flight path across the province. About 15 minutes after take-off, a yachtsman Mark Holbrook, saw it flying low and straight in good visibility.

In front of the Chinook was the Mull of Kintyre, the top of it covered in cloud. To the left was open, unfettered sea and continued good low-level visibility.

The pilots entered onto their navigation computer the pre-planned change of course: a left-turn to avoid the Mull. About 18 seconds before impact everything seemed normal.

However the Chinook did not make its intended turn.

Instead it flew a course – nobody knows for certain in these last few seconds if it was going straight, weaving or undulating – towards the bad weather on the top of the Mull. The station commander at RAF Odiham, the UK's main Chinook base, would later tell an RAF Board of Inquiry that he did not believe that the crew would have elected to fly straight towards the bad weather on the Mull.

At about 6pm several people on the Mull heard a dull thump followed by a loud whooshing sound. The air was filled with flames, and two cyclists on the hillside were enveloped in smoke.

Chinook ZD576 had hit the hillside, bounced, broken up and landed again about 300m further on. All the occupants of the aircraft suffered major trauma on impact and died instantly.

The RAF could have investigated the incident itself, but it chose to request help from the Department of Transport's Air Accident Investigation Branch.

The investigators concluded that there was no evidence of a technical malfunction capable of causing the crash. Later a RAF Board of Inquiry could not determine why the pilots had not made a left turn as planned and blamed them for flying into the Mull.

Queen's regulations state that: "only in cases where there is a absolutely no doubt whatsoever should deceased aircrew be found negligent."

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Jonathan Tapper and Rick Cook were convicted posthumously of gross negligence. No professional airman can be branded with a more infamous mark of disgrace.

Ministers of the last two governments, and the Ministry of Defence, have defended the decision to blame the pilots with vigour, on the basis of the report by the Air Accident Investigation Branch.

However there may have been a world of difference between "no *evidence* of technical malfunction" and no malfunction.

*** * * * ***

Four years after the crash on the Mull of Kintyre, Bric Lewis finds himself piloting a Chinook which is flying particularly smoothly.

Inside the cavernous cabin of a Chinook the ferment of noise is intrusive. With two large jet engines and six 60-foot rotor blades slapping the air at 225 revolutions per minute, you can cup your hand over someone's ear, shout and they will not understand a word.

But when Lewis exclaims involuntarily "Oh God" into the microphone of his headset, and the words are transmitted instantaneously to all those on board, the cabin goes almost ethereally quiet, as if life itself were held in suspension.

The Chinook is falling out of the sky ... upside down ...yet the displays in the cockpit show no warning lights… no evidence of any technical malfunction… ***no evidence of technical malfunction***.

It was exactly the phrase that had been used four years earlier to condemn the two pilots, Jonathan Tapper and Rick Cook after the crash on the Mull of Kintyre. Lewis and his crew knew then that, if they did not survive, they too stood to lose not only their lives but their reputations.

It was a simple equation: accident plus no evidence of technical malfunction equals pilot error.

Yet Lewis's aircraft had become uncontrollable without warning, for no apparent reason.

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At around the same time as the incident involving Bric Lewis's Chinook in the USA, the United Kingdom Armed Forces Minister Dr John Reid was taking centre seat before the House of Commons Defence Committee.

He could not have looked more grave.

The television crew made their last-minute checks as the high ceilings of the committee room soaked up the light banter. Some MPs tried to engage Dr Reid in small-talk. He seemed to resist.

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The Committee was convening to discuss one of the most notorious military aircraft crashes of the past 30 years: the loss of a Chinook ZD576 on the Mull of Kintyre, Scotland in June 1994.

"This was a tragic, tragic loss of life," said Bruce George, chairman of the Committee, "Their deaths were a severe blow in the fight against terrorism."

A clue to the importance of the meeting was the fact that Reid, by his own admission, had spent two days preparing for it. On the outcome of the hearing would rest Reid's ministerial credibility, at least in the eyes of his department. Officials and some military officers wanted a minister who was able to defend one of the most controversial decisions the armed forces has made in recent years: the decision to find the dead pilots of ZD576 guilty of gross negligence.

The verdicts against Flight Lieutenants Jonathan Tapper and Rick were based on the fact that there was no evidence of any technical malfunction which could have caused them to crash into the Mull of Kintyre. So it was taken as read that, for no reason which has been ascertained, that Tapper and Cook decided to fly a serviceable aircraft into the ground.

Some MPs including Martin O'Neill, Menzies Campbell, Robert Key, James Arbuthnot, and a peer Lord Chalfont, have expressed doubts about whether the lack of evidence of technical malfunction could be used as a basis for assuming there were no malfunctions.

However the Ministry of Defence has for the past five years defended the decision to blame the pilots. Its officials and armed forces ministers have always resisted calls from MPs for a new investigation.

In March 1998, MPs were given a chance to challenge some of the evidence, face to face with the minister and his advisers. Depending on the evidence presented, MPs would be either satisfied that the verdict was correct or could press for a re-opening of the inquiry.

There had already been an investigation by the Department of Transport's Air Accidents Investigation Branch which assisted a Board of Inquiry convened by the Royal Air Force, and a Fatal Accident Inquiry conducted by a civil judge in Scotland.

As these inquiries were regarded as exhaustive, and had concluded that there was no technical malfunction which could have caused the crash on the Mull of Kintyre, the Defence Committee agreed not to challenge or endorse the findings of earlier inquiries into the accident. MPs were to ask questions on the "wider issues."

Jonathan Tapper and Rick Cook were two Special Forces pilots who had been selected to fly the mission from Northern Ireland to Inverness in Scotland. Before the flight, Tapper and Cook had, separately, expressed their doubts about whether the newly-modified Chinook ZD576, was ready for operational service.

Chinook ZD576 had recently come out the maintenance depot. It had been upgraded from Mk1 to Mk2 status. Among its new features was a complex and innovative computer system to control the engines, called FADEC. It stood for Full Authority Digital Electronic Control, though some in the military world call it the Full Authority Digital *Engine* Control.

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Since the installation of the FADEC modifications, the Chinook Mk2 had had some problems. Warning signs had been illuminated in the cockpit; warnings of the most serious kind, indicating a possible engine failure. A few weeks before the crash of ZD576, one of the two engines on *this* helicopter had been replaced because of a faulty torque meter.

These and other technical problems had made Tapper and Cook anxious about flying in the Chinook Mk2.

The helicopter was not the easiest aircraft to fly at the best of times. Any significant warning sign in the cockpit, such as "ENG FAIL" for engine failure required a series of checks to establish whether or not it was a spurious warning. What if something were to go wrong while those crucial checks were being carried out? Something serious?

On Friday, 27 May 1994, six days before his last flight, Tapper had asked permission of his Squadron Leader David Prowse to keep an extra Chinook Mark One in Northern Ireland for an additional period. The Mk1 version of the helicopter was without FADEC.

The RAF's Board of Inquiry was told that Tapper and Cook had been particularly concerned about FADEC-related incidents.

Tapper and Cook were uncertain how it would perform during operational sorties. They wondered "what sort of emergencies or situations the present number of spurious and unexplained incidents would lead to," said Lieutenant Ian Kingston RN (Royal Navy), at the RAF Board of Inquiry in 1995.

The Inquiry was also told that the problems with the Chinook Mark two were not always of a trivial nature. Squadron Leader David Morgan said there had been emergencies of a "flight critical nature" which "have mainly been associated with the engine control system FADEC." These emergencies included episodes of the engine running out of control, he added.

For Tapper, aged 28, and Cook aged 30, death was not the only fear. Both pilots had lost close friends in three earlier Chinook accidents. None of the pilots had been totally exonerated after these crashes. In no fatal Chinook crash in more than a decade have the pilots been totally exonerated.

Tapper and Cook feared that if they lost their lives in an accident, their reputations would die with them.

Tapper's request for a Chinook Mk1 was refused because there were none available.

He died a few days later in the "mark two" aircraft he had been reluctant to fly.

The concerns that Tapper and Cook had expressed about flying a newly-modified, perhaps jinxed aircraft, which had been in the maintenance depot once too often, were held to be groundless. Ministers have said, repeatedly, that the new FADEC system played no part in the crash.

Indeed, on this last flight of ZD576, ministers said that nothing had gone seriously awry except the judgement of the pilots.

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"There isn't a shred of evidence that there was any technical malfunction on this Chinook," Reid said in a Channel Four interview.

As not all MPs were convinced that this was the case, Reid, in a formal white shirt with gold cufflinks, gold watch, and gifted with an unaffected voice which he used with the clean, measured articulation of a practiced orator, came to answer questions from the Defence Committee on 4 March 1998.

"There have been a lot of misinformed statements," said Reid, "some of them sincerely pursued, others because of the virtue of the headlines they might create. Therefore I welcome the opportunity to explain or inform whenever I can on these."

He said that the Defence Secretary George Robertson and other ministers have tried with "some pain, some sympathy, some scepticism and some scrutiny to look at these events." He added: "We are all capable of making mistakes but to the best of our abilities we have not been able to find ground for re-opening the inquiry."

In his sometimes lengthy tracts of verbal evidence he spoke with quiet, imposing authority.

"I have looked at it in detail not just because it is a matter of public interest but because this deals with human beings who died, and human beings whose families are in anguish because a judgement was made that they [the pilots] were in error. That is not something to be taken lightly."

For the Ministry of Defence, the hearing was an unequivocal success. After Reid's oral evidence and further information from the Ministry, the Committee concluded that there was "no compelling evidence of any fundamental flaws in the design of the Chinook Mark 2 or its components."

The Committee's report also sought to lay to rest any notion that the last flight of ZD576 may have had a serious technical malfunction.

It appears, however, that Reid had not been briefed comprehensively by his officials and therefore had not told the whole story. Nor had the Ministry of Defence. Nor had the Air Accidents Investigation Branch.

The crash investigators had not presented all the evidence because they had not, in turn, been given all the facts.

- Investigators had not been told by the RAF about a serious incident involving the ZD576 which had led to an engine being replaced ... six weeks before the ZD576 and all its occupants were destroyed in a crash.
- Investigators were not told that the Ministry of Defence was suing the manufacturers of the FADEC at the time of the crash of ZD576.
- Investigators were also unaware that a basis for the case against the contractor, Textron Lycoming was the defects in the design of the FADEC ... the system that had given rise to Tapper and Cook's concern.
- The Fatal Accident Inquiry in Scotland which spent a considerable time studying the FADEC after the Mull of Kintyre crash, was not told that the Ministry of Defence was suing the FADEC's contractor Textron Lycoming, mainly over

defects in the design of the FADEC… the system that had given rise to Tapper and Cook's concern.

- The FADEC contractor was asked to help the investigators of the crash of ZD576 determine whether their equipment was faulty (at a time when the Ministry of Defence was suing the same contractor over defects in the FADEC engine control system).
- When fault codes were found in the memory of one of ZD576's surviving engine control systems, the contractors said none of these was significant. MPs were unaware that the assessments of the fault codes in the FADEC were carried out by the same contractors.

By their own admission, however, investigators had not understood all of the fault codes. One of those codes found in the wreckage of ZD576 was "E5." It was described by the contractors as a "typical nuisance fault."

Investigators did not know that it was the pre-existence of this "E5" code that had contributed to the severe damage to a Chinook in 1989.

- The Fatal Accident Inquiry in Scotland was not told, at the time of its investigation, of a report by the multinational independent computer company EDS-Scicon which had found what it described as 485 anomalies in the Chinook's FADEC software. And there's no mention of EDS-Scicon's findings in the RAF Board of Inquiry 's report. This is despite the fact that the RAF Board of Inquiry took evidence on the FADEC system.

Indeed the investigators were unaware that EDS had found so many anomalies that it had stopped its analysis of the software after examining less than 20% of the code. By this time, EDS-Scicon had identified 56 of the most serious "category one" anomalies. This high level of anomalies was indicative of poorly-developed code, said EDS-Scicon.

- The Fatal Accident Inquiry in Scotland was unaware of a report that had been written by the Assistant Director Helicopter Projects six weeks before the crash of ZD576. The report expressed concern about the "low" level of flight testing on the Chinook FADEC. The Assistant Director had added that the FADEC engine control software needed to be revised "in pursuit of a satisfactory resolution of all safety case issues." There's also no mention of the Assistant Director's concern about FADEC in the RAF Board of Inquiry's report.

The gaps in the level of understanding of the investigators ran deeper still.

- Investigators did not test two key instruments that give an early warning of one of the dangerous occurrences on a helicopter: an engine runaway which can, in extreme cases, lead to rotors flying off. Prior to the crash of ZD576, there had been a number of engine runaways involving the newly-modified Chinooks.
- Investigators asked Boeing to help conduct a computer simulation of the crash of ZD576. The simulation differed fundamentally from some of the evidence in the wreckage.

- The simulation did not take into account the unusual position of the pilot's foot pedals. In a Chinook which is under control a movement in the pedals of between five and 10% is normal. But when the wreckage of ZD576 was examined the pedal position indicated a 77% movement towards its maximum extension. On a Chinook travelling at speed the pedals are not used to turn left or right. One of their main functions is to keep the aircraft under control by stopping it turning sideways. The pedal position could have moved when the crash occurred. It is also possible that John Cook, like Bric Lewis four years later, was struggling to save an aircraft in which the flying controls were not responding.

Was it really the case that there was not a shred of evidence of technical malfunction on ZD576?

The House of Commons Defence Committee was given technical evidence that was not always accurate. It was told that, because one of the two engine control computer systems on the Chinook had survived the impact, it indicated that the other was working. Dr Reid, based on briefings by his officials, told MPs:

"...if one was working normally the other one was working normally."

This is not the case. There was some sharing of information between the Chinook's two FADEC systems but they operated largely independently of each other: one controlled the No1 engine and the other controlled the No 2 engine.

So, saying that if one was working the other was also working, was a little like saying that, in examining the wreckage of a car crash, that if the front brakes were found to have worked normally, the back brakes must also have been working normally. It was also of note that the computer systems that controlled each engine were going wrong with such regularity before the crash of ZD576, that there were not enough spare devices to go around. So aircraft were cannibalised for their systems.

It was not only MPs who were, on occasions, given the wrong impression.

A briefing note prepared for Ministry of Defence spokespeople said that the Chinook's navigation computer system enabled the RAF Board of Inquiry to conclude that "the aircraft kit was functioning properly."

The Tactical Air Navigation System was a computerised navigation system which used satellites, a Doppler velocity sensor and the aircraft's compass heading to help the pilots maintain the correct flight path.

The system was not a purpose-built flight data or cockpit voice recorder, neither of which was fitted to ZD576. The Tactical Air Navigation System did not say how the engines or the computer systems that controlled them, were functioning. It did not give an account of the tens of thousands of components on the Chinook.

The chronology of events before and after the crash was also of note.

In the years before the crash of ZD576 there had been a number of disagreements between defence officials and the contractors over various aspects of the engine control computer system.

Indeed, at the time of the accident on the Mull of Kintyre, the Ministry was in the final throes of preparing a legal case against the contractor, Textron-Lycoming over defects in the design of the FADEC system.

After the legal action was settled in secret in the Ministry's favour in 1995, by which time MPs were asking detailed questions about FADEC, officials began to vigorously defend the system against questions about its reliability.

By the time Reid came before the House of Commons Defence Committee in 1998, he referred to the pre-April 1994 problems with the engine control system as "relatively trivial." He said there had been five faults with the engine control system during 950 flying hours, between May 1993 and April 1994. "None of them related to the software," he said.

Reid was referring to Chinook Mk2s in general, and the faults he referred to were those which came under the terms of the warranty agreement with the contractors. His figures did not include a series of incidents which affected one helicopter in the particular eight-week period between April and May 1994. The incidents were mostly warnings that came up in the cockpit about possible engine failure. The aircraft was ZD576.

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The story of the 1994 crash on the Mull of Kintyre is not merely one of whether the pilots were to blame. It is the story of a political and technical cover up which has lasted for five years. There's no suggestion that Reid deliberately misled MPs, but the quality of his briefings is in doubt.

Our investigation also raises the question of whether the pilots were ordered to fly ZD576 before the newly-modified aircraft was ready for operational service ... at a time when the government's own airworthiness assessors had indicated that they regarded a re-write of the software in verifiable form to be essential prior to them recommending a release of the newly-equipped Chinook into service.

Despite the concerns of the assessors, the RAF, in conjunction with the Procurement Executive of the Ministry of Defence, agreed to clear the FADEC-equipped Chinook Mk2 for flight in November 1993. In a written statement to the Defence Committee last year, the Ministry said:

> The RAF in conjunction with the Procurement Executive (of the Ministry of Defence) took account of the US Army's experience both in ground and flight testing the FADEC and noted that no flight critical problems had been experienced."

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This statement told only half the truth. Evidence has, in the past few weeks, come to light which shows that there had been a flight safety critical accident involving the Chinook Mk2. Moreover it involved a Chinook belonging to the UK government. The incident in 1989 was so serious that it caused the destruction of a Chinook Mk2 ... and it was caused by a defect in the design of the FADEC. Indeed the UK government won a legal action against the FADEC's contractor on the basis that the design of FADEC was defective, and had led to damage to a Chinook which cost millions of pounds to repair.

The Ministry mounted a cover-up after the accident. Reid told the Defence Committee in 1998 that the accident was not to do with the FADEC software.

So it appears that the Chinook Mk2 was given a clearance to fly in 1993, mainly on the basis of an incorrect assumption that there had been no flight safety critical problems. Also the Ministry's statement that it cleared the Mk2 for flight after taking into account the US Army's experience of FADEC gives an incorrect impression.

For the US Army did not buy a FADEC system that was exactly the same as the RAF's version. Indeed the Assistant Director Helicopter Projects said in a confidential memo shortly before the crash of ZD576, questioned the validity of comparing the tests that had been carried out on the US's FADEC-equipped engines with the tests on the RAF's FADEC-equipped engines. He described the flight tests on the RAF's version of FADEC as "low."

In the same memo the Assistant Director counselled that "full account" should be taken of the views of the aircraft's assessors at the Aeroplane and Armament Experimental Establishment (A&AEE).

So, despite the concerns of the A&AEE - concerns that the Assistant Director Helicopter Projects had urged should be taken full account of - and despite the incorrect impression that there had been no flight safety critical problems during ground or flight testing of the FADEC, the Chinook Mk2 received a clearance that would leave Tapper and Cook with no choice but to fly the aircraft as instructed.

It would also emerge that, a day before the crash of ZD576, airworthiness assessors had suspended flights on the newly-modified Chinook because they had not had satisfactory explanations from the contractors over a number of unexplained incidents. Most of those incidents had involved the new FADEC system.

Such was the concern of the trials pilots that they refused to fly a Chinook Mk 2 even for a 12-minute daytime trip from the A&AEE's site at Boscombe Down to RAF Odiham, the Chinook's main base. The then senior unit test pilot at RAF Odiham, Squadron Leader Robert Burke, had to take an operational crew in a car from RAF Odiham to Boscombe Down to collect the Chinook M2 and bring it back to Odiham.

The dispensation not to the fly the Chinook Mk2 was afforded only to trials pilots. Tapper and Cook, as operational pilots, were operational pilots who could not refuse to fly the Chinook Mk2 unless it had been refused clearance for safe flight.

Trials flying on the Mk2 did not resume at the A&AEE until November 1994, more than four months after the crash, and only then after there were further modifications.

Our investigation also raises questions about the lengths to which the Ministry of Defence went, after a fatal accident, to protect its contractors from any suggestion that their equipment may have been faulty.

Reid was adamant last year that the Ministry's legal action over the Chinook which was destroyed in an accident 1989, was taken on the basis of faulty testing procedures, not because of the software.

"We did not sue them because of a failure of the FADEC software," Reid told the House of Commons Defence Committee in March 1998. "This is one of the misconceptions that has been allowed to flourish... it was essentially about negligence in testing procedures and not with the software..."

Yet the documents filed by the UK government against the manufacturer of the engine control systems contained a series of allegations about the design defects in the software, including a claim that the FADEC was not airworthy.

The documents also alleged that development tests on the hardware were inadequate and that there was a failure to document the software adequately. Insurers for the contractor, Textron Lycoming, denied the allegations, and criticised a test that had been carried out on the system, but the company ended up paying the Ministry of Defence more than $3m in settlement.

So Reid, in giving the UK government's position, was actually affirming the defence that had been put forward by Textron-Lycoming's insurers, not the successful case on which the Ministry's allegations were based.

Reid also told the Committee, based on his briefings, that the engine control system was not safety-critical. However Boeing, which had a contractual responsibility to deliver the aircraft to the Ministry with, in effect, an assurance that it was safe, *did* categorise the engine control system as safety critical.

These and other facts have emerged only after years of campaigning by the families of the two dead pilots; specialists who have been concerned enough to pass on documentary evidence; and to a much lesser extent MPs, and journalists.

Was this unofficial investigation necessary?

The grief of the families of all 29 people who died on ZD576 cannot be imagined. But should the families of the two pilots have endured such extended and intense suffering? To lose a son in the service of one's country is a sacrifice that the parents of anyone in the armed forces must be prepared to make.

But to have the memory and reputation of a dead son vilified by the service to which he has given his life ... without any evidence to prove gross negligence beyond all doubt ... and without his testimony or defence ... could be regarded as a pitiless and posthumous defamation.

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It's a phrase that haunts pilots ... no evidence of technical malfunction.

Now, four years after the crash on the Mull of Kintyre, Bric Lewis is piloting a Chinook that seems to be trying to kill him and his crew.

The Chinook has been undulating gently between 1,100 to 1,500 feet in cold but otherwise perfect weather.

Altitude hold had not been engaged. So Lewis has only a light hand on the controls, allowing the helicopter to float up a little and then he would bring it down again.

Despite the noise, cold and an inevitable vibration that a first-time Chinook passenger calls bone-shaking, Lewis' flight has been exceptionally smooth. The co-pilot Pat Nield had noted that the helicopter was performing better than any Chinook he had flown out of the maintenance depot.

They are now at about 1100 feet, at a speed of around 160 mph. A few seconds earlier, Lewis had tried to correct the nose-down pitch by pulling back on the cyclic lever, but it did not respond.

The cyclic is one of three man controls on the Chinook.

It looks a little like a joystick on a computer game. It is between the pilot's knees. Moving it towards the left turns the helicopter to the left. Pushing it forward points the nose down, so the aircraft descends. A backwards pull and the Chinooks increases height, the nose pitching upwards.

So, to bring back the nose to a level position from its downwards tilt, which is a normal divergence in a Chinook, Lewis pulls back on the "cyclic."

At around the same time, the helicopter's tail end starts to slew towards the front. Lewis tries to correct this "yawing" movement by using the pedals.

Using a combination of pedal and cyclic, Lewis tries to force the tail of the Chinook back into position. But he fails to halt the slide of the tail as starts to swing the helicopter around.

Even with the pedal jammed hard against its stop the Chinook is becoming uncontrollable.

The co-pilot Pat Nield is not permitted to fly the Chinook at the same time as the pilot. Although the cockpit's two front seats have dual flying controls, linked by levers as on some learner cars, the regulations prohibit more than one person using the controls at any one time. This is to prevent a conflict of intentions working their way through to sensitive flying controls.

But as the abrupt yaw begins, Nield is not prepared to be idle. So he screams: "Catch it Bric, catch it."

And he takes the controls.

By this time the helicopter is on its side. The cyclic is not functioning. It's as if it were stuck in concrete.

At last the nose pitches up ... but it continues to do so until the aircraft starts to roll over ... onto its back.

All the crew know that unlike most airplanes, helicopters can hover, or go up and down on a vertical axis and even backwards. They're remarkably versatile. They can carry 55 soldiers and unofficially 80 or more out of troublespots.

On hooks and cables underneath the fuselage they can carry the equivalent in weight of several large vehicles, which is one reason that they have been used with indispensable regularity by the Americans in the Vietnam war, the British in the Falklands conflict and in Bosnia, and by NATO during the Gulf war. Today the Chinook is being used in the crises in Yugoslavia.

Boeing, the manufacturer, also says it's fast. Aerodynamically the Chinook has the flight profile of a large cow lying on its back, two of its legs straight in the air, each of which supports a set of three rotor blades. But the two large jet engines, on each side of the rear rotor assembly, give it a top speed of more than 160 mph fully loaded; faster than some lighter, sleeker helicopters, says Boeing.

But Lewis, Nield and the crew know there is one thing their helicopter cannot do: fly upside down.

It's at this point, when the Chinook flips over that Lewis says "Oh God" into his headset microphone.

Even if the crew has not fully comprehended until this point that they are close to death, they know it now.

Leisure pilots, when their aircraft takes on a will of its own, have been known to make matters worse by extravagant or injudicious efforts to secure their safety. Even when professional pilots know that death is imminent, they will rarely show any signs of panic, as cockpit voice recorders testify.

The utterance of a phrase such as "Oh God" is often the closest that a professional pilot will come to an admission that their predicament is precarious.

"We need, uh, closest airport available ..." were the last recorded words of a pilot of a Valu-Jet passenger jet whose cockpit was engulfed in flames in 1996. The cockpit voice recorder ended about two minutes after the pilot's request to air traffic control. The jet crashed in a swamp near Miami, killing 110 people.

"Oh what's happening?" asked the co-pilot of a Lauda Air Boeing 767 passenger jet as one of its computer-controlled engines did something that had been considered impossible: it went into reverse thrust (full braking mode) in cruise flight, rendering the aircraft uncontrollable.

"Oh what's happening," said the captain, repeating the words of his co-pilot. Yet his final few words showed an optimism that even the thought of imminent death could not repress. "Lets do it like this" he said. The cockpit voice recorder then recorded the background wind noise as the aircraft gathered speed, heading almost vertically towards the ground. There were several seconds before impact. The crash killed 223 people. There were no survivors.

Similarly the pilots of a Lufthansa Airbus which crashed after landing on a runway at Warsaw airport in Poland also showed no signs of panic in the last moments of the flight. The aircraft had the opposite problem to the Lauda Air 767 in that the computerised engines refused to allow the pilot to deploy reverse thrust braking control.

"Was machen wir jetzt? (What shall we do now?) says the pilot when he realises that the other two main forms of braking - the computer-controlled "spoilers" on the wings and the software-controlled brakes on the landing gear's wheels – are also refusing to operate.

Tja?, du kannst nmehr machen – (Well? you can't do anything anymore)" says the captain. In fact the pilots did do more. Though it was a fatal crash, they saved many lives by steering almost clear of a bank at the end of the runway. If the pilots had suspected in that moment that they would be blamed, their instincts were sound.

What all these incidents had in common were pilots who, in the seconds before life on board was extinguished, continued to do what was drummed into them during training: never stop flying aircraft.

And that's what saves Bric Lewis and his crew. With his helicopter upside down and the ground rushing up he is still trying to persuade the controls to respond.

He knows the cockpit is low. It is going to hit first. Yet there is time to think, to know what it feels like in the last few moments of life. Lewis observes that the feeling in his stomach resembles that of descending rapidly in a lift. And there is seemingly nothing he can do. "They lied," he thinks, "They tell your family it's instant."

"Oh Jesus," thinks the flight engineer Peter Biessener. "This is it."

Bill Gorenflo, the mechanic, is already injured. Before the aircraft became uncontrollable, he had unbuckled his belt to get his coat because the cabin was cold. When the Chinook flipped over he was slammed into the aircraft structure near the heater. Then he was thrown against the radio compartment.

"Oh God no," he says, waiting for the impact. He pictures his six year-old son, directly in front of him. "God no!" he says.

Lewis and Nield are still trying to get the cyclic lever to bite. And then it becomes unstuck.

Then there's the opposite problem: it's so loose it's ineffectual.

But the right pedal begins to respond. And when Nield pulls back on the cyclic it begins to function.

Then, as inexplicably as the Chinook had turned over, it flips back again into a normal wheels-down position.

"God we're right side up," says Biessner.

But the Chinook is now was only 250 feet above the ground. The rotor blades are in overspeed, spinning much faster than they should. If the rotor on a helicopter spins too quickly, there's a danger the blades will fly off. And now it's making a screaming sound.

But the rotors provide immediate lift and the Chinook's descent slows suddenly, as if a parachute has opened above it. For Nield, it feels as if the bottom is going to drop out of the aircraft.

The helicopter is going forward but is yawing again to an extreme. Fortunately there are no obstructions ahead; only level ground. At this moment the nose begins to lift without any command, as if in a repeat of the earlier incident in which the helicopter inverted.

Trying to land as soon as possible, Lewis and Nield go to use another of the main flying controls on the Chinook: the collective or thrust lever.

It isn't working.

The collective lever resembles the handbrake on a car. Some pilots call it "the collective," others the thrust lever. Whereas the cyclic is between the plot's legs, the collective is to his side. Any movement of the lever directly alters the pitch of all six rotor blades in unison. The more the collective is pulled, the more the angle of the blades is turned against the air, giving helicopters the familiar "slapping" noise as the rotors blades attack the surrounding air.

It is the collective which enables helicopters to rise or descend on a vertical axis. It is an important flying control when landing.

Although Lewis pulls on the collective lever with considerable force, it barely moves. Nield is also trying to force it up without success. But they are now so close to the ground that by pulling on the cyclic, they can bring down the back wheels. Then the helicopter is stationary.

Lewis is screaming: "We made it! We killed the beast!" Everyone gives each other highfives in the cockpit.

Now, when it doesn't matter, they find that the collective lever is working perfectly. So does the cyclic, though a pedal is stuck.

The engines start to wind down. That's when the crew hear three loud bangs in quick succession.

The blades are striking the fuselage.

In some previous helicopter accidents in which the rotor blades have been out of control, they have pounded and then sliced the fuselage, and its occupants, into sections.

Nield tries to duck down over the console. Lewis tries to get down by the pedals. But their shoulder harnesses are locked.

Biessener is crawling on the floor towards the front of the cabin. Nield is shouting to him: “Stay back stay back.”

Gorenflo the mechanic is trying to open the rear cabin door but without success.

And then there is silence. The engines have stopped ... the rotors have stopped ... the Chinook has given up trying to kill them.

“Finally it gets quiet,” says Gorenflo, explaining the incident afterwards. “I lookup. My face is hurting, My back is hurting. And we get out of there. It’s cold out there. I’m shaking. And I’m hurting. And I’m thinking what’s just happened? I go back in. Pat’s still inside, standing there. We just hug each other. I say: “Man you guys saved our lives. What in the world...? He says’ “I don’t know. Just thank God we’re on the ground.”

Biessenger says: “At the hospital I stared thinking that this as really a good day. Because we should have been a big pile, just a smoking hole. Chinooks don’t go upside down and come back to life. They just don’t do that… We thought that if they ever put this aircraft back together, we want it back. Because it stayed together. I mean, no matter what it did wrong, it still *stayed together*.

Nield said: “I don’t know how this thing righted itself other than God reached down and snatched this aircraft and tuned it over.”

By saving themselves and the crew, Bric Lewis and Pat Nield had not only saved their lives but their professional reputations.

Statistically, if pilots die in a crash where no obvious, serious defect is found, they are likely to be blamed for the accident.

As Lewis and his crew had survived they were able to give an account of the uncommanded flight movements, and the simultaneous control jams. Otherwise the investigation might have pointed towards pilot error.

After all, if investigators had not been able to find anything seriously wrong with the aircraft when it was intact, they would almost certainly have found no a serious faults if the helicopter had been wrecked.

Put another way, had Lewis and his crew died, there would have been no evidence of a technical malfunction capable of causing the crash .... the phrase that was used to punish the dead pilots, and their families, after ZD576 hit the Mull of Kintyre.

* * * * *

At the Defence Committee hearing in March 1998, Reid, among other things, sought to show that the crash on the Mull of Kintyre was an isolated incident.

> “As far as I am aware, despite the fact that the Chinook is flying with us, and with the Dutch, and with the United States and elsewhere there has only been, prior to that [the Mull of Kintyre crash], one Chinook accident. It was not a Chinook mark-2. It was a Chinook Mark-one. The first thing I would say is that the ill-informed speculation ... that Chinooks are everywhere falling out of the sky is completely wrong.”

Reid was right to make the point that the Chinook has an impressive safety record. However the statistics he gave MPs at the committee hearing were wrong. After the hearing the Mod issued the corrected figures.

In the UK, there were nine serious accidents involving RAF Chinook between 1984 and 1994. In five of them, the pilots had lived to explain what happened, and in none of these was blame attributed to the aircrew. The same could not be said of the remaining four crashes, all of which were fatal. Three of the four were put down to aircrew error. The fourth was, officially, "not positively determined." The evidence in this last crash of a Chinook during a post-maintenance test flight in the Falklands Islands pointed strongly towards a technical malfunction. Eyewitnesses saw the helicopter in straight and level flight. Then the nose dipped down slightly at first; and the aircraft fell out of the sky, cockpit first. The last words transmitted by the pilots were unintelligible.

Investigators found a failure in a flying control, known as the cyclic trim actuator, though they said that this was not serious enough to cause the accident unless there was a separate serious simultaneous malfunction which could have prevented recovery of the aircraft.

A second problem was indeed discovered: the malformation of a component. It was found during practical tests that if the pilot had applied a rapid control input in response to an unidentified nose-down pitch, it is possible that a flying control jack known as the Upper Boost Actuator could have jammed. This, together with the failure of the cyclic trim actuator, would then have produced a dive resembling the last fatal trajectory of the Falklands crash.

The subsequent RAF inquiry did not conclude that it was a failure by the manufacturer, maintenance specialists or any subcontractors.

"Due to lack of evidence the Inquiry could not completely discount a number of other causes. These included ... crew incapacitation or physiological problem."

When the Ministry of Defence was asked recently for evidence of any fatal crashes in the past 10 years which have led to the manufacturers being held to blame, it made no response.

In the US, according to figures published by Boeing in September last year, there were 435 Chinooks in the US Army, Army Reserves and National Guard. None of these were fitted were the FADEC system. There were a further 25 Chinooks with FADEC systems. None was using exactly the same system as that used by the RAF.

Figures of Chinook accidents in the USA prior to 1994 have not been made available by the US Army Safety Centre. In the period between 1994 and 1998, according to the US Army Safety Center in Alabama, there were 116 serious accidents between 1994 and 1998 involving Chinooks. Seven of these were fatal and one of them, in March 1996, involved a FADEC-equipped helicopter. Repeated requests to the US government for information about the crash of the FADEC-equipped helicopter have gone unanswered.

However the US army is reasonably open about its Chinook crashes in general and publishes details of the lessons learned. It has also disclosed that it has, in the past, mistakenly blamed dead pilots for Chinook crashes that were later found to have been caused by technical malfunctions.

A US Army newsletter published in 1998, said that the pilots were blamed posthumously for the crash of a Chinook which had flown from an area of good visibility into one which required permission to fly using instruments.

The Chinook had passed through its assigned heading when radar contact was lost. "At the time of the accident all available evidence indicated that the primary cause of the accident was human error ..." said the newsletter.

Since then US army investigators found that, from October 1992 to June 1996 seven Chinooks experienced varying degrees of electrical power failure which could have affected all primary and standby instruments, and the computer-based Automatic Flight Control System.

The report concluded that the crew was making a turn when they had lost "at a minimum" the primary flight instruments and the computer flight control system. Investigators could not say for certain what caused the crash but the names of the pilots were cleared.

The US Army Safety Centre in Alabama, also reported in April 1999 on a succession of "uncommanded manoeuvres or flight-control lockup in flight" that have affected the Chinook.

It said that "computer simulation is not sophisticated enough at this time to produce the exact maneuvers of the incident aircraft, therefore no absolute cause-and-effect relationship has been established."

After the 360-degree "barrel roll" of a CH-47 Chinook in 1998, for example, the US Army issued a short summary of its findings. It said that following "months of investigation and extensive research, testing and analysis the cause of this accident has never been determined." ***There was, officially, no evidence of technical malfunction.***

The newsletter added that the US Army, other relevant parties including the manufacturer Boeing would "continue to monitor and evaluate all CH-47 flight-control anomalies to determine the cause of this accident and take corrective actions."

One result was that the US Army issued a formal Aviation Safety Action Message which requested information from the military aviation community on uncommanded control inputs. The Analytical Investigation Branch at Corpus Christi Army Depot, which does much of the maintenance work on Chinook CH-47 helicopters in the US, found that there had been many incidents, mostly involving suspected problems with the Automatic Flight Control System and the integrity of electrical systems.

Some of the problems related to the controls locking or failing to operate for no apparent reason.

When maintenance specialists later tried to replicate the problem, they could find nothing wrong.

By April 1999 the cause of the barrel roll on Bric Lewis's Chinook had still not been identified.

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It is indisputable that pilots ***are*** the cause of most major crashes. Boeing has produced a paper which says that the largest single cause of air crashes is "flying pilot adherence to procedure" which is a euphemism for "flying pilot not adhering to procedures."

After a fatal crash, the aircraft and component manufacturers will, however, have the resources to defend the integrity of their equipment, as will the certification authorities, the air traffic control centre, the meteorologists, and all those who are alive to defend vigorously any imputation of blame.

Dead pilots have no voice and since statistically they are known to be the weakest link in the safety chain, some authorities may find it difficult to begin a fatal crash inquiry without a preconception that the likely outcome will implicitly impugn the competence and professional reputation of the pilots.

A hint that these preconceptions exist may be seen in the comments of the then Prime Minister John Major, less than a day after the crash on the Mull of Kintyre.

He told reporters he would not be grounding the Chinook and added: "It looks as if it was a straightforward accident in appalling weather." The implication was that the weather and not technical malfunction, had something to do with the crash.

Major was not to know then that, a few minutes before the crash, a yachtsman Mark Holbrook, had seen the Chinook flying overhead, the sun glinting off its fuselage.

The comments of the Prime Minister were made before investigators had inspected the surviving parts of the wreckage to see whether there was anything wrong with the aircraft.

His comments were also several months before an RAF Board of Inquiry would report its findings. And the Scottish Fatal Accident Inquiry which would take evidence over a period of four weeks, and inspect thousands of documents, did not start until more than a year after Major's remark.

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Specialists who study crash reports can see that it is sometimes the pilots who are blamed because the alternative of an ambiguous conclusion is less attractive.

Ambiguity might suggest or even point a finger at politically-sensitive contributory factors such as serious technical malfunctions. These would then raise difficult questions after a fatal crash about legal liability, about why the aircraft was allowed to fly, how it was certified and whether the crash was really the result of an oversight or incompetence by a governmental agency or authority.

For example Peter Ladkin, Professor of Computer Networks and Distributed Systems, Universität Bielefeld, Germany, who has made a study of civil aviation accidents believes that the pilots were wrongly blamed after an Airbus A320 crashed after landing at Warsaw airport. It was said that they had landed too fast.

Professor Ladkin says that blaming the pilots did not answer questions about the design of the aircraft's braking systems. The pilots had not been able to apply the brakes manually; the computers had been programmed to decide what the pilots could and couldn't do. Sensors and software sat between the pilots and the brakes which "listened" to what the pilots wanted to do, and then decided whether to act on the commands. In the Warsaw incident, the systems decided that the pilot was not really trying to land and so refused to apply the brakes. The aircraft was unable to stop safely.

Blaming the pilots also turned attention from the out of date information given to the pilots about the weather. They had been told to expect windshear, (a downdraft of air which can severely destabilise an aircraft). In response they landed faster than normal to give the aircraft extra stability and lift. But the meteorological advice was out of date. There was no windshear by the time the pilots landed. It has been suggested that the Polish government's meteorologist was in the toilet at the time of the landing.

Blaming the pilots also turned attention away from why the government had allowed a high bank to be built at the end of the runway. The aircraft had crashed in the bank, which caused it to break up.

On the rare occasions when manufacturers have been blamed after fatal accidents, they do not always accept the findings. McDonnell Douglas has never accepted any responsibility or blame in connection with faulty cargo doors which were said during Senate inquiries to have caused two of the worst accidents in aviation history.

In one of the crashes, the cargo door of a DC10 become detached from the rest of the plane. It landed in a field. Five miles beyond that was the wreckage of the aircraft, and 345 bodies. There had been 100 complaints about the doors prior to the two fatal crashes.

After the crash of ZD576 on the Mull of Kintyre, the Air Accidents Investigation Branch made no attempt to blame the pilots. They said the "pre-impact serviceability of the aircraft could not be positively identified but no evidence was found of malfunction that could have contributed to the accident ..."

Since the investigator's findings were published, ministers and the Ministry of Defence have quoted the report's phrase that "no evidence was found of malfunction" as supporting the accusation that the pilots must have been to blame for the crash of Chinook ZD576.

Recently, however, an investigator at the Air Accident Investigations Branch in Farnborough, England, explained the rationale behind the phraseology used in the Branch's final report.

"No evidence of technical malfunction does not mean ***no*** technical malfunction," he said. "We use our words with some care. If other authorities wish to suggest that no evidence of technical malfunction means that pilot error is the primary cause of an accident, that is their decision. But it is not one we would necessarily endorse."

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

Chapter Two

Summary of Chapter Two

The FADEC engine control computer system – the dangers of new safety-critical systems

The advantages of FADEC –suppliers case to Ministry of Defence.

Contract for new Chinook FADEC system awarded without open competition

Tension in relationship between RAF and contractors re access to FADEC information.

Pilots accused of gross negligence train for RAF career as work on FADEC starts

DEVELOPMENT OF THE CHINOOK’S FADEC ENGINE CONTROL SYSTEM

The Chinook had proved itself as a dependable and impressive transportation machine in most major conflicts since and including Vietnam. But this was to change.

In the early 1980s a major modification of the mark one Chinook was planned. It was to turn the workhorse into a modern aircraft. Among the improvements was an innovative computer system that would control the engines. The software would not merely monitor the engine, nor would it merely finely tune the engine power. It was to be given "full authority" and hence its name: Full Authority Digital Electronic Control.

At one extreme the FADEC could shut down the engine, or it could accelerate the speed of the rotor blades to the point of causing an accident. If the rotors go too fast on a helicopter they can, literally, fly off. Elaborate protections were necessary to protect against "overspeed" incidents.

But the FADEC as designed for the RAF Chinook fleet had few safety features which did not depend on software. It would be described in a Ministry of Defence report as a "high-risk approach."

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How the system developed, the problems it encountered and the disagreements that arose between the Ministry of Defence and the manufacturers are revealed in dozens of documents, details of which have come to light for the first time.

They show that the dangers inherent in a new design of computer system being bolted onto a tried and trusted design of aircraft were recognised within some parts of the Ministry of Defence and RAF but not in others.

It has been known in the engineering community for centuries that innovative ideas which flourish in the longer term may have a disastrous beginning.

New designs of bridges, ingenious in concept but not fully thought-through, have collapsed.

That technology does not prove itself straight away was brought home with the fatal crashes of the Airbus A320, the world's first passenger jet in which only software sat between the pilots and most of the major flying controls. After its introduction, the A320 had a poor fatal accident record though this has greatly improved in time.

Another example was the introduction by McDonnell Douglas of a new feature on its DC-10 aircraft: large, innovative cargo doors which opened outwards, so allowing more storage space.

There were teething problems. Until they were redesigned the doors had a tendency to detach themselves and endanger the aircraft.

There was so little appreciation of the risks associated with a new engine control system for the Chinook that a small number of senior officers in the armed forces expressed anger and incredulity that the Ministry of Defence's own appointed software specialists could not simply accept the new computer systems without raising questions.

Much later, those same officers refused to accept the possibility that the malfunctioning of a software-based fuel control system could cause a Chinook to crash. Yet Boeing, the manufacturers of the Chinook, had classified the computer system as a flight-safety critical component. This meant that its malfunctioning could, in certain circumstances, lead to a complete loss of control of the aircraft.

The FADEC on the Chinook comprises two main parts. One is the Digital Electronic Control Unit (DECU) for each of the helicopter's two engines. The DECU is a computer that monitors electronic signals that indicate things like engine and rotor speed.

The computer also receives electronic commands from the pilot and converts this into data which is transmitted to control the flow of fuel to the engines. The system controls other engine functions such as ignition. Each DECU also has a display for diagnostics purposes which shows some fault information related to the performance of the engine and the FADEC itself.

The second part of the FADEC is a hydromechanical unit that receives signals from the DECU. In response to these, the hydromechanical unit pumps the correct amount of fuel to the engine.

In principle the FADEC is a good idea. Although non-FADEC engines have some automatic features, the pilots are required to play an active part in monitoring the engine's behaviour and making frequent adjustments to maintain performance. It was not an efficient use of the pilot's time and the human intervention led to unnecessary wear and tear on the engines and components.

Also, in the high-vibration environment imposed by helicopter engines and rotor blades, purely hydro-mechanical engine control systems had short useful lives. Maintenance costs were high, reliability low. The FADEC's software-driven automatic controls are more finely tuned. They have fewer mechanical parts, and so can achieve longer lives.

Also the engine performance is superior; smoother fuel flow, lower fuel consumption, higher accuracy without pilot interventions.

From the pilot's perspective FADEC is in theory a major advance. He is relieved of many of the routine tasks required to monitor the engine and fuel flow. In many helicopters, there is no accelerator as on a car. Nor are there throttles as on a conventional passenger jet. On a Mk2 Chinook, the pilot operates the controls and the FADEC provides the power and fuel to achieve the desired speed and flight path.

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Computerised engine controls have been widely used on military aircraft since the 1970s. They went generally into service in commercial aircraft, including helicopters, from the early 1980s onwards.

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In 1984 the subcontractors who were to build the Chinook's FADEC submitted a proposal to the Ministry of Defence which described the system in enthusiastic terms.

"The latest state-of-the-art component and manufacturing technology is employed in the proposed design to provide a low cost high reliability solution."

"It is estimated the direct maintenance cost per hour will be reduced by a factor of 10 and a substantial reduction in maintenance and overhaul costs will provide gross savings of nearly $30m when projected over 20 years."

"The airframe-mounted Digital Electronic Control Unit provides a built-in, alphanumeric diagnostics display for the FADEC that can be interrogated on the ground or during flight."

"The proposed FADEC design is based on substantially identical units currently being developed and qualified for Lycoming ALF 502 and Rolls-Royce GEM engines."

Therefore technical risk was described by the subcontractors as "extremely low."

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At the time of its conception, the FADEC proposed for the Chinook was not intended as a fully digital system.

For reasons of safety, each FADEC was to have two "lanes" which performed similar functions. The main or primary lane was to be a computer system. The back-up, or as it called "reversionary" lane, was to be based on more conventional analogue technology.

But as time went on the project became more technologically ambitious and, without any opposition from the Ministry of Defence, the manufacturers went ahead with a system which was digital in primary and back-up mode. Unusually in a FADEC system, there was no mechanical backup.

The wisdom of this approach was never questioned at the time. But 15 years later the technological pendulum swung back, in favour of mechanical back-up systems for FADEC.

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In 1999 the Chinook's engine makers announced that they had begun a research project in Farnborough, England, to build a successor to FADEC. They would call it Epic ... "Unlike a FADEC that relies on dual electrical systems for power source redundancy, the Epic system will feature independent mechanical backup subsystems for all critical control functions."

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The award of the original contract for the Chinook FADEC was made without any open competition or public announcement.

The Ministry of Defence later defended this in a statement to Computer Weekly but gave no specific response to the allegation that it had failed to seek competitive bids. "... Mod adopts the procurement strategy which is most appropriate for the equipment being procured," it said.

The early documents submitted to the Ministry to persuade officials of the virtue of a FADEC system were well presented and technically detailed. However the arrangements for managing the project were complicated by the number of subcontractors and the relationships between them.

Hawker Siddeley Dynamics Engineering, a specialist branch of the British Hawker Siddeley aerospace group, wrote much of the FADEC's software. At first, Hawker Siddeley had nothing to do with the Chinook programme. Boeing, the US aircraft and aerospace company based in Seattle, USA, manufactured the Chinook.

On 25 October 1984, Hawker Siddeley signed a joint-venture agreement with a US company, Chandler Evans of Connecticut which manufactured controls for aerospace engines. In turn Chandler Evans signed a joint-venture agreement with what was then Avco Lycoming, a Boeing subcontractor, which supplied engines for the Chinook.

So the FADEC programme involved Boeing as the Chinook's manufacturer, and three main subcontractors: Lycoming as the engine supplier, Chandler Evans who helped to build and design parts of the FADEC, and Hawker Siddeley wrote the software.

By the early 1980s, it was already clear that the UK was to lead the way in the development of the FADEC system, but it was not exactly clear *who* in the UK was leading the development, the subcontractrors or the Ministry of Defence.

By 1986, two years into the FADEC programme, the RAF was expressing concern about its lack of involvement in the project, and the difficulties posed by the coagulation of different companies.

"Clearly we have been brought in late," says an internal RAF report, "and there will be little or no chance for CSDE (the RAF's Central Servicing Development Establishment in Norfolk) to influence any part of the design."

The report also expressed concern that the FADEC's planned flight and qualification tests, and those that would be conducted by the RAF's software specialists at the Aeroplane and Armament Experimental Establishment at Boscombe Down at Wiltshire in England were timetabled late in the project.

This would mean, said the report, that any changes will either cause production delays or "will lead to disruptive retrofits." But the subcontractors expressed “confidence in their engineering."

The RAF report observed: "This is obviously a high risk area."

It went on to suggest that openness and easy communication between all the parties was not yet a feature of the contracts.

"Direct access to subcontractors such as HSDE (Hawker Siddeley) was requested, and refused by Avco's programme manager ... who did not wish to 'lose control' of the information flows.

"He did accept the principle of [the RAF's] CSDE requesting and being given information, however, which represented an advance over his earlier position.

"The compromise solution reached was that CSDE would feed to him, in the near future, an initial list of questions, which he would in turn feed to the subcontractors as necessary ... of course HSDE is only one of four contractors ... Incidentally Avco only have influence over CECO (Chandler Evans) and HSDE. Questions on the Boeing side will have to be aimed directly at Boeing in a separate list (copied to Avco), fed only through the UK Chinook Liaison office.

"On this last point neither Avco nor CECO will release drawings containing proprietary information. They will however release ... line diagrams such as those in Mod leaflets etc..."

The complications in the inter-relationships between all the various parties to the contract, was not an auspicious start to the development and testing of a system that Boeing had categorised as potentially critical to the safety of the Chinook Mk2.

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During these early years in the development of the FADEC, Jonathan Tapper and Rick Cook, the pilots of ZD576, were training for a career in the RAF.

Tapper gained a private pilot's licence before he was old enough to drive.

When he was 16, at Dulwich College where he was a member of the RAF section of the college's combined cadet force, he won a flying scholarship so securing a private pilot's licence.

He joined RAF Cranwell in 1984, a year after Rick Cook who was two years older and had already begun flying helicopters. By the age of 20 Cook had flown hundreds of hours in the Chinook helicopter, mainstay of the RAF's transport fleet.

They were to become friends, a team who would not separate until their violent deaths in a Chinook nine years later.

Cook had completed his flying training - earned his wings - in 1985, and Tapper a year later.

The possibility of premature death was rarely discussed. But they were aware of a fatal crash of a Chinook during a flight test in the Falklands Island in 1987. There were no survivors, though there were eye-witnesses who saw the helicopter drop out of the sky for no apparent reason.

Later, Chinook crews, as part of their training briefs, were given two versions of the crash. One was the official version: cause not positively identified (possibility of aircrew incapacitation or physiology not ruled out). The second unpublished version was that it was caused by a technical malfunction. The crews were given advice on how they should react to such an emergency in future.

There was little public discussion on why the aircrews were not exonerated. This, and other suggestions that the culture of the RAF militated against criticising a manufacturer after a fatal crash, was of concern to Tapper, Cook and other pilots.

In the RAF, honour is more than an anachronistic affectation. Gaining one's wings is a cause for celebration, and a genuine reason to feel satisfaction at having achieved a high level of attainment at an early age. To go further and earn the respect of colleagues and senior officers, is a treasure beyond value. But to lose that approbation and one's life at the same time, and be unable to challenge the vilification of your reputation, is the ultimate fear of professional pilots.

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Chapter Three

Summary of Chapter Three

The problems of an engine overspeed

An actual overspeed – a pilot faces one

Boeing expresses concern about design of "FADEC" engine control computer system.

A fundamental flaw is overlooked

A Chinook crashes in North – a human disaster

The FADEC fault codes that were ignored in Mull of Kintyre crash

The importance of a FADEC "E5" fault code – found in a Chinook accident in 1989 and in Mull of Kintyre crash

Eyewitness accounts of the destruction of a Chinook, partly because of FADEC "E5" fault code.

Defence Minister tells House of Commons that 1989 accident was "irrelevant."

RAF recommends full reappraisal of FADEC engine control computer system in wake of 1989 accident – but Defence Minister tells House of Commons accident was not due to software.

Why a FADEC system subcontractor rejects a suggestion by Boeing, the Chinook's manufacturer.

Internal documents reveal the concerns of the FADEC contractors over "numerous" problems.

The Defence Minister gives the House of Commons incorrect information on FADEC - details.

Investigators of the Mull of Kintyre crash admit they don't understand FADEC's "E5" fault code.

The Mod's foremost FADEC expert is not asked to help investigators of Mull of Kintyre crash

A senior Chinook unit test pilot in RAF is ordered not to help Mull of Kintyre investigators.

Why MPs were given incorrect information– one theory

Was there a cover-up over the fact that the Mull of Kintyre helicopter was unfit for flying?

A FADEC OVERSPEED ACCIDENT

An uncontrolled engine overspeed on a helicopter is an emergency. It can happen in seconds.

The problem is compounded by the fact that helicopters, unlike cars, do not have a manual accelerator, which continuously changes engine speed according to the pressure on the pedal. In a helicopter during normal flight the engine speed is largely an automatic process, whether or not the aircraft is fitted with FADEC.

Squadron Leader Robert Burke, a senior unit test pilot at RAF Odiham, Hampshire, at the time of the crash of ZD576, Hampshire, the RAF's main Chinook operating base, has had nearly 8,000 military hours and more flight testing hours on Chinooks than any other pilot.

He says that apart from the danger of the rotors flying off, the vibration during an engine overspeed can so disturb the equilibrium of the helicopter that other things may go wrong or the instruments can become unreadable. It could lead to a fatal loss of control if an overspeed caused, or were coupled with, a second serious problem.

A number of the most serious commercial airliner accidents have occurred because of several separate issues which in themselves were not serious but together were catastrophic. In the Warsaw crash of an Airbus A320 the lack of a real time weather report would not have been a problem in itself.

It led to the pilots landing faster than necessary to avoid windshear that, in the event, did not occur. This would not have led to disaster had it not been for a thin film of water on the runway which had not been cleared by the authorities.

So the wheels "aquaplaned," skimming the surface, without gaining enough rotary speed to tell the computer braking systems that the aircraft was landing. Partly because of this, the computers refused to allow the pilot to use the aircraft's braking systems. So the spoilers on the wings, the wheel brakes and reverse thrust on the engines did not work until too late. Even then, without the normal function of these braking systems, the landing would probably not have fatal had there not been a bank at the end of the runway.

This is a typical example of how fatal crashes occur because of simultaneous, multiple problems.

In the seconds before the crash of ZD576, Robert Burke, who has studied the evidence from the accident in detail, believes that the pilots may have been contending with a problem such as a temporary overspeed.

An example of an engine overspeed is given by the US Army Safety Centre. A Chinook had departed from a naval air station when the pilot noticed that the rotor revs per minute were accelerating past 105%. On Chinooks the rotors do not go faster or slower according to the speed of the aircraft. They should always be the same speed, about 225 revolutions per minute. This is the case whether the helicopter is on the ground ready for take off, or it is flying at top speed at its maximum weight.

When everything is normal, the rotor speeds are at an optimum 100%. To accelerate or climb the pilot would normally put the nose down and/or raise the pitch of the rotor blades. Almost indiscernibly, the fuel system should then automatically detect a slowing down of the rotors because of the demand for additional lift, the then instruct the engine to deliver the power that is required to keep the rotors turning at 100%. In effect the fuel control system delivers the power required to keep the aircraft on the flight path and speed dictated by the pilot.

In the example cited by the US Army Centre, the pilot tried to bring down the rotor speed when it went past 105%. At first he did what training dictates: he raised the "handbrake-like" collective lever which alters the angle of attack of the rotor blades, putting them under a load. This should bring down the rotor speed – but it didn't. So then the pilot had to move the engine condition lever to bring the engines down to idle.

When there was no immediate improvement, the pilot aborted known emergency procedures and used the emergency beep trim. This is an electronic button which brings down the rotor speed in punctuated stages. This had no response. So the pilot closed down the engines. However the rotors remained at 120% throughout descent and landing. It was fortunate that a landing was made on level ground. In a hilly or mountainous region, the terrain may not have been conducive to a safe landing.

There was no evidence of technical malfunction.

The incident occurred on a Chinook which was not fitted with the FADEC system but a semi automatic hydromechanical unit. With a FADEC system the instances of overspeeds should be reduced or eliminated because well-written software can be more reliable than hydromechanical units, though when things go wrong, the cause can be harder to find.

The designers of the Chinook FADEC faced a particular problem: novelty. Although the basis of the design was that used in other FADEC systems supplied by the subcontractors, some of the software was new and this made the whole system unique.

Perhaps it was not reasonable to expect the designers to build a new system that was safety critical, new, innovative, unproven by years of practical use, and yet flout convention by working perfectly from day one of operational service.

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

Few software programs are bug-free at the point at which they are delivered to the market.

With the FADEC system, it would have to guard against overspeeds while ensuring that the opposite did not happen ... an engine rundown. The system could not be tested and the lessons learned during operational use, without the possibility of lives being lost.

Design documents from Chandler Evans and Avco Lycoming highlight the challenges they faced.

For example the original design of the FADEC allowed for both engines to be tripped if they went into overspeed. But in a review of the specification Boeing spotted this anomaly.

If both engines went into overspeed, and both were tripped, and ran down to idle, that could leave the Chinook's pilots without sufficient power to fly out of trouble.

Like most aircraft, helicopters can descend without engines. In a helicopter it is called autorotation, where the rotors revolve on free-spinning rotors. Even if the only power is that of the air which is pushed against the rotors as the aircraft falls out of the sky, this rush of air may power the rotors sufficiently to provide enough lift for a safe landing.

But, as all pilots know, it can be extremely hazardous to autorotate over hills, in clouds or over a mountain range. So Boeing issued a warning 1986 that it would not approve the FADEC for flight unless "appropriate circuitry" was included in the FADEC to preclude the tripping of both engines in an overspeed.

This solved the problem of both engines running down. But how would the system cope with one or both engines running up?

One response of the designers to the threat of overspeeds was to ensure that if the FADEC failed it would freeze the automatic throttle in a safe position. In theory this would prevent a runway because, even if the FADEC failed, the throttle could not pump unlimited quantities of fuel into the engine.

But a fundamental flaw was overlooked. It would later lead to the destruction of a Mk2 Chinook newly equipped with FADEC.

The problem that was not recognised was one that afflicts all computer systems: they are without human instinct and cannot deal with an emergency that the designers have not anticipated. The FADEC would do only that which humans had programmed it to do. And if the FADEC did not know there was a fault with itself, or did not recognise that its systems or software were incorrectly designed, it would not necessarily shut off fuel in the event of an overrun.

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RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

In 1986, while work was continuing on the Chinook's new FADEC, one of the world's worst civil helicopter crashed in the North Sea, killing 43 oil workers and two crew. A commercial company on behalf of the petroleum company Shell Oil had run the Chinook.

The crash was unusual for two reasons. The manufacturer Boeing was blamed, though not until several years later. Also the helicopter had been fitted with a cockpit voice recorder which showed a general noise increase shortly before the end of the flight. It was clear from the recorder that the crew had noticed the increase in vibration and noise, though it was too late for them to react. A report by the Air Accidents Investigation Branch in Farnborough, England, found that the Chinook's gears had been modified and the changed design had been inadequately tested before going service.

What was called a "design" fault allowed the two sets of rotor blades to smash into each other. The Chinook fell 500 feet into the sea.

Boeing offered compensation, reportedly of £170,000 per person, but the families rejected it. There were protracted legal proceedings with Boeing challenging the findings of the Air Accidents Investigation Branch. It said the allegations that it was to blame were a "serious miscarriage of justice."

But investigators had proof, in particular the cockpit voice recorder.

Even so Boeing took the case to a judicial review which it lost. The cost of the accident, and being blamed for it was high: workers refused to fly on Chinooks and British oil companies boycotted the helicopter.

The case showed that air investigators had no insurmountable difficulties, when armed with a cockpit voice recorder and what was, compared to computers, a relatively orthodox and pellucid engineering device. Gears could be picked apart, studied and some faults seen with the naked eye.

But how would an investigation proceed if highly specialised devices such as computers were suspected to be at fault? The crash of ZD576 on the Mull of Kintyre showed that, to some extent, the investigators need the co-operation of the suppliers in assessing whether specialists equipment is faulty.

The question arises of whether it is reasonable to ask manufacturers, in the wake of a fatal crash, to identify faults in their systems and equipment that may have contributed to the accident.

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The development of the FADEC during the 1980s was fraught with more difficulties than had been expected.

The work began to run behind the original schedule. The initial proposal had envisaged the system going into production two years after it was given the go ahead. The United Kingdom Procurement Office at the British Embassy in Washington signed a contracts letter with Avro Lycoming on 23 December 1985. By 1987 the system was still being tested.

The delays were costing the subcontractors money. The documents show that Chandler Evans and Hawker Siddeley had agreed to meet all development costs except those related to "prototype production hardware."

A report by Chandler Evans dated 1987 shows the results of tests on the primary and reversionary lanes of the FADEC software. It was found that despite a number of problems including power interrupt testing in both primary and reversionary lanes which yielded "poor results" the overall system stability was "excellent."

Despite the problems described, said the report, "phase one software was found fully acceptable for the initial engine development testing. The outstanding problems ... will be resolved during phase two testing."

By 1988 not all issues had been resolved.

During phase three testing of both DECUs, it was said that the "fault detection and substitution logic had numerous problems."

Meanwhile a document written by Lycoming - now called Textron Lycoming - gives details of the results of a 25-hour "endurance" test of the FADEC by the RAF.

The report highlights multiple failures but, as in the other tests, ends with a positive conclusion.

Among the " significant" control system incidents listed were that the DECU showed a fault code of B2. This indicated a possible failure of the FADEC's backup reversionary mode. By the time the report was written the fault had been "identified and corrected."

Another failure had occurred in the reversionary backup mode, though the report said hat the primary and backup lanes had failed in a safe manner with the fuel controls frozen. "The cause of the problem was identified and corrected."

A further fault was indicated by an "F3" code which indicted that the DECU had sensed differences in the sensor signals that registered the speed of the gas generators (N1A/N1B difference).

A passing reference was made to another fault code which had appeared in the DECU's display – "E5," which was later to become highly significant.

The conclusion of this test, from the manufacturer's point of view was that the Chinook engine had successively demonstrated the requirements of the test specification. The report went on: "Various functional and design problems were exhibited by the FADEC control system. Each of these problems and its cause has been identified, corrected and tested."

Three of the "significant" fault codes found in the 1988 RAF test of the FADEC system – A7, F3 and E5 - would reappear on the display of a DECU in the fatal crash of the Chinook Mk2 on the Mull of Kintyre in June 1994.

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RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

Ministers and the Ministry of Defence have stated repeatedly that the FADEC software was not safety critical. They have said this to point out that any failures of the FADEC could not cause the loss of the helicopter or its occupants. A statement issued by the Ministry this year said:

"As far as safety criticality is concerned, Dr Reid made it clear that the FADEC system is not safety critical as defined in UK standards. This is because the Chinook has two engines, each FADEC equipped. If one engine failed, the aircraft could fly safely on a single engine. The likelihood of a double engine failure is remote. However, if both FADECs did fail, the aircraft is designed to glide down to the ground in a controlled manner."

But the FADEC ***was*** a safety critical system according to a document written in 1987 by Chandlers Evans which said that some unlikely failures could have a "catastrophic effect" on the safety of the aircraft. These potentially catastrophic failures did not relate to a single or double engine failure, as the Mod's statement referred to, but the threat of an engine overspeed – which the Ministry did not warn MPs about.

The disclosure of the safety criticality of the system is contained in a document headed "Failure Mode Effect and Criticality Analysis" which is standard assessment carried on safety-critical software to prioritize the severity of certain failures.

The analysis said that the "potential for a category 1 (catastrophic) failure mode exists within the boundary of the system under analysis." Two double, simultaneous failures were said to cause such a danger. "... the first possibility involves the transference of incorrect data" which, in certain circumstances "could cause an unlimited runaway upwards or downwards from one engine control system..." This could happen if the other engine has a undetected failure which would "permit such an occurrence."

The second possibility involves that of an undetected failure in a system which could "cause it to go into an unlimited runaway up or run down condition ..."

It adds: "Either possibility is extremely remote viz. in the order one per 10,000 million per flying hour."

Catastrophic was defined in the documents as causing death or severe injury of personnel or system loss."

The extremely remote possibility of a dangerous engine overrun was again recognised in 1988 in a number of reports.

And then it happened.

On January 20 1989, during a full ground test of a Chinook which had recently been fitted with a new FADEC system, there was a rotor overspeed which caused millions of pounds worth of damage to an RAF Chinook.

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Exactly the same set of circumstances that caused the January 1989 incident was highlighted at meeting in July 1986 of Chandler Evans. Concern was shown about "the loss of two rotor speed sensors signals being a soft fault."

In the terminology of FADEC systems, a soft fault is a less serious problem than hard fault. The majority of potential faults are classified by the manufacturers as soft faults. One engineer at Chandler Evans thought that the loss of two sensors - which could led to an engine overrun – should be classified as a hard fault.

No decision on how to classify the loss of the two sensors was taken at the meeting. It was unclear whether the problem was ever uprated to a "hard" fault.

The importance of the two speed sensors was explained in documents filed by the UK government against the contractors of the FADEC system.

"One of the major operating parameters of a helicopter engine is the rotation speed of its power turbine." This is given the term 'N2.'

"N2 is a piece of information that is critical in the operation of the FADEC. The power turbine is directly connected to the aircraft's rotors and thus N2 determines rotor speed.

Unless the FADEC "knows" how fast the rotors are turning, it cannot increase or decrease the flow of fuel to the engine to enable the rotors to remain at their optimum speed.

"When N2 drops below the level needed to meet the pilot's demands for speed and power, the function of the FADEC is to increase the fuel flow. If N2 is too high the FADEC decreases the fuel flow."

Such was the importance of the N2 signal that Lycoming designed the system so that N2 is measured by two separate input sensors, which are called N2a and N2b.

The ides is that if one sensor fails the FADEC will still know how fast the rotor is going, and therefore will continue to call for the correct amount of fuel.

For extra safety, the signals from the two sensors were sent to the DECU via two separate cables. The DECU then processed the two signals and computed the amount of fuel.

If all the protections in the DECU's primary and reversionary lanes failed to prevent an overspeed, the system also contained an overspeed limiter. The device was designed to detect an N2 which was higher than anything likely to be encountered under normal conditions.

So if N2 went over a pre-determined level the limiter would run down the engine to idle very quickly.

There was another protection in the system. Normally the two N2 sensors would be expected to send very similar or identical readings to the DECU, since both sensors register the same thing: the power turbine speed of the engine. What if the one of the two sensors which measured the N2 rotor speed was faulty and gave a false reading? Which sensor would the DECU take as the correct one?

The issue was an important one. If the DECU took a wrong N2 reading, it might think that the rotors were going faster or slower than they were actually rotating. If that happened, the FADEC system might try to compensate by delivering too little or too much fuel to the engine.

So the DECU was programmed to look for any difference of more than five per cent in the signals from the two N2 sensors. If it detected that there was a difference, the DECU software was programmed to select the higher of the two signals. At the same time it would "latch out" the lower of the two signals, so that the lower signal was no longer received by, or available to, the DECU.

When this happened the DECU would display a special fault code: "E5." It meant that that the DECU had "seen" a difference of more than five per cent in the two N2 speed sensors and had "latched out" one of the signals.

The problem that had not been considered sufficiently at this time was this: What if both N2 sensors were knocked out at the same time? For example the existence of the "E5" code meant that the DECU was "seeing" only one of the two sensors. What if that one active sensor then ceased to work?

The manufacturers would soon find out, a discovery which would lead to a legal case between their insurers and the Ministry of Defence.

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The key to the problem of an engine overspeed accident in 1989 was the fault code "E5." When the code appeared on the display of the FADEC's DECU system, it indicated to aircraft operators or maintenance staff that the DECU had locked out one of the two N2 sensors because of a difference of more than 5% in their readings.

What proved disastrous was that the FADEC was incorrectly programmed to interpret the loss of both N2 sensors as a complete loss of engine speed. Therefore the FADEC thought that, as there was no indication at all of any rotor speed, it should pump maximum fuel into the engines to bring up the speed of the rotors... but actually the rotors were working normally, so the sudden influx of fuel caused the rotors to turn dangerously fast. As mentioned before, an overspeed is potentially perilous on a helicopter because the rotors could fly off.

A fail-safe design should have stopped a rotor overspeed even in the event that a maximum flow of fuel was given to the engines... but the fail-safe system did not work properly.

Back in 1984 before development work was fully underway, Chandler Evans, in its FADEC proposal to the Mod dated March 1984 had commented that a failure of the digital circuits contributing to an "unprotected runaway," had a failure rate of less than one event in 100,000,000 hours of engine operation.

The problem that would actually occur, however, would not be a failure of the digital circuits but a faulty system design.

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When the crew and test engineers arrived at Boeing's Flight Test Facility at Wilmington, Delaware, USA, on 13 January 1989 to assess the performance of the new version of the Chinook equipped with FADEC, they had little idea of how the computer systems would behave if both speed sensors were lost.

Three months before the test, a Chinook belonging to the Ministry of Defence had been flown to Wilmington for the installation of the new FADEC.

During the first week of testing of a Chinook on the ground, the participants noticed that the DECU frequently displayed an unexplained and unpredicted fault code - E5. Most of the participants were not to know that E5 faults had occurred during tests the year before.

In most instances E5 was shown during engine start up, even after an engine had been shut down and its DECU reset.

In a period of seven test days, 15 fault codes were logged. Of these seven were E5 faults.

On the morning of 20 January, a briefing was held to discuss what would happen during that day's testing of the Chinook engines and FADEC.

From Boeing there was a test pilot, a test director, a director of flight operations, a co-test pilot and three engineers. Chandler Evans provided a highly experienced systems engineer and there was a sergeant from the RAF.

It was agreed to make a "major" change to the test plan, to allow two engine starts and shutdowns. This was requested by Chandler Evans and Boeing's test co-pilot to clear the DECU fault indications. The engine starts were requested because of the recurring 'E5' fault codes on the DECU during previous tests.

The test plan called for one of the cables carrying the N2b speed signal to be disconnected, partly to simulate the effects of small arms fire. The aim was also to validate Lycoming's design of the FADEC that required the continued safe operation of the aircraft with one of the main cables disconnected.

Although the purpose of shutting down the engines and turning off the power was to clear and reset the DECU displays, the logs of the final test of the helicopter show that after both engines were powered up for the last time, an E5 fault was displayed in the DECU of engine number one. For some reason, engine start-up seemed to be "latching out" one of the N2 sensors, triggering the E5 code.

So, on the last test, the DECU was reading only one of the two speed sensors. For a disaster to occur, all it needed was for someone to disconnect a main cable which contained this remaining sensor's signal.

RAF documents show what happened.

At 0900 hours on January 20 the RAF sergeant boarded the test aircraft. At the correct time he was to instruct the Boeing electrician to disconnect a main cable as required by the test schedule. The RAF representative was acting as an intermediary in relaying the instruction because the electrician did not have a headset with intercom.

A Boeing fire truck was in position about 100 yards from the aircraft. Also standing by was an Instrumentation Ground Station which was due to receive data test by telemetry.

After the initial tests, it was declared that both DECUs had been reset and were displaying '88,' an indication that they were not registering any faults.

When the connector carrying the N2b signal was disconnected, the RAF sergeant heard the engine noise increasing. He was also aware of an increasing whine from the transmission system. "I looked out of the back of the aircraft, over the open ramp and saw a slight raising of the rear of the aircraft."

Meanwhile the flight test crew chief from Boeing heard one of the pilots say words to the effect of "It's going out of control." He said there were violent vibrations but no particular noise.

Due to a previous test where there had been a significant torque split – a mismatch in power between the Chinook's two engines – an engineer from Boeing was closely monitoring the torquemeter. When the cable carrying the one remaining N2 speed sensor was disconnected, he saw a torque split developing and called "torque split." He observed the No 1 engine's torque rising above its 100% level. He also noticed an increase in the Chinook's transmission noise.

"My attention was then directed to the aircraft's nose rising from the ground and becoming light on the landing gear." This was despite the fact that the helicopter had been loaded with three 1000-pound ballast pallets.

An aircraft tractor had also been secured to the aircraft with chains.

For safety's sake the captain lowered the collective lever to a level which stopped the rotors from giving any lift.

The engine control levers, which helped to provide a step-control to engine power, had already been turned to stop. But this had no effect on the gas generator speed or the torque on one of the engines which was now about 120%, compared to the normal maximum of 100%.

By the time the rotor speed reached 130% the civilian from Chandler Evans stopped monitoring his displays and "took a crouching position alongside the instrumentation station." Eventually the rotor speed reached 142%, at which time the pilots faced what was later described in an RAF inquiry as an "unexpected, rapidly developing and alarming situation." The captain and the co-pilot then took one of the only options open to them. Not knowing which engine was running away, the co-pilot decided to pull both of the Emergency Engine Fuel Cut Off Levers, known as the "T" handles. This is not a recommended action during a flight.

The RAF sergeant and the electrician remained in position but a Boeing engineer had already decided to leave the aircraft via the open ramp, to check the rear of the aircraft. He saw the engines were vibrating laterally on their mountings.

When starved of fuel, the engines shut down. Initially, apart from the oil on the windscreen, there was no visible evidence of any damage. But the Chinook had to be rebuilt because of the stress imposed on the components and equipment during the overspeed. Since a helicopter loaned by the Ministry of Defence to Boeing had been, in effect, destroyed, the Mod found itself out of pocket to the tune of more than $5m, taking all costs into account. But the matter did not end there.

The controversy over the design of the FADEC system had only begun.

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Mentioned almost unnoticeably in the documents which described the 1989 incident was a reference to the fact that, during the overpeed, there had been a rapid acceleration of the torque needle. The pilot reported that it had been about 70% while the other needle [for the second engine] was at zero.

Five years later the Chinook which crashed on the Mull of Kintyre would show a torque mismatch on its instrument readings. But in the Mull of Kintyre crash in 1994, investigators were unable to check the functioning of the torquemeters. They considered that the read-outs found in the wreckage which indicated a torque mismatch between the engines may have been altered by the impact. In any case the investigators did not consider the torquemeters to be significant. "Testing of the torquemeters and triple tachometers could not be attempted because of lack of facilities but their functionality was dubious and testing was not considered critical."

However the investigators in 1994 would not be given access to the full history of the problems with the FADEC during its development. Nor would the investigators be given details of the 1989 incident in which the Chinook was almost destroyed during the FADEC test. This meant that the investigators in 1994 had no idea about the significance of the 'E5' fault code which had played a central part in the Chinook accident in 1989.

Also at the Defence Committee Reid told the House of Commons that the Fatal Accident Inquiry, set up in Scotland to investigate the Mull of Kintyre crash, was not told of the 1989 accident because it was considered "irrelevant."

After all, the investigators of the Mull of Kintyre crash had concluded that there was no evidence of a technical malfunction capable of causing the accident.

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After the engine runaway in January 1989, a Boeing flight engineer who had been monitoring the accident from a data acquisition ground station bear the helicopter, went to recover all the data from the incident.

A telemetry tape had not recorded good data. He asked for the on-board test data to be played but this yielded no sensible data. "I was later advised that all analogue data had been lost." The only data available was on rotor speed and fuel flow. The Boeing engineer added: "To date we have been unable to reproduce the cause of this analogue instrumentation failure."

Most of the data that would have shown how the instrumentation, the FADEC and the helicopter had performed during the engine overspeed was lost.

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The first recommendation of the RAF inquiry into the 1989 accident was that:

> "Before any further FADEC testing takes place on the aircraft, a full appraisal of the FADEC system design be carried out by the contractors; this activity should be closely monitored by DHP [Director of Helicopter Projects at the Ministry of Defence].

The RAF inquiry had learned that, during the design and early development of the Chinook's FADEC, the contractors had identified the loss of either of the two speed sensors as a "negligible" problem; that is one which "will not result in personal injury, occupational illness of system damage." However the analysis went on to assess the loss of both sensors as a Hazard Class One; that is catastrophic. However it said that the likelihood of this occurring was "remote." The meaning of remote in this context was an "occurrence so unlikely that this hazard will probably not be experienced."

A later analysis by Chandler Evans would categorise the 'E5' indication on the DECU as a soft fault, with no operational effect on the FADEC and requiring no pilot action. Yet it was the presence of the E5 code, which showed that a signal from one of the sensors had been latched out, together with the disconnection of the "P3" cable containing the one remaining sensor, which had caused the overspeed.

The inquiry criticised an analysis by the contractors which had not considered the simultaneous E5 fault condition and a disconnection of the PL3 cable.

It said that the Chandler Evans closed-loop test, simulating this degraded mode and done without the E5 fault, gave a false sense of security. "In this totally unexpected and unpredicted situation the instinctive actions of both pilots were aimed at keeping the aircraft in contact with the ground and shutting down the engines. It is noticeable that neither pilot was aware of which engine had runaway up..."

One of the few clear indications of an engine runaway had been the torquemeter ... the same instrument that the Air Accidents Investigation Branch, when investigating the crash of ZD576, did not check because it was "not considered critical."

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In their own investigations into the 1989 incident, Lycoming, Chandler Evans, Hawker Siddeley and Boeing agreed that the FADEC did not handle adequately the loss of both N2 sensor inputs. They added that there had been an "ambiguity in interpretation of system requirements."

It was agreed that there would be a correction to the fault logic in the FADEC so that, if an "E5" fault code indicated that one of the N2 sensors was latched out and the other sensor was then lost for any reason, then the software would re-acquire the original sensor's signal.

This modification was important. The problem before was that the FADEC had interpreted the loss of both speed signals as no signal at all, and had wrongly assumed that the engine had run down. To compensate for this, and force the engines back to what the FADEC thought was their required speed, the system had called for maximum fuel which caused the overspeed. With the modification, the DECU would now always receive at least one speed signal and so would "know" how fast the engine was going.

A post-incident analysis by Lycoming did not explain why the DECU had, in the accident, called for maximum power, rather than the fuel control fail in a frozen position. In the Mod requirements, the FADEC was supposed to have a "failure accommodation capability." This would enable the system to accommodate the loss of at least one sensor ..." And in the event of a serious failure, the system should freeze the fuel controls at a safe, constant level rather than allow an engine runaway.

But in the January 20 incident, the fuel control had not frozen in a safe position ... and the problem with E5 fault codes appearing on the DECU continued.

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Textron Lycoming disclosed in 1989 that it had decided not to comply fully with a request from Boeing.

"Textron-Lycoming has conducted an assessment of the points made by Boeing Helicopters and the Chandler Evans analysis. Our conclusion is that the detailed analysis recommended by Boeing Helicopters cannot be justified, although some limited fault analysis may be beneficial."

The same document also referred to the actions taken since the overspeed incident in 1989. It described: "actions since the overspeed incident" and said that "software changes are being introduced to correct the speed signal logic..."

A Textron paper went on to draw attention to the fact that Boeing had raised a variety of issues with the FADEC's design that were of "potentially safety critical" relevance and should be included in various forms of analyses including what was called a "fault tree" analysis. But a Textron Lycoming memo in March 1989 said: "If Fault Tree analysis is required at all ... the bounded analysis recommended by Chandler Evans should ... be the most cost effective approach at this point in the FADEC development."

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By mid-1989, four years after the original contract for the FADEC had been signed, there had been no formal testing of the complete software by the RAF, though there had been testing of individual modules. Originally the contractors had anticipated that the system would be in production within two years of the go-ahead.

By May 1989, not all the problems had been solved. A letter from Chandler Evans to its subcontractor Hawker Siddeley on 24 May says that during testing of the latest software configuration "we have recently experienced hard [the most serious type of] faults ... This is an extremely critical item which could jeopardize continuation of the flight test program, and it needs immediate attention... we feel that it will be necessary for Hawker Siddeley software engineers to visit Chander Evans and work with our systems engineers to establish a short term solution for flight test units.

"As mentioned earlier, more extensive fixes are required for production. You will appreciate that these items require considerably more effort in the next few months than appear to be included in your current plans."

By this time the US Army had expressed considerable interest in the UK's pioneering of the FADEC system and was considering whether to make the same enhancements to its Chinook fleet. A test was soon to take place to qualify a new Lycoming engine equipped with FADEC for the US Army.

However Textron Lycoming, the manufacturers of the Chinook engines, wrote to Chandler Evans on 1 May 1989, expressing concern about the FADEC.

"I am optimistic about the RAF FADEC Program despite recent setbacks and expect to start production negotiations (preliminary) in the May/June timeframe.

"I must however express my (our) concern about the FADEC DECU. We are about to start a 150 hour endurance test to qualify the [US] Army's T55-L-714 [engine with FADEC]."

The letter added that the "eyes of the world" including "Boeing/RAF/MOD (PE) [Procurement Executive] will be focusing on FADEC." In a possible reference to the 1989 accident at Wilmington it went on: "We absolutely cannot afford another problem if we are to retain FADEC's technical credibility."

Although the results of an audit of the Hawker Siddeley software "indicate some obvious improvement" the letter said that the Ministry of Defence remains generally unsatisfied ... I hope you will transfer the concerns expressed into appropriate corrective action and thus clear up any remaining customer concerns about FADEC software. Thank you for your continued cooperation in achieving our mutual business objectives."

There was a further problem ... the FADEC's documentation.

In safety critical software the documentation is regarded as critical because it lays out what the software is supposed to do.

It also indicates whether the software is performing in a way it is not supposed to do. One of the agreed standards to which the FADEC system was written was Joint Services Publication 188 (JSP 188). This is the standard, issued by the Ministry of Defence, that defines the requirements for the documentation of software in military operational real-time computer systems. The third edition of the standard was incorporated into Textron-Lycoming's contract with the Ministry.

The JSP 188 standard states:

> "The aim of documentation produced for JSP 188 shall be to provide a thorough in-depth understanding of the operational system program(s).
>
> "The software documentation shall be presented as a single entity ..."

It was later claimed by the Mod in its legal case against the contractors that the "computer software was not adequately documented" at the time of the accident. The Mod said that "despite being certified by Lycoming," the documentation "had not been properly prepared and had not been verified by Lycoming." As a result, at the time of the incident "there was no way for a reviewer or tester to determine whether the FADEC was safe – other than to use it and see what happened. When Lycoming attempted to do just that, the consequences were catastrophic."

Later, in 1998, Reid's account of the 1989 Wilmington accident was that it was caused by negligence in the test, rather than any defects in the design of the FADEC.

"It was not – I repeat it was not – on account of the failure of the software."

His remark was contrary to the case papers filed by the "Government of the United Kingdom of Great Britain and North Ireland" in support of its claim against Textron Lycoming over the 1989 accident. The UK government's case, to use the written statements of its own specialists and the Procurement Executive, was that:

> " ... Textron failed to design the FADEC system so as to protect against the potential adverse consequences of disconnection of the PL3 connector in the context of an "E5" fault situation."
>
> "In the design, development, manufacture and testing of the FADEC system, Textron was negligent." And further that the "FADEC system provided by Textron failed to provide adequate overspeed protections required under the contract and Specification R-1209."
>
> "The FADEC system, in short, was constructed by Textron in such a way that the loss of both N2 signals would cause a catastrophic engine runaway, unless the flow of fuel to the engine were somehow reduced."
>
> "The FADEC failed under expected circumstances."
>
> "The computer software was not adequately documented."
>
> "The Subsystem hazard analysis was inadequate"
>
> "Flaws disclosed in the development tests were not properly analysed or remedied."

> "having initially claimed that the design project presented very low technical risk and that the project would be based on existing technology, Lycoming followed a high-risk design strategy that relied on unproven software as the only significant guard against catastrophe
>
> There was also the "deletion of an engine shut-down capability independent of the software."
>
> "The almost total reliance of the Lycoming-designed FADEC on the DECU software for engine and aircraft safety constituted a flawed system design."

Lest there still be any doubt that the British government, contrary to what Reid told MPs, believed that the cause of the 1989 accident lay in the design of the FADEC rather than testing procedures, a letter was sent by the British Defence Staff at the British Embassy in Washington to the Vice President of Military Engine Programs at Textron Lycoming on 16 March 1990.

It made a formal claim for compensation over the accident and said: "We have concluded that Textron was negligent, and failed to use the care and skill contractually required of it, in the design and testing of the FADEC system."

Also the legal case papers, filed by the UK government in the US, said unequivocally that the 1989 accident was due to a "design flaw in the N2 software logic" of the FADEC.

"If Lycoming had properly responded to information that it had, or ought to have had, it would have corrected the flaw before it caused damage."

Yet Reid, in television interviews and before MPs in the House of Commons repeatedly told MPs, sometimes with some force in his voice, that the 1989 accident happened because of the negligent way the test at Wilmington had been carried out.

Reid told the Commons Defence Committee in March 1998: "We sued them for negligence in their testing procedures. We did not sue them because of a failure of the FADEC software. This is one of the misconceptions that has been unfortunately allowed to flourish... the case was essentially against Boeing and Textron Lycoming for negligence in their testing procedures, not against the software. I hope that is a full answer and I hope that clarifies things."

It did not clarify things. As has been shown, Reid's answer was wrong.

Reid's assertion about the negligence in testing procedures was not an allegation which materialised out of thin air. It was the position adopted by Textron's insurers as they sought to fight the UK's government's case. It was the argument advanced by the United States Aviation Underwriters, insurers for Textron-Lycoming.

In denying the UK government's claim for compensation in respect of the 1989 accident, the underwriters said:

"Our investigation has revealed that the overspeed incident resulted from an intentionally induced dual point failure. This failure involved an "E5" difference fault followed by the disconnection of the PL3 connector. This dual point failure was never contemplated by the contract between Textron Lycoming and the Mod, and was clearly outside the scope of the approved test plan."

The letter from the underwriters continued... "it was a dual point failure, testing for which was not contemplated by the contract for the development of FADEC. The requirements of Specification 1209 paragraph 11.1 do not address dual point failures ... prior to ground testing all contractually required analyses and simulations were conducted fully and properly..."

But Textron lost the arbitration hearing and in November 1995 it paid the UK government just over $3m in compensation.

Therefore Reid, in answering MPs questions, had taken the position adopted by Textron. This is despite the fact that the Mod won its case against Textron by proving that it was the FADEC software which was at fault, not negligence in the testing procedures.

Why had Reid put up such a assertive defence of the FADEC system by giving MPs the line taken by the suppliers, rather than that of its own technical specialists?

It would not be the only occasion he would do so. In answering other questions from MPs Reid stated as the UK government's position the views of the FADEC's contractors, even when those opinions were at odds with those which had been expressed in writing within the Ministry of Defence.

That Reid may have been inadequately briefed is given some credence by the fact that he does not appear to have been told that, a month following the 1989 incident, a joint team of Lycoming, Chandler Evans, Hawker Siddeley and Boeing met and agreed to a series of measures to correct the FADEC in response to the accident.

The meeting had been shown a chart that was headed:

Royal Air Force FADEC program – Corrective Action.

The chart recorded chronologically the series of events. It said the accident had happened in January, that there was an investigation in February, followed by a:

- system specification review
- an update of the FADEC Failure Modes Effects and Criticality Analysis
- a software requirement update
- a hardware review
- a plan to implement software changes
- a plan to test the changes and
- a plan to define long-term changes in terms of hardware and software.

Lycoming itself had identified a failure in the design of the FADEC software as the main cause of the 1989 accident. On 6 March 1989, two months after the incident, it issued a Systems Specification Change Request which said:

Reason For Change (Problem):

Rotor overspeed incident during flight test caused by error in speed select logic.

Seven years after the overspeed accident, a Fatal Accident Inquiry in Scotland into the Mull of Kintyre crash spent a considerable amount of time days studying the FADEC system of the Chinook. It was told of the 1989 accident. The Defence Committee asked Reid why. Reid replied:

> "For reasons which will be obvious from what I have said, that it was essentially about negligence in testing procedures and not with the software, it was not regarded as highly relevant to the inquiry."

He was asked again and Reid made his point clearer.

> "There was certainly a reference to the FADEC at the Fatal Accident Inquiry, I would take advice as to whether there was specific reference to the court case [over the 1989 accident]. I do not think there was but since it was actually referring to specific negligent practices in testing, rather than the intrinsic quality or reliability of the system, it is not immediately obvious to me why it should have been in any way relevant to the inquiry."

* * * * *

It was also odd that the Mod and its software specialists at the Aeroplane and Armament Experimental Establishment at Boscombe Down in England continued regularly to express concern about the FADEC software ... until a few days after the Mull of Kintyre crash. Then the pungency of the Ministry's criticism began to lose its edge.

From that point onwards, whenever parliamentary questions would be asked about the Chinook's FADEC, ministerial replies displayed a mixture of surprise at the critical tone of the questioner and bewilderment that anyone should consider the system to be in any way relevant to the crash.

At the Fatal Accident Inquiry into the Mull of Kintyre crash, the expert who was called to give evidence on the FADEC, was an independently-minded investigator at the Air Accidents Investigation Branch who sought to be as helpful as his knowledge would allow.

However he was not a helicopter specialist. Neither was he someone who had an exhaustive knowledge of the FADEC, a point he was willing to concede when he said that his understanding was too limited to answer many of the questions at the inquiry.

One such question was whether he knew what the fault indication "E5" stood for, as the code had been found on the computer display of the one DECU which survived the 1994 crash. "No I don't. Offhand no," said the investigator.

The most able FADEC adviser to the accident investigator would have been Malcolm Perks. He worked for Rolls-Royce where he supervised the design and development of the first digital control for the Rolls-Royce Gem 43 engine.

From 1998 through 1994 he was head of Head of technology at Rolls-Royce Aerospace Group and later head of Unit Engineering for Control Systems during the development of a FADEC system for large-engine aircraft such as the Airbus A330 and Boeing 777.

At the time of the Fatal Accident Inquiry, Perks was acting as the Mod's chosen FADEC expert in the Ministry's case against Textron Lycoming, which is the manufacturer of the Chinook's engines and engine control system.

Yet Perks was not asked to help the investigators at the Air Accidents Investigation Branch. He was not asked to give any evidence to the RAF Board of Inquiry or the Scottish Fatal Accident Inquiry.

At that time, neither the inquiry judge, nor the families of the dead pilots knew of Perks' existence.

Retired Squadron Leader Robert Burke, the senior RAF Odiham unit test pilot, who at the time of the Fatal Accident Inquiry was, from a pilot's perspective, unusually knowledgeable about the DECUs, and had experienced two engine runaways on the FADEC-equipped Chinook, says he was specifically ordered not to take part in the inquiry.

Why was the Mod apparently going out of its way to reduce the odds against discovery of information about the real problems with FADEC?

The 1989 accident showed that a faulty design of the FADEC could endanger the aircraft and its occupants. The problems immediately before the crash of ZD576 had shown that the Chinook in early 1994 was still prone to overspeeds and FADEC-related incidents.

If the full extent of the FADEC's problems became generally known, people would then have started to ask why the cream of Northern Ireland's intelligence community, and a special forces aircrew, had lost their lives in a newly-modernised helicopter that was not demonstrably safe ... and perhaps should not have been allowed to fly at that time.

Perhaps this is why details of the 1989 accident were kept from accident investigators, and the Scottish Fatal Accident Inquiry.

Chapter Four

Summary of Chapter Four

THE PROBLEMS WITH ZD576 IN THE WEEKS BEFORE ITS LAST FLIGHT

By 1990 FADEC systems were being used increasingly in large aircraft because of their reliability, ease of maintenance and the ability to lower costs while making life in the cockpit easier for pilots. But they were not always without fault.

Between 6 October 1989 and 19 February 1990, British Airways 747-400 jumbo jets had experienced uncommanded in-flight closure of all four throttles on six separate flights.

On one of the flights it had happened several times. Several other airlines had suffered the same problems including Northwest.

It was found that the problem was caused by what was described as a "spurious signal to the FADEC" from a module which handled the management of stalls. The spurious one-word command resulted in the system closing down the throttles to reduce speed.

Yet the loss of power usually occurred when the 747 was climbing or at cruise altitude.

Boeing discovered that the problem was caused by the over-sensitive logic of the system and modified the software to read an eight-word command before acting.

Five years later, after the Mull of Kintyre crash, the fault codes found in the surviving DECU would all be said to relate to minor or "spurious" signals ... but as the pilots of the afflicted Boeing 747-400s had discovered spurious signals in the context of a FADEC system are not always harmless.

* * * * *

Ministry of Defence documents show that, between 1989 and 1994, there were series of disagreements between the Chinook's engine and engine systems contractor Textron and the specialists who were appointed by the Ministry to assess the quality of the FADEC's software.

In 1989 it had been the Ministry's position that the FADEC "lacked airworthiness."

There were still serious criticisms of the FADEC in the run-up to the crash on the Mull of Kintyre. Most of the concerns were expressed by the Aeroplane and Armament Experimental Establishment (A&AEE), the Ministry of Defence's airworthiness and aviation software advisers, based at Boscombe Down, Wiltshire.

However when, in 1998, the then defence minister Dr John Reid came before the House of Commons Defence Committee, he gave answers which disparaged the views of the A&AEE.

For example an issue would arise over whether the FADEC software had been written in a way which made it amenable to independent verification. Reid faced questions about this at the Defence Committee by, among others, Menzies Campbell who asked:

"As a layman, you are telling the Committee, I think, that an up-grade of an existing aircraft is flying with software in relation to the FADEC system which cannot be validated?

Reid replied:

"No, cannot be validated by Boscombe Down; scientists in that section of Boscombe Down."

Also at the same committee hearing in 1998, a Ministry of Defence official, Colonel Barry Hodgkiss showed little support for the position that the A&AEE had adopted over the FADEC software prior to the crash on the Mull of Kintyre. The colonel told MPs:

" ... the software was designed under an internationally agreed code of practice which is used by the Civil Aviation Authority as well as, as the minister has stated, the Federal Aviation Authority. It is the international standard code and it is that to which the Chinook FADEC software is designed and built and tested. It has satisfied all these tests.

"All it has not satisfied is an internally-imposed test procedure which Boscombe Down believe they should apply ..."

However in a memo dated 3 June 1994, a day after the Mull of Kintyre crash, the A&AEE argued that the software did ***not*** meet the international standard for aviation software RTCA Do. 178A although Textron had repeatedly insisted that it did.

In the same memo, the A&AEE also alleged that the software documentation did not meet the Ministry of Defence's JSP 188 standard for software in military real-time systems.

The memo, written by the Electronic Assessment Section (EAS) at Boscombe Down said:

> "EAS do not agree that the ... software meets the requirements of JSP188, the documentation standards for this level of software. The traceability study of the documentation revealed inconsistencies such as requirements not being implemented and conversely things appearing in the code which did not appear in the requirements ... This does not meet the requirements of JSP 188."

Textron, the FADEC's contractor, insisted that the software did meet the international standards. ***So Colonel Hodgkiss, in evidence to the Defence Committee, appeared to be siding with the contractors over the opinions that had been expressed by the Ministry's own software and airworthiness assessors, the A&AEE.***

It would later transpire that it was not only the A&AEE that had expressed concerns about the FADEC software. A senior official working for the Ministry of Defence's Procurement Executive revealed in a memo that, in relation to the Chinook's FADEC, there were safety case issues outstanding. His memo was dated a few weeks before the crash.

MPs at last year's Defence Committee hearing were not told or given any inking that concern was being expressed at this level.

* * * * *

The Aerospace and Armament Experimental Establishment is not, by history, tradition or recruitment practice a home for tetchy, caviling, noncomfomist malcontents.

Its pedigree as a centre of excellence for testing aircraft, equipment and weapons systems can be traced back to 1914. It was not known as the A&AEE until 1924 and today it is part of the Defence Research Evaluation Agency.

It was at the outbreak of World War Two that the A&AEE moved to Boscombe Down near Amesbury in Wiltshire. The site has an airfield which was extended and improved in February 1940. Much innovative aviation development work was carried out at Boscombe Down during the Second World War where it also served to test RAF fighter aircraft.

Since then the A&AEE has built up a worldwide reputation for its evaluations. But it had no final say over whether the Chinook should be given a Certificate of Airworthiness. It could only make recommendations.

The way the certification process works, in theory, is that the RAF can release into service an airplane with one wing if it believes there is an operational need to do so.

The formal process is that a Controller Aircraft Release notice is issued by the Controller Aircraft to the Service Department stating that a new type or mark of an aircraft or aircraft weapon system has been developed to a stage that is suitable for use by service aircrews.

The release document forms the basis of the formal release of the aircraft of weapon system for Service use and is prepared by the Controller Aircraft in conjunction with the relevant Operational Requirements and Service branches.

When all the trials and demonstrations indicate that the aircraft has achieved a "suitable" standard of airworthiness the Controller Aircraft will issue the initial release. Responsibility for this lies with the Ministry of Defence Procurement Executive.

In the case of the Chinook, it was returned to Boeing for a mid-life update to be equipped with FADEC and other enhancements. The first aircraft were sent for trials at the A&AEE. Its job was to provide recommendations for a release.

In the event, the A&AEE studied the Chinook's FADEC software in detail, and a separate, independent report was commissioned from EDS-Scicon, one of the world's largest military IT companies.

To the disgust of some senior officers in the RAF, a disgust which was expressed in writing internally, A&AEE said it regarded a re-write of the software in a verifiable form to be essential prior to them recommending a CA release.

However the Chinook project director took advice from several other sources. His "reasoned" view was that a release could be issued. This release was subject to a weight restriction, so that if one engine failed because of a FADEC malfunction, the Chinook would still be light enough to fly out of trouble using the one remaining engine.

However the weight restriction did nothing to address the problem of a series of malfunctions, spurious warnings, or even an overspeed which could almost destroy the Chinook Mk2 as the Mod and Boeing had discovered in 1989.

Also the restriction assumed that if the FADEC failed, it would fail in a predictable way and cause the engine to run down. However the 1989 accident highlighted the fact that the FADEC could be defective in a way which had not been predicted. The 1989 incident was caused not by a failure of the software, but a flaw in the logic of its design. The software did what it was programmed to do, and still the aircraft was destroyed.

Despite the continuing concerns of the A&AEE, the new FADEC-equipped version of the Chinook was given permission for operational service by the RAF in conjunction with the Ministry of Defence's Procurement Executive in November 1993. This was before the A&AEE at Boscombe Down in Wiltshire was able to give a positive and unqualified recommendation that the aircraft be released for operational service.

* * * * *

None of the assessments of the FADEC system conducted by the A&AEE in the run up to the crash on the Mull of Kintyre crash was ever published, but they have become available.

The FADEC software reviewed by A&AEE included what it called a "very large number of errors found in the code."

Following the review by the A&AEE, EDS-Scicon was commissioned to produce an independent report. If senior officials in the Ministry of Defence had hoped that, being independent of the A&AEE at Boscombe Down, EDS-Scicon would give the FADEC software the all-clear, they were due to be disappointed.

EDS was so concerned about the results of its work, and the density of anomalies found that it produced a report after reading less than 20% of the code.

And, rather than wait until completing its assessment, EDS-Scicon sent to the contractors Hawker Siddeley what was described in the report as "urgent requests for help on anomalies, which might have safety implications."

Later, in January 1998, Reid wrote to an MP Nicholas Soames saying that all the points raised by EDS had been "addressed in detail" by Hawker Siddeley. Reid's letter did not say that EDS had told the Ministry of Defence that the code needed a limited re-write.

* * * * *

The quality and accuracy of information given to MPs about the analysis of the FADEC code by EDS and A&AEE, ranged from ambiguous to inexplicable.

Reid told the House of Commons Defence Committee in 1998 that the problem with the code was that it could not be read using the automated tools which were preferred by A&AEE. "That is the problem we have," said Reid. "Their tools cannot apparently read this software."

He reinforced his statement by saying:

> " ... It is not ideal, I admit that, but it is not within my powers to say to Boscombe Down, "Please go and get something which can read this", because apparently, for reasons which are above my computer knowledge and probably anyone else around the Committee, they cannot read this particular piece of software which is used in a whole range of aeroplanes which are flying all around us all the time."

Colonel Hodgkiss made a similar point to MPs:

> "That is really the problem that Boscombe have, their tools are known as SPADE AND MALPAS and they are the two tools which will enable them to read the software, as the Minister has said. They are perfectly able to read the documentation of the software, but it is the software itself they cannot get into. Clearly there are many, many thousands of lines of code and without a software tool to get in there, they do not have the ability to read."

Another of Reid's answers to MPs at the Defence Committee went further.

> "My understanding of this, and I will let Barry [Hodgkiss] come in again, is that Boeing and Textron Lycoming could give them (A&AEE) a way of reading it but that is not the way that Boscombe Down want to read it. The way they want to read it and test it, they cannot do it."

It was true that the software was not amenable to being read using automated tools such as MALPAS AND SPADE. It was also true that the code, mostly in the Assembler computer language, was difficult to read.

But EDS and A&AEE were nevertheless able to read the code, and they did so.

Both organisations were able to write in detail on the results of their scrutiny of the code.

Textron-Lycoming, in its 51-page response to the issues raised by EDS and A&AEE noted that EDS-Scicon had been able to read the code. Textron also noted that EDS had read the code in "extreme detail" without help from Hawker Siddeley. Textron also observed that Boscombe had completed work on the primary lane and a substantial portion of the reversionary lane.

Incidentally, senior Mod officials had not expected this Textron-Lycoming document to come to public attention. When the then defence minister John Spellar was asked by Conservative MP Robert Key in December 1998 if he would place in the House of Commons library a copy of the Textron response to the points made by EDS and the A&AEE (called the Textron White Paper), Spellar replied:

> "The information provided by Textron Lycoming in their white paper is commercially confidential. Accordingly I am withholding the information requested under exemption 13 of the Code of Practice on Access to Government Information."

Yet the paper was widely circulated within the defence establishment, and had no security markings.

This raises the question of whether ministers were using an exemption to the Code of Practice on Access to Government Information to deny access to information which would question the accuracy of ministerial statements.

A month before Spellar's refusal to publish the White Paper he had asserted in a Parliamentary reply that EDS stopped work on the code because the software documentation was not amenable to "State (sic) Code Analysis."

* * * * *

Entitled T55 (the Chinook engine) Software Verification report – Final Report, EDS produced tables to show how much of the code it had read and the results, before it abandoned the work because of what one executive said was the "density" of the anomalies found.

EDS-Scicon had read 17.4% of the primary lane of the FADEC software before presenting its findings. It had read 19% of the code of FADEC's reversionary or back-up lane.

The EDS report said:

Total Number of Anomalies in Each Category

Category 1	Category 2	Category 3	Category 4
56	193	132	104

> "In a rigorously developed safety critical system which has been written according to a strict coding standard, the code can be expected to contain none, or very few category one anomalies and only a small number (in the order of tens) category two anomalies. The other types of anomalies are likely to be more common, although in a carefully developed system there ought not to be too many category three anomalies.
>
> "A category one anomaly indicates an actual coding error or non-compliance with the documentation. However this does not mean that it necessarily has any safety implications, it may not even affect the overall operation of the system. Each category one anomaly has to be investigated in this case ultimately by Hawker Siddeley to determine its impact on the system behaviour."
>
> "When a response from Hawker Siddeley indicates that an error does not have any safety impact or does not significantly affect the operation of the system, it should be emphasised that latent errors in the code may still have serious implications for future maintenance of the system."

EDS was pointing out that, when upgrades or enhancements are made to the software at a later date, any latent errors already in the code could cause problems, or even have unpredictable consequences.

The report continued:

> "Likewise category two anomalies need to be checked to ensure that the intended function is performed. Category two anomalies may not have any immediate effect on safety but they represent poor coding practice or poor correspondence between the code and the documentation and as such, may have serious implications for any future maintenance..."
>
> "Another effect of a large number of category one and two anomalies is to diminish their impact. On well written and documented code with few significant anomalies, each category one or 2 anomaly is viewed seriously and causes some concern. When there are hundreds of such anomalies the threshold of what is acceptable tends to be diminished by the presence of so many anomalies due to poor programming style and inadequate documentation ...

Despite the potential seriousness of the problems identified by EDS-Scicon in less than 20% of the code, a defence minister John Spellar commented in a Parliamentary answer on the EDS report by saying that "485 observations were made, but none were considered safety critical and most related to errors in the documentation."

Another defence minister Dr Reid wrote to an MP saying that "EDS identified a number of anomalies in the sense questions raised rather than faults identified."

But the EDS report did find faults. The A&AEE referred specifically in a memo dated 3 June 1994 to the "very large number of errors found in the code ... by EDS."

EDS gave a detailed commentary on its results. In keeping with other reports of this nature, where a consultancy was remarking on the work of a software house, the language used was as objectively free of blame as was possible in the circumstances. Even so it suggested that the problems were more fundamental than superficial.

The A&AEE supported EDS's findings and added that it had found the FADEC software "unacceptable."

In its 3 June 1994 memo, the A&AEE said:

> "Textron also claim that 70,000 hours of test were performed. It is believed that most of this testing was not done using the current production RAF version of the FADEC software which makes a large proportion of it irrelevant, and that which remains relevant has tested a truly miniscule fraction of the possible input conditions. The A&AEE found the software to be unacceptable."

* * * * *

In November 1993, four months after EDS's report, the Chinook Mk2 received its Controller Aircraft release. The Mod later explained why.

> "The RAF in conjunction with the Procurement Executive (of the Mod) took account of the US Army's experience both in ground testing and flight testing the FADEC and noted that no flight safety critical problems had been experienced. Therefore while the views of Boscombe Down were carefully considered, these were weighed against the flight safety criticality of the FADEC.
>
> In view of the fact that the Chinook has two engines, each fitted with FADEC, it was accepted that in the unlikely event of a FADEC failure in both primary and reversionary modes, the aircraft could still be flown safety on one engine. The likelihood of both engines being simultaneously afflicted with an incapacitating fault is infinitesimally small but even in the unlikely event that all power is lost, the Chinook is designed to descend in a controlled manner. With this mind the RAF and the Procurement Executive agreed that the Chinook Mk2 could be cleared for safe flight."

Arguably there were flaws in the statement:

- the statement mentioned the US's experience of FADEC but the US Army was buying a different FADEC-equipped engine than the one used by the RAF. The software for the US "T55-L-714" engine was not the same as the software on the RAF's T55-L-712 Chinook engine. Also, in the early 1990s, the US modified only a small number of its Chinooks to take the FADEC (and of these, one was lost in a fatal crash in 1996, the details of which the US has declined to release, even under the Freedom of Information Act).

-The assertion that no flight safety critical problems had been experienced did not take into account the failure of the system's fault logic in the 1989 accident in which a Chinook had nearly been destroyed.

-the statement made the assumption that if the FADEC went wrong, it would do so in a predictable way, causing an engine to run down. It also assumed that the FADEC would know that it had failed, or that its design logic was flawed. A more serious problem could be an engine overspeed such as the one which nearly destroyed the aircraft in 1989. Also investigators of air crashes point out that experience shows that serious accidents are usually the result of two or more simultaneous issues (as in the 1989 accident) rather than something relatively simple and transparent such as a single engine failure.

- International standards for the writing of safety-critical code recognise that systems cannot be validated in use without putting lives at risk, and even then latent design or programming faults may not materialise until many years later. Therefore the standards for ensuring software is safe put the emphasis, not on flight tests, but on regulatory authorities assessing the quality of the documentation, the way the code was written and the quality of the software testing. It was in these three key areas that either EDS or Boscombe Down, or both, had expressed particular concern. EDS had remarked that a hallmark of poorly developed code is a "large number of category one and two anomalies."

Taking the last point in isolation, there was evidence of doubts among regulators, in this case A&AEE, as to whether the code met international standards for safety-critical systems. And as compliance with those standards was arguably the only way of having confidence that a system was safe, should the FADEC-equipped Chinook have been certified as airworthy at that stage?

* * * * *

The Ministry of Defence issued a statement in 1998 which, among other things, gave the impression that EDS's concerns had been assuaged by Hawker Siddeley. The Mod statement quoted EDS as saying that "all 60 category one anomalies have been reviewed and mitigation solutions have been defined, none of which involves code changes, all have been agreed as feasible by Hawker Siddeley. Their review has raised only minor comments and points of clarification which, where appropriate, have bee included in the reports."

But the EDS quotation was taken out of context. The company's comments were made in the context of an ongoing analysis of the software and an exchange of views with Hawker Siddeley. The comments reflect Hawker Siddeley's opinion rather than that of EDS. A spokesman for EDS, when asked whether it had expressed satisfaction with the FADEC software said: "No, we did not say we were satisfied."

* * * * *

By December 1993, Squadron Leader Robert Burke, RAF Odiham's senior unit test pilot, was flying the Chinook Mk2, equipped with FADEC. He was not impressed.

He found that: "There were, and still are, very large numbers of DECU fault codes in the Chinook Mk2 caused by electrical power interrupts. In many cases these were caused by the Chinook's own electrical power system. This type of problem is typical of digital computing systems, and affects home PCs just like aircraft computing systems. This problem got so bad on the Chinook Mk2 at one stage that the operational squadrons had developed their own procedures to get round it."

He also found that as in the 1989 accident when the engine control lever failed to work, that "on several occasion the Engine Control Levers were disabled by FADEC during operation of the Mk2. This meant that the aircrew lost their primary means of regulating engine speed between stop and flight. Other problems included engines going beyond their normal temperature range ("this is still happening and the last incident was at Boscombe Down during early march 1998"), and what he called "numerous" cases of torque mismatches ("these are still happening – the most recent incidents I know of being in Bosnia in January 1998"). In addition "very large numbers of DECUs were returned to their makers for fault investigation. At one time, operational squadron aircraft were grounded for lack of DECUs to put in them."

Burke also experienced rotor overspeed incidents. When questioned on this at the Defence Committee in 1998 Dr Reid would say: "I have had my records checked. No such incidents were ever reported to the best of my knowledge. If he did experience these, not only should he have reported them but under the terms of reference of the job he carried out he was obliged to report them ... so all I say is that while it is easy to quote supposed facts on the basis of supposed experts, when I check out these facts I find that they do not appear to stand up."

However Burke says the incidents happened at Boeing in Philadelphia where he was performing the role of a co-pilot. It was the captain's responsibility to report the overspeed incidents, but because of their seriousness, Burke wrote handwritten reports, which were given to the UK Chinook liaison officer. Burke says that the captain also filed reports on the incidents which happened within 24 hours of each other. During the second incident there were representatives from Boeing and Lycoming present.

After Reid's disparagement of Burke at the Defence Committee hearing last year, the Ministry of Defence conceded in a statement that it had found a report written by Burke, in his handwriting, relating to an overspeed incident on 14 December 1993. The Ministry said it "could find only one incident." The Ministry did not give the cause but said that it was "not caused by a FADEC software failure."

It should be remembered, perhaps, that the overspeed accident in 1989, was not caused by a software failure but a flawed design of the software. The two are not the same thing: a failure implies a programming fault but it is design flaws which, in crash investigation reports, tend to emerge as a more serious contributory factor.

Burke said of the attack made on him by Reid over the alleged failure to report the US overspeed incidents as "just one example of where the minister appears to have been misled either by staff working within his own department or by selective briefing."

He explained what tends to happen when an overspeed occurs normal flight. "If you're at low level you may suddenly find yourself in the clouds. That's because, to load the rotors and bring their speed down, you raise the collective lever which tilts the rotors, increasing their angle of attack. The side-effect of an overspeed is that you go up."

Could this help to explain one of the mysteries of the Mull of Kintyre crash: the fact that the aircraft flew unexpectedly and inexplicably from an area of good visibility into cloud, within which hid the deadly hills of the Mull?

Burke recalls that in one overspeed incident he raised the collective lever so much "it was under my armpit."

That was the position the collective lever was found when the wreckage of the Chinook on the Mull of Kintyre was examined. Or were the pilots raising the collective lever to the maximum for no other reason than to pull up the nose to avoid the Mull?

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By the time the A&AEE was beginning its comprehensive assessments of the FADEC software in earnest in the early 1990s, Jonathan Tapper, in spite of his youth, had accumulated more than 2,000 hours as a first pilot of helicopters.

During the late 1980s, while the FADEC contractors were trying sort out "numerous" faults, he was serving at RAF Aldergrove, Northern Ireland's main aircraft base, and was then seconded for two years for the Sultan of Oman's Airforce.

By the time he was selected for Special Forces flights, the requirement being for "stable extroverts" he had already flown the Gazelle, Wessex, Huey and Chinook helicopters. He had married in October 1989 and had his first child in August 1993.

Rick Cook, meanwhile, had served in the Falklands Islands, later at RAF Odiham (home of the UK Chinook fleet) and was promoted to Operations Officer Special Forces during the Gulf War. Between September 1992 and December 1993 he was on detachment flying Chinooks in the US with the American military forces. In September 1994 he was due to be posted onto the staff of the SAS.

He married around the same time as Jonathan Tapper and had a daughter Sarah who was nearly two at the time of the accident. Tapper's second child was born on 18 July, six weeks after his death.

By early 1994, in the weeks before the last flight of a Chinook Mk2, airframe registration number ZD576, the problems on the newly-equipped helicopters were becoming so well known that some RAF pilots were growing anxious about flying it. Rick Cook was aware of the problems. He also discussed with friends his concern about the RAF's tendency to blame the pilots in any fatal crash.

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In the months before the final flight of Chinook ZD576, concern over the quality and reliability of the Full Authority Digital Electronic Control system was growing.

By this time, however, the Chinook Mk2 with the FADEC system had been given approval for release into operational service. The Aeroplane and Armament Experimental Establishment at Boscombe Down in Wiltshire, England, which had the task of assessing the FADEC, had said that it wanted the software re-written in a verifiable form before it would recommend a release into service.

The software was not re-written before the service was cleared for operational service.

In March 1994 Textron Lycoming, the Chinook's engine contractor who supplied the new FADEC, issued its response to questions over the safety of the new system. "This report," said Textron, "responds to EDS Scicon and A&AEE Boscombe Down concerns with the T55-L-712F FADEC software in a very substantial and complete manner."

The report, also known as the "Textron White Paper," concluded that the " .. DECU software for the T55-L-712F engine has been designed, developed and qualified in accordance with applicable contractual specifications and meets the agreed requirements for function, reliability and safe design."

The International standard RTCA/DO-178A design and development process was "rigorously adhered to during ... software development and as such was an orderly, disciplined and traceable process." The FADEC was subject to "70,000 functional test hours" which "exceeded by an order of magnitude the amount of testing typically employed for many safety critical flight control systems now in production."

The report referred to the unlikelihood of sudden loss of an engine, and made the point that would later be regularly quoted by the Mod that "most of the aircraft operating conditions can be safely continued with single engine power."

However the report – written three months before the crash on the Mull of Kintyre – also drew attention to the possibility of an overspeed.

> "Although there is some signal sharing between the engines, there is no FADEC failure mode which would result in creating an unsafe condition on the other engine. The worst case inter-engine failure effects which have been identified are: 1) possible switch to reversionary due to loss of load share capability or 2) a possible disabling of the other engine's overspeed system during that flight such that it would not act to reduce fuel, should the remote possibility of a load disengagement occur."

Near the end of Textron's report was a certificate, signed by Chandler Evans, which stated that: "No flight safety risk has been identified. To the best of Chandler Evans' knowledge, the software is airworthy and suited to its intended application on the T55-L-712F and HC Mk2 (Chinook) aircraft."

An identical certificate was signed by Textron-Lycoming.

Textron's assurances did not satisfy Boscombe Down's concerns. In a memo, the Electronic Assessment Unit at Boscombe Down said: "In general the Textron white paper made many claims that are not borne out by [our] knowledge or experience of the FADEC software or project to date."

The A&AEE said that Textron had cited "numerous" reviews as evidence of the integrity of the FADEC." Boscombe Down, however, was "aware that many adverse comments and results were obtained during the reviews which Textron have, in this document, chosen to ignore." The A&AEE went on to say that Textron made no mention of the fact that "while A&AEE did review the reversionary lane code and a proportion of the primary lane, it was found to be unacceptable."

Boscombe Down also said that although analysis of the code had proved difficult, it was not impossible.

The Boscombe Down memo dated 3 June 1994 said: "Code for use in safety critical applications should be sufficiently simple and traceable to be understood by an independent team of verifiers ... it is true that static code analysis alone cannot provide sufficient evidence to demonstrate that the FADEC is safe. It was however sufficient to show that the software is unsuitable in its present form, for use in a safety critical application."

Referring to EDS's report, Boscombe Down said: "An anomaly DOES imply that an error exists, either in the code or the documentation."

But the Defence Minister said that there was no cause for concern. In a letter to MP Nicholas Soames in January 1998, Reid said:

"EDS-Scicon identified a number of anomalies in the sense of questions raised rather than faults identified. These were addressed in detail by Hawker Siddeley Dynamics Engineering, the FADEC software designer, and Textron-Lycoming, the engine design authority, who confirmed that no flight safety risk had been identified and that the software was airworthy and suited to its application. Textron-Lycoming added that that, of all the units flying in the US Army and with other countries, there had been no flight safety related FADEC software caused accidents."

Another Defence Minister John Spellar said in November 1997 that since FADEC came into service on Chinook Mk2s there have been 519 formal incident reports, known as incident signals. Of the 519 signals, "70 have been FADEC related." Of these, seven were spurious, 24 arose through carrying out overspeed tests other than as designed, three were unconfirmed, and 36 were attributed to system faults. Of the 36 attributed faults, 14 were due to mechanical failure, five were due to electrical failure and 17 were software faults."

But back in early 1994 pilots and engineers did not need to be given any statistics to know there were difficulties. As the disagreements between the A&AEE and the system's contractors continued, pilots encountered a succession of corporeal problems on the Chinook Mk2.

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The Chinook Mk2 and the ZD576 in particular had experienced a range of technical problems in the weeks and months before the crash on the Mull of Kintyre. Details are contained in a series of incident reports on an RAF database.

On 5 January 1994 an engine fail warning came up in the cockpit of a Chinook Mk2 during a check. After a few hours of flight it came on again, though on both occasions the engine was found to be working normally.

On the 26 January, during a sortie when both engines were operating in FADEC back-up mode, the "engine fail" warning appeared for up to 10 seconds. When a check was carried out on the DECU display of the FADEC it showed "no fault found."

A day later a Chinook pilot, during a sortie, noticed an "engine fail" warning in the cockpit. Again the DECU showed no fault.

In March 1994 what was described as a "FADEC system fault" was reported. "Remedial action in hand," it said. And in April there was what was described as a spurious "engine fail" warning.

These incidents related to the Chinook Mk2 but not specifically to ZD576 which would be flown for the last time on June 2 1994 by Rick Cook and Jonathan Tapper.

That Chinook had its own history of problems.

On 21 April 1994, the ZD576, during a transition to hover, seemed to have torque mismatch of 40%, but no engine warnings illuminated and it was not possible at that time to assess which engine had been at fault. The engine was quarantined at RAF

Odiham for investigation into "serviceability of engine mounted torquemeter components." The incident was considered serious enough to replace the engine. The cause was said to be a faulty torquemeter.

A lesser torque split had been noticed as a symptom of the engine overspeed which nearly destroyed a Chinook in 1989.

After ZD576 crashed on the Mull of Kintyre, there were indications in the instrumentation found in the wreckage of a torque mismatch. However the investigators of the Mull of Kintyre incident would report that a test of the torquemeters "could not be attempted because of lack of facilities but their functionality was dubious and testing was not considered critical."

Squadron-Leader Robert Burke, the main RAF Odiham unit test pilot at the time, said that the torquemeter is a "crucial" indictor of whether an engine is about to run out of control or overspeed. He observed that an engine on the way to an overspeed may, if stripped down at that point, display no signs of any technical malfunction of an overspeed.

After the apparent torque mismatch in April 1994, the DECUs on ZD576 were checked to see what fault codes were displayed. One reason they were checked is that the FADEC system is designed, among other things, to match torque between the two engines.

However the incident report recorded:

"no fault codes indicated on the DECUs."

Five days after this incident on the ZD576, the same aircraft had another problem. It was reported that, with the engine control levers at flight idle position, there were no torque indications to either engine and No 1 engine was "running high."

The Ministry said only that the incident was related to the remedial work from the incident a few days earlier. "It was not a new incident," said the Mod.

Two weeks later, on 10 May 1994, ZD576 had yet another potentially serious – perhaps even potentially catastrophic - problem. A large spring became detached from the collective lever. It was found that the bonding had failed to keep the spring in place. Although its absence from the collective lever was a minor problem, in that it made the lever heavier to use, it would have been a potentially catastrophic problem if it had jammed in the controls. The assembly in which the spring is housed brings together some of the Chinook's main flying controls.

When Bric Lewis, flying a Chinook in the US in 1998, found that his flying controls had locked, the aircraft was by that stage uncontrollable.

In the case of ZD576, the assembly was replaced after the spring de-bonding incident. However there is evidence that the problem may have re-occurred on the last flight of ZD576. Crash investigators would report that the "possibility of a control system jam could not be positively dismissed."

By now all the spurious signals, warnings, and other technical problems, were conspiring to make it a distinct and growing possibility that, soon, an operational flight would suffer two or more separate but simultaneous problems.

A control jam on top of a other cockpit warnings, perhaps at a time when the pilot was dealing with say a torque mismatch, temporary overspeed, or an emergency power signal, could be sufficiently distracting to cause a fatal accident.

A week after the spring came loose on the ZD576's collective lever assembly, a pilot flying the same aircraft noticed an engine power warning come on three times. Also the engine temperature went beyond its normal level. Part of the FADEC was sent to Chandler Evans in the US for investigation, and the engine was removed and rebuilt. The Mod said later it was not a FADEC fault.

The problems did not end there.

On Thursday 26 May, a week before the last flight of ZD576, various warnings were displayed in the cockpit including a "master" caption and No 2 engine fail notification. The "engine fail" warning had illuminated for only 10 seconds. In retrospect this may seem a short time. But it took only 10 seconds for a Chinook to be nearly destroyed in an overspeed accident at Boeing flight test centre at Wilmington in the USA. It can also be an unnerving for the pilot to be told that the engine has failed at a time when he may be struggling with another problem.

Such was the seriousness of the incident on 26 May 1994, that ZD576 was diverted to Luton.

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In 1994 there was hardly an abundance of serviceable Chinook aircraft in the RAF. This was partly because many Mk1s were in the workshops being fitted with FADEC and other enhancements. At its lowest point during 1994 the availability of the aircraft fell to 40.6% (in comparison with 68% in 1998).

This is one reason that the RAF found that it was impossible to meet a request by Jonathan Tapper for a Mk1 Chinook to be on stand-by. Tapper, like a number of other pilots, had expressed reservations about flying in the Mk2.

His request for a Mk1 was refused by the second in command of 7 Squadron at RAF Odiham, Squadron Leader David Prowse who felt that, if he had agreed to Tapper's request, there would be too many Chinooks in Northern Ireland.

Pilots involved in trials flying were in a different position. At the time of the crash of ZD576, they were not obliged to fly the MK2s.

This suspension of trials flying about after the flame-out of a Mk2 engine on 7 March 1994. The failure was said to have been due to something other than a software fault and flying resumed on 20 April. But, as indicated earlier, in the period up to 2 June, when ZD576 made its last flight, there were a number of incidents involving airborne Chinook Mk2s. About half a dozen of these incidents, according to an Mod statement, were due to "FADEC malfunction." Its statement added: "There had also been other incidents involving Chinook Mk2s on the ground."

The Ministry of Defence Procurement Executive sought explanations of the various incidents from the aircraft and engine manufacturers but, in the absence of satisfactory explanations, Boscombe Down suspended trials flying.

The Mod gave no indication that pilots had not wanted to fly the Chinook Mk2. "The postponement of the flying trials at this time was therefore an expediency within the proper exercise of airworthiness considerations by Boscombe Down ..."

However this expediency, this right to take part in a suspension of flying on the MK2 while the incidents were investigated fully and any problems corrected, was not extended to Rick Cook and Jonathan Tapper.

They were not trials pilots. They were operational, Special Forces pilots. And when they were ordered to fly ZD576, a refusal would have been tantamount to insubordination. Both pilots had risen rapidly through the service. The last thing either of them wanted was any hint in their records that they would contemplate disobeying an order to fly.

And so, with trials suspended, incidents involving the FADEC unexplained, Boscombe Down insisting that there was a re-write of the software in a verifiable form before they would recommend a release of the Chinook Mk2, a separate independent report from EDS-Scicon saying that there was 485 anomalies in less than 20% of the code and documentation they had examined, Rick Cook and Jonathan Tapper were given no choice but to take the cream of Northern Ireland intelligence officers on a 90-minute flight from Northern Ireland to Inverness in Scotland ... in a Chinook Mk2 newly equipped with FADEC.

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Before ZD576 had left the ground for the last time, concern about the FADEC system was being expressed not only by the A&AEE at Boscombe Down, or by EDS, but by one of the most senior helicopter officers in the armed forces: the Assistant Director of Helicopter Projects.

Through a chain of command the Assistant Director is accountable to the Secretary of State for defence who, under the Air Navigation Order 1989, has ultimate responsibility for ensuring the airworthiness of military aircraft.

The Assistant Director, in a document marked "Restricted – Commercial" stated that a "critical issue" was whether it was valid for the contractor to suggest that the tests it had carried out on the US Army's T55-L-714 engine were valid to support a different version of the engine and FADEC used by the RAF. He also remarked that the number of flight hours on the RAF's T55-L-712F, at 45, "would appear to be low, and perhaps accounts for why such problems such as spurious engine fail captions and the 2.5hz oscillation (problem) were not identified at the time."

He also said it was "disturbing to see Textron claiming that one engine control system is not flight critical on a twin-engine helicopter. Clearly they do not appreciate how often, in flight, twin-engine helicopters have no flyaway capability on one engine."

Yet the memo added that Textron had met its legal and contractual obligations. " ... DHP [Director Helicopter projects] has already concluded from a separate exercise that with respect to the contracts in force at the time, Textron would appear to have met their obligations in a legal and a contractual sense.

"On the face of it, therefore, Textron are in a formidable position when they claim to have done nothing wrong in certifying the product (which the Mod has accepted). It is important therefore to understand and take full account of A&AEE's views, since the strength of counter arguments will be crucial to our commercial position in future negotiations to revise the FADEC software in pursuit of a satisfactory resolution of all safety case issues."

Here was the Assistant Director of Helicopter Projects in 1994 saying that A&AEE's views should be taken full account of – whereas Reid at the Defence Committee in 1998 disparaged the A&AEE.

The Assistant Director was also saying, a few weeks before the crash of ZD576, SUGGESTING that there were still safety case issues outstanding relating to the Chinook Mk2's FADEC system.

Chapter Five

THE CRASH

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

Northern Ireland's first Chinook Mk2 with the new FADEC system made its début sortie in the province on 1 June 1994.

The next day was its last fatal flight.

Before the arrival of ZD576 in Northern Ireland, there had been a history of FADEC-related problems on the aircraft, though these were described in 1998 by the Defence Minister Dr John Reid as "relatively trivial."

On ZD576's first day's flying in the province of ZD576 there was a further problem. The crew noticed there was a fault with what was thought to be the Power Turbine Inlet Temperature (PTIT) gauge. The instrument is not totally dissimilar to an engine temperature in a car. According to a senior unit test pilot at RAF Odiham at the time, Squadron leader Robert Burke, the PTIT gauge can provide, among other things, an early warning of an engine overspeed.

When ZD576 returned to RAF Aldergrove on 1 June 1994, after its first flights in the province, the PTIT gauges were assumed to have been the cause of the fault rather than any underlying problem and they were changed over by a technician.

Such was the importance of the gauge - the PTIT is one of the main engine parameters used by the FADEC to help it monitor engine performance - that its correct operation was checked during a short proving flight of ZD576. The fault did not reoccur.

A problem, apparently with the PTIT gauge, would not reappear until the following day: June 2 1994.

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Flight lieutenant Tapper had been preparing for the arrival of ZD576. His Squadron Leader David Prowse took three pilots, including Tapper, for 20-minute flights around RAF Aldergrove to familiarise themselves with the Mk2. The sortie consisted of a circuit with the Automatic Flight Control System switched off (which can destabilise the aircraft), two simulated emergencies, and a quickstop.

Prowse felt that Tapper was content with his abilities on the Mk2. "However Flt Lt Tapper was the sort of person who, no matter how well you told him he was doing, he would not have necessarily believed you."

He added: "I was happy with his ability to operate the HC2 (Chinook Mk2) in Northern Ireland. There were several reasons that led me to believe this. Firstly we had been in touch on the telephone quite frequently in the fortnight prior to the change over of HC1 (the mark one version of Chinook) to HC2, discussing not only detachment administration procedures, but also points concerning the introduction of the HC2 in Northern Ireland. Secondly his handling of the simulated emergencies led me to think that he had been preparing for the arrival of the HC2 because he knew his way around the Flight Reference Cards, which are particularly confusing. He had also mentioned to me that the detachment had been conducting their own seminars concerning the HC2."

Prepared Tapper was, inwardly confident he wasn't. Prowse said that Tapper "requested permission to keep an extra HC1 in Northern Ireland for an additional period." This was because Tapper was concerned about the "limited operational capabilities" of the Mk2. Because of the concerns expressed by the A&AEE, and the Assistant Director of Helicopter Projects, the Chinook had been given permission to fly only with stringent conditions attached.

These included a weight restriction in case the Chinook needed to fly on one engine, and an icing limit which prohibited flying in temperatures of less than four degrees centigrade. There would later be implied criticisms that Tapper was flying too low as his Chinook approached the Mull of Kintyre but his critics may not have been aware of the facts surrounding the icing restriction.

This icing restriction was regarded as particularly onerous by Tapper who had mentioned it in discussions with members of the Chinook aircrew at RAF Aldergrove.

For example, the restriction limited the ability of the Chinook to fly into clouds where the temperature could cause water droplets on rotors to turn quickly into ice. Pilots who fly Chinooks in the US Army are warned that, "aircraft icing usually occurs in cumuliform [simple forms of clouds, frequent in the summer sky] or stratiform [as in stratified] clouds from sea level to 15,000 feet, most often between 1,500 and 6,000 feet."

As the icing restriction implied that Tapper might have to maintain low-level flight [the safe altitude to fly over the Mull of Kintyre being about 2,800 feet] he sought advice on the implications of breaking the limitation for operational or emergency reasons. Prowse said:

"Flt Lt Tapper told detachment pilots that he had discussed this [icing limitation] with Squadron Leader Milburn ... and had been told that under no circumstances could the Controller Aircraft Release (a permission for the aircraft to be released into service) be broken and if the aircraft was involved in an accident, and the CA release was broken, the captain would be held personally liable for any civil litigation action."

Prowse added: "Knowing Flt Lt Tapper's character and attitude as I did, I believe he would not have broken these specific regulations."

It was not only the icing restriction that worried Tapper. He and Flight Lieutenant Cook were concerned about the problems with the FADEC on the Mk2.

At the RAF's Board of Inquiry in 1994 Prowse, under oath, said: "The concerns they had with reference to the HC2, I believe, did worry both pilots in two ways.

"First, was the uncertainty of how the aircraft's Fully Automatic Digital Electronic Control system would perform during operational sorties in Northern Ireland, and what sort of emergencies or situations the present amount of spurious and unexplained incidents would lead to.

"The second was the instability that was put upon all aircrew serving on 7 Squadron during the ad hoc introduction of the Chinook HC2 into RAF service ..."

There were other pressures on the pilots. Tapper had been reading the Chinook Mk2's flight reference cards to understand how the aircraft would react to unforeseen malfunctions. The cards, among other things, provide a list of functions, switches or warnings to check or act on, by rote, in the event of an emergency. Flight reference cards may also provide look-up reminders of how equipment and warning lights function, rather like an instruction manual in a car.

There was also a manual for the Chinooks, the equivalent in the civil aviation world of a flying manual. This explained how the systems and other items worked. Normally the manual contains limitations to explain any shortcomings over how the systems function. On the Chinook Mk2 the page marked "limitation" was blank. It said simply:

To be issued

Therefore it was not obvious to the pilots of Chinook Mk2 how they should cope with the sort of malfunctions which had been experienced in the weeks before 2 June.

Squadron Leader David Morgan would later tell the RAF's Board of Inquiry that the Mk2 flight reference cards did not cover undemanded engine shutdowns, engine run-ups, spurious failure warnings, and the misleading and confusing cockpit indications.

He said: "...The Chinook HC2 Flight Reference cards were based primarily on the Chinook D Model which is not fitted with FADEC. Drills relating to FADEC were based on the best information available on how the system would respond during certain malfunctions."

The information that ***was*** contained in the cards was confusing. "A number of emergency drills, in particular electrical and hydraulic, were poorly laid out and required the crew to be familiar with the drill to avoid confusion. The shortfall in the Chinook HC2 flight reference cards was discussed with the crews during their conversion courses" he said. Some pilots had to rely on photocopied versions of the flight reference cards.

A measure of the fact that the reference material had not kept pace with problems since the FADEC's introduction was a hand-written annotation by Rick Cook on one of the pages. Under a printed subsection which explained when and why the "Engine Fail Caution" warnings would show in the cockpit, Rick Cook had penned in capital letters in the margin: "Note: the engine fail caption + master caution light come on together [illegible] to give spurious warnings of an engine failure. If all engine indications are normal, the master caution light + the engine fail caption cleared in 12 seconds."

This indicated to Cook that he might have to wait for 12 seconds for an "engine fail" warning to disappear before knowing for certain that it was a spurious warning. Pilots say that 12 seconds can seem like an eternity in flight, particularly if other warnings are indicated at the same time, whether or not they later turn out to be spurious.

The near-destruction of a Chinook Mk2 in 1989, for which the Mod received more than $3m in compensation, was caused in 10 seconds.

Tapper and Cook had tried to minimise the risks, but they knew they could not prepare for every eventuality. The problems with the FADEC – with any piece of software when it goes wrong – were not always predictable.

Both pilots showed outward signs of quiet confidence, but there was also some evidence of anxiety. At 9pm on the evening before his last flight, Tapper was in his room. Lieutenant Duncan Trapp, a squadron navigator with the Chinook attachment at RAF Aldergrove, spoke to him. He discovered that Tapper was preparing maps for the following's day sortie.

About two days before the crash, Tapper had spoken to his father. "We were having a good conversation," said his father, "then suddenly the timbre of his voice changed entirely. He said: 'Dad; the Mark Two is coming in.' I said what does that mean? He said well I have got to check it out very carefully. I was lost for words because I could see there was something clearly wrong but he was not prepared to amplify. It was only afterwards that I found out the extent of the problems they were having ... the aircraft should not have been in squadron service."

That was Mike Tapper's last conversation with his son.

It also appears to have been a working evening for Flt Lt Cook. Neither Tapper nor Cook was in "scruffs bar" at around 10pm when Flt Lt Duncan Trapp went for a drink.

Cook had been telephoned by his wife Sarah who had been going through the bank statements. She wondered why so much money was going out in life insurance. "It was one payment after another," said Sarah Cook. "He said he wanted me looked after

–if anything happens to me, he said, you're the most important thing to me. I want you looked after.''

Rick Cook's father John had also been a pilot, firstly with the RAF, then on a British Airways 747 jumbo, then on Concorde. "We talked about the problems that one gets with a lot of new avionics and the software in the avionics systems, and in the engine control systems but some of the RAF's problems seemed to be worse than anything I had ever come across. So we talked a lot about it until his last leave when he knew he was being ordered to fly the Mark Two in operational circumstances.

"One day I was in the garden and he came up to me and said: 'you will look after Sarah and Eleanor won't you Dad.'" Eleanor was his daughter who, at the time of the crash was coming up to her second birthday.

"I said of course. Get on with the job. You do it very well. I did not take it too seriously, but he came up to me again in the house a day or two later and said the same thing. The last time he came up to me was in the garden so I said: 'Rick c'mon. What's worrying you? He said: 'Dad, the aircraft's not ready; and we haven't had enough time flying it to recognise and cope with all the warnings that are coming up."

Sarah said Rick had been reading the flight manual in bed. "He was ***that*** concerned," she added.

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Some time after the 2 June flight, Rick Cook's daughter Eleanor, now four years old, sits on her mother's lap, watching a video of her father in RAF uniform but with an open collar, walking away from a Chinook, smiling into the camera. "There's daddy," says the cherubic Eleanor as she waves to the TV set. The Chinook on the video is then pictured taking off, and Sarah asks her daughter where her daddy was going.

"Into the sky," says Eleanor without hesitation.

* * * * *

<u>0730, June 2 1994</u>

Members of the crew of Chinook ZD576 rose at around 7.30am on 2 June, had breakfast, then collected their weapons and ammunition from the armoury. Flight lieutenant Rick Cook, in the officer's mess, was also seen having breakfast but there was no sign that his co-pilot and captain for the day's duties, Flight Lieutenant Jonathan Tapper had eaten.

At 8.35am the crew members joined Tapper and Cook, who each had around 3,000 military flying hours, for a flight planning briefing which started at 8.45am.

"During this briefing," said one of their colleagues, Sergeant John Coles, "Flt Lt Tapper stressed the flight safety and operational considerations of the Chinook HC2's [the Mk2, FADEC-equipped Chinook] limited release to service. Both Flt Lt Tapper and Flt Lt Cook mentioned during the brief the limitations of the Chinook HC2's icing clearance with regard to that day's weather."

During flight planning, it had become clear that, taking the icing restriction and the weather into account, it would be unwise to attempt a trip in cloud using instruments. It was decided, said Kingston, that a "VFR" flight would be the only option. VFR – visual flight rules – meant that Tapper had intended to fly not in cloud but low enough to see where he was going.

Therefore, once he had crossed the North Channel, there was a good chance that Tapper would be below the level of the top of the Mull of Kintyre. This should not have presented a problem. A slight turn left before the Mull would have taken ZD576 past the landmass of the Mull and into unfettered open space again ... unless something happened on board which would prevent a left turn.

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The Joint Air Tasking Operations Cell had programmed a long task schedule for the Chinook ZD576 that day. At 9am Flt Lt Tapper approached Squadron leader Michael Strangroom who was responsible for the supervision of Puma and Chinook flying from RAF Aldergrove. Tapper wanted to discuss the day's duties which consisted of routine troop and dependent movements between main operating bases in Northern Ireland. This was not particularly demanding and he anticipated he would complete it quicker than the programme schedule.

As all the crew had completed what was described as "extensive" pre-planning for the trip that afternoon from Northern Ireland to Inverness in Scotland, Tapper wished to use the same crew all day.

He also drew to the squadron leader's attention the fact that the workload would require an extension to the normal flying limits of seven hours as the tasks would take approximately eight hours.

For pilots flying in Northern Ireland their seven-hour limits were extended almost routinely. "I was content with his plan in outline and saw no reason not to grant the extension to eight hours and did so." Strangroom said Tapper "gave the impression of a competent captain in control of the situation."

Strangroom formed the impression that if Tapper's eight hours of flying were reached, he would stop over in Inverness, although no accommodation had been booked. Tapper knew that if he wanted to fly back to Northern Ireland that evening, and he was beyond his eight hours, he could request a further extension by making a secure telephone or radio call from Inverness.

The importance of the people aboard the late-afternoon flight was known already. Strangroom said: "I was aware of the nature of the task and of the status of the manifested personnel and was therefore aware that the task would carry a high priority."

That morning, at 9.45, the Chinook left RAF Aldergrove for its normal duties in Northern Ireland and landed again at 3.20pm. Sergeant Coles noticed during the sortie that there was audible interference on the VHF/AM radio when certain frequencies were selected on the Racal RNS 252 satellite navigation computer system. Tapper also suspected that the RNS 252 SuperTANS navigation computer was not working properly. In addition, the crew mentioned to operations staff on the ground that the RNS 252 had been unreliable. Tapper asked for a check but no fault was found.

During the morning's sorties, the crew had also noticed what appeared to be a fault with the PTIT gauge. They sought engineering advice at RAF Aldergrove.

The problem appeared to be of the same type that had affected ZD576 the previous day when the gauges were changed over and their correct operation checked during a subsequent proving flight.

During the previous month, May 1994, there had been what were described as "PTIT excursions" on ZD576 which had led to the replacement of a Digital Electronic Control Unit, the main computer component of the FADEC.

No mention would be made in the report of AAIB crash investigators about any of the PTIT problems on the final two days of ZD576, the first and second of June 1994.

At 4pm on the afternoon of 2 June 1994, the crew and pilots were in the operations room at RAF Aldergrove. Cook had a fax of weather information. Later in the flight planning room they were completing their sortie brief, before leaving in a Sherpa van with the rest of the crew to Chinook HC2 ZD576.

Flt Lt Trapp said: "On all my meetings with Flt Lt Tapper and Flt Lt Cook on the afternoon of 2 June 1994 they appeared to be approaching the sortie in a confident and professional manner. Flt Lt Cook mentioned to Flt Lt Tapper that they would have to have a close look at the weather as it did not look brilliant."

If all went well, the sortie would not be overly challenging. But Tapper and Cook knew that if things started to go wrong, as had happened a number of times in the weeks before 2 June, and indeed to a limited extent on that very morning, the Chinook might not be easiest aircraft to fly.

* * * * *

At 5.42pm the Chinook ZD576 took off from RAF Aldergrove. Tapper, Cook and the two other crew members appreciated the Mk2's relative smoothness. Vibration – a bane of flying on the Chinook - was much better dampened on the Mk2 than on the Mk1.

This was of little comfort to Cook and Tapper. They were aware that the Aeroplane and Armament Experimental Establishment at Boscombe Down had, only a day before, suspended trials flying in the Mk2 because of a lack of satisfactory explanations from the FADEC's contractors over the incidents in the past few weeks. It would not be for another four months – November 1994 - that Boscombe Down would resume flying trials, and then only after modifications had been made. The weight restriction would remain beyond November 1994, partly because the software had not been re-written to make it verifiable.

Rick Cook had noted that there two sets of rules, one governing the pilots at Boscombe Down who, in June 1994, had been released from the obligation to fly the Mk2 because of reservations that related to airworthiness, while operational pilots had no such dispensation.

For Cook and Tapper, the fact remained that, whether or not trials pilots were flying the Mk2, the FADEC-equipped helicopter had been authorised for operational service by the Secretary of State, through his delegated officers.

The Mod's response to Boscombe Down's concern was to say that the Chinook Mk2's release into service had the proviso of a weight restriction in case a FADEC malfunction caused an engine failure.

But this restriction assumed that a FADEC malfunction would cause an engine simply to fail. It did not allow for other, unpredictable actions behaviour of the FADEC.

Boeing had already identified a number of ways in which problems with the FADEC, in association with malfunctions on other components on the aircraft, could be potentially catastrophic.

The danger was not just that an engine could fail, which could in certain favourable circumstances be managed safely ... but that a combination of warnings, real or spurious, together with an actual problem such as a jamming of the flying controls, could make the aircraft uncontrollable. Even if it was uncontrollable for a few seconds, pilots know, from knowledge of earlier accidents, that this is all it takes for fatal accidents to occur.

The pilots also know that if the software behaves unpredictably, it will not necessarily leave any physical trace of its deeds. In the 1989 accident at Boeing at Wilmington, USA, the FADEC did not "know" it had been at fault. It behaved the way it had been designed. The problem lay in the system's design.

Even if there are some signs in the wreckage of software problems, the pilots know that, statistically, the finger of blame in any crash is likely to point to them if they do not survive.

* * * * *

Three minutes after take-off, ZD576 made radio contact with the Strike Command Integrated Communications System.

On board were two pilots, two crew, nine Army intelligence officers, 10 Royal Ulster Constabulary special branch officers, and six agents of the MI5 counter-intelligence service. The passengers included the top intelligence officer in Northern Ireland. The baggage included classified papers, mobile phones, and portable computers, none of which was x-rayed.

Several people in Northern Ireland saw the Chinook fly at low level over the Antrim hills to a point close to Carnlough. At 5.55pm Scottish Military Air Traffic Control received a routine single call from ZD576.

"Scottish Military. Good afternoon. This is Foxtrot 4 Juliet 40," said Tapper.

For no reason which has been ascertained, the call went unanswered.

A short time later, ZD576 was seen by an amateur yachtsman Mark Holbrook, flying below cloud at about two to three nautical miles from the Mull of Kintyre lighthouse. It was flying in a straight line, at a level altitude, about 200-400 feet above sea level, towards the Mull of Kintyre.

The visibility at that point was about one mile in haze, with about 80% cloud cover. "It was well below cloud and visibility was quite good," said Holbrook two days later. "You could see the sunshine glinting off the fuselage."

He added: "There was certainly low cloud sticking to the coast but it was not sufficient to cover the lighthouse."

The RAF Board of Inquiry would say later that the weather in the vicinity of the Mull at that time was "very poor" with cloud and hill fog extending from below lighthouse level, about 300 feet, to "at least" the summit of Beinn na Lice, which is the highest point on the southern tip of the Mull, at 1400 feet.

The weather at the time would prove a controversial point. At a later Fatal Accident Inquiry in Scotland, counsel for the Ministry of Defence would seek to show what the weather was like at the time of the accident, partly by way of an assessment by a forecaster. But the judge, Sheriff Young said the forecast related to the weather at the forecasting site. "... the weather forecaster wasn't standing at the Mull of Kintyre lighthouse. How does he know exactly what was going on?" asked the Sheriff.

The reply by the Mod's counsel might, perhaps, have been more decisive. "If there was any question of that, one might have expected to see some questioning about that. I am simply proceeding on the basis of the evidence, which is in the terms of the aftercast, and the histories of weather gatherings are not something which I personally can help .."

The judge Sir Stephen Young, in his summing up after a Fatal Accident Inquiry which lasted more than three weeks would say that, as the crew flew across the North Channel they "would have been able to see that the Mull of Kintyre was shrouded in mist." A witness, who could not be identified but was known as "H" said the "proximity to the Mull of Kintyre would been readily evident" to the pilots.

Robert Burke who has flown Chinooks in the vicinity of Mull several times, said that even when the lighthouse is totally obscured in fog, "you can see as you come the across the water the waves breaking in the distance; you can't mistake where the land is."

Tapper and Cook would have known that the safe height required to overfly the Mull was 2,800 feet, which would have meant transferring from visual flight rules – from seeing where they were going – to IMC (instrument meteorological conditions), which required a reliance on instruments. The Chinook might then have run into an icing problem.

Although 2,800, the height required to overfly the Mull, was below the level at which ice would normally be expected, it is known (and the US Army Safety Centre at Alabama has issued such a warning in connection with Chinooks and other helicopters) that ice particularly forms in stratified clouds - the type of clouds near the Mull on June 2 – at between 1,500 and 6,000 feet.

Therefore it would have been clear to the pilots that any attempt to overfly the Mull would have been risky, especially with so much high ground in the vicinity, and taking into account the icing restriction.

But there was no indication that the pilots had planned to fly over the Mull. They indicated on their RNS 252 navigation computer that they planned to make a left turn about 15 to 20 seconds before the crash. The fact that they had registered this "waypoint" change suggested that they had seen the Mull, knew where they were and had planned to turn left, avoiding the landmass in front of them.

The waypoint is a latitude-longitude point which is recognised by the geographical database in the RNS 252 computer. When a pilot approaches and sees a waypoint he will change the RNS 252 to the next waypoint and the system's display will then show the number of degrees of turn that is required to reach it. Though they can sometimes be inaccurate, the RNS 252 can also make life much easier for pilots by helping them to fly from waypoint to waypoint.

The waypoint that ZD576 was heading for was the lighthouse on the Mull. Normally, pilots would have seen the lighthouse and switched the RNS 252 to the next waypoint (at Corran), which is exactly what Tapper did.

The RNS 252 then showed that a left turn was necessary to head toward Corran. This would also have enabled Tapper and Cook to continue flying low, under visual flight rules. So Tapper altered the course selector on his horizontal situation indicator with a view to making the left-turn.

The waypoint change indicated that the pilots knew where they were about 15 to 20 seconds before impact.

What happened next is less clear.

That ZD576 did not make the left turn that it indicated it was going to make is not in dispute. The RAF, relying on evidence from the RNS 252 navigation computer as examined by the manufacturer RACAL, and a simulation by Boeing and others, suggested that ZD576, when land was drawing near, continued almost straight ahead, without slowing down.

This was contrary to regulations, because the Chinook was flying directly towards the cloud on the Mull, without switching to IMC (instrument meteorological conditions). There was also a danger of icing in the clouds, a possibility that Tapper had particularly wanted to avoid. Also it was contrary to Cook and Tapper's intention of remaining under visual flying rules.

Most serious of all, the data from the RNS 252 showed that the Chinook was climbing but nowhere near enough to overfly the Mull.

Why did it not turn left and continue instead to head towards the Mull? If the pilots had intended to fly over the Mull why did they enter a normal waypoint change suggesting a safe left turn, and then not turn left? Or, if they had intended to fly over the Mull, why was their rate of climb nowhere near as steep as it should have been?

Had the pilots simply mistaken where they were, and realised too late that they were fatally close to the Mull?

Or had something gone wrong, such as an unpredictable problem with the FADEC or a jam of the flying controls ... or both? Could there have been the start of the now-familiar but highly-dangerous problem of engine overspeeds?

Robert Burke pointed out that, according to pilot training, overspeeds are contained by applying collective lever to load the rotors, a side-effect of which is that the aircraft rises ... possibly in this case an unexpected, unwilling and fatal climb into cloud. There was evidence in the crash of the collective lever having been raised to its maximum height.

But if the pilots were in an emergency, knowing that, within seconds, they were about to strike land, as helpless to save themselves as the crew of the Chinook in the USA which turned upside down (see part 1), would they not have sent a signal to the outside world?

And here, there was a possible clue later found in the wreckage. In the case of the Chinook in the USA which overturned and the crew were convinced that they were going to die, no emergency code was sent, although they arguably had time to do so.

But on the ZD576, there was evidence to suggest that one of the four crew members may have tried to send an emergency code.

Like most Chinooks, ZD576 had an "IFF" radar transponder, which sent a regular signal to air traffic control that identified the aircraft. In the cockpit there was a display which contained four numbers, from one to eight. The digits were shown on a rotary display, controlled by a thumbwheel. So if a digit was set at say zero, moving it back one position would cause it to display "8." Moving it back two places would cause it to read "7."

A normal position for the IFF display would be 7,000.   The emergency code was 7700.

It would transpire that after the double-impact of ZD576 that a number of the instrument positions would be rendered unreliable in their readings. The RNS 252 navigation computer, for example, would be found at "off." But the manufacturer Racal said that it could tell from its examination of the equipment that it had been on at the time of the first impact.

The IFF transponder was found with the code "7760." Possibly it was a random figure as the RAF Board of Inquiry would later suggest. But what if one of the pilots, or a member of the crew, in the seconds before the crash, had been trying to set the counter at the 7700 emergency position at the time of impact?

This would then have indicated that the crew were facing an emergency.

There was another clue: Rick Cook's intercom would later be found in an "emergency" position.

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

At about 6pm several people heard a dull thump followed by a loud whooshing and whistling sound. Two cyclists on the hillside were then enveloped in smoke, and the second lighthouse keeper, who was driving down the road to the lighthouse, saw an area of flames behind him on the hillside.

"There was a sensation of great pressure all about us and then the sound of rotor blades, followed by a thud and then an explosion that I can only describe as a firework display coming up through the mist," said Russell Ellacott, a visitor to the Mull.

Chinook ZD576 had crashed into a steep hillside on the Mull of Kintyre, at a height of 810 feet at a ground speed of about 150 knots, in about a 30-degree nose-up attitude, and banked slightly left.

Sarah Cook had been watching television, waiting for "Eastenders" to start. It was about 7.25pm when Michael Buerke appeared on the television with a news flash that a helicopter had crashed on the Mull of Kintyre. "I knew then that it was Rick," said Sarah.

After initial impact at which the aircraft suffered extensive break-up, it became briefly airborne again, continued to disintegrate and finally came to a rest about 300m beyond the initial impact point. There was an extensive post-impact fire which ignited large areas of the surrounding peat and heather. The RAF said that all the occupants of the aircraft suffered major trauma on impact and died instantly.

Shortly afterwards the scene was filled with the sight of police, firefighters, ambulance crews, a local doctor, RAF fire engines, search and rescue helicopters, and an RAF Mountain Rescue Team. The local lifeboat was also launched.

Meanwhile differences in procedures between the civilian and military authorities were beginning to emerge. The RAF Board of Inquiry said later: "These differences prolonged the period before proper control of access to the site was established, and initially impeded liaison between the Mountain Rescue Team and the police. Nevertheless appropriate site control measures were evident by the time of the Board's arrival on site on 3 June."

An RAF internal memo dated soon after the crash stated briefly what had happened and said: "Details of passengers and crew suppressed on security grounds."

Three days after the crash a leading Sunday newspaper, briefed by defence officials, was able to give an exact break-down of status of those on board: for example how many were M15 agents, and how many were Royal Ulster Constabulary special branch officers.

The paper was also briefed about the purpose of the flight: to transport the security and intelligence officers to a conference at Fort George near Inverness.

With remarkable prescience, the newspaper was further able, on the basis its briefings, to say what would be the outcome of months of an investigation that, at that time, had barely started.

It said that "evidence suggesting pilot error rather than mechanical failure as the likely cause of the Chinook helicopter crash, emerged yesterday."

The then Prime Minister John Major, a day after the crash, said: "It looks as if it was a straightforward accident in appalling weather."

For the families of the 29 crew and passengers, the feeling of loss must have been unimaginable. But for the families of Tapper and Cook, the grief was soon to be compounded... just as Rick Cook and Jonathan Tapper had predicted.

Chapter Six

Summary of Chapter Six

The Funeral
Inconsistencies emerge in official investigation
Investigators do not fully understand FADEC
Ministers say engines and FADEC were working
"E5" fault code in surviving FADEC – same code as in severely damaged Chinook in 1989
FADEC equipment examined and its fault codes assessed by the contractors

At the televised military funeral, the RAF praised the pilots.

Their coffins were draped in the Union flags and over the public address system a stentorian voice said: "Flight Lieutenant Tapper was a superbly qualified, loyal and dedicated member" of the forces. "He and his other three crew members have flown on operations in many parts of the world. They served their country with modesty and courage."

Soon, at the RAF's Board of Inquiry, the bodies of the pilots would be cast into a pit of opprobrium, branded with the worst failing of which professional airmen can be accused.

And not a word would be said about whether their helicopter was, at that stage, fit to fly that mission.

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The Air Accidents Investigation Branch in Farnborough (AAIB), part of the Department of Transport, was not a particularly uplifting place to visit. Inside a huge hangar, within the perimeter of a large
well-protected site containing a number of government buildings, were the reconstructed remains of the jumbo jet which was blown apart over Lockerbie. There were also seemingly dozens of wrecks of smaller aircraft in what looked like the aftermath of a large bomb which had destroyed a crowded airfield. It was too easy to forget that human beings had once entrusted their lives to what were now distorted lumps of prosaic metal.

Investigators at the AAIB take their jobs very seriously but there are not many of them. Much of their work, when it comes to inspecting specialist equipment relies on the support and facilities of aircraft manufacturers, though the investigators usually oversee the work.

This was the case with the inspection of specialist equipment after the crash of ZD576.

The investigators are not omniscient. A cockpit or flight data recorder is an invaluable help. The AAIB, in their report on the crash of the ZD576 referred to an earlier fatal crash of a Chinook, operated by a civil aircraft company on behalf of Shell Oil. This recorder "had within 48 hours of impact pinpointed the component whose failure caused the loss of the aircraft together with data on the progression of the failure. Such analysis can also provide a high level of confidence as to the satisfactory operation of engines, transmission and rotors in the absence of the malfunction."

A recorder may also gives investigators a source of information that does not rely on subjective assessments by the manufacturers.

However ZD576 was not equipped with a cockpit or flight data recorder.

For two fathers John Cook and Michael Tapper, the death of their sons in a helicopter they had expressed concerns about flying, was a catastrophe of loss, grief and futile foreboding. For John Cook there was also a dreadful irony, the pain from which has not eased with the passing of time.

While a pilot for British Airways, he had led successful negotiations with the Air Accidents Investigation Branch for the installation of cockpit voice recorders on large passenger aircraft. He had recognised the value that recorders would have to families of dead pilots because the tapes might record audible warnings, pilots expressing concern about a malfunction, or unusual engine, gearbox, or other noises.

Cook said: "I fought to have the recorders installed and then I lost a son in an aircraft which didn't have one."

* * * * *

Even when wreckage contains a functional cockpit and flight data recorder, manufacturers, governments, politicians and investigators will sometimes argue with passion over the interpretations of the recorded information.

After a Boeing 757 crashed in South America, killing all on board, it was discovered that the autopilot computer had stalled the aircraft because the system was linked to a faulty airspeed sensor. Some said that the cockpit voice recorder showed that the aircraft had failed to warn the pilot that the autopilot was linked to a faulty airspeed sensor. Others said the voice recorder showed how the pilot ignored other warnings which, if taken together, would have indicated that the autopilot was linked to a faulty sensor. And they blamed him for not understanding the logic behind the design of the autopilot and how it inter-related with the sensors.

Even if the official interpretation of information on a cockpit or flight data voice recorder is subsequently disputed, its existence rarely fails to yield some important information. Conversely, the absence of any purpose-built accident data recorder or cockpit voice recorder means that the findings from the wreckage of the aircraft may be largely speculative.

Ministers would imply later that the findings from the wreckage of Zd576 were inconvertible. Dr John Reid, then Armed Forces Minister referred in an interview with David Harrison of Channel Four to existence of "concrete evidence."

> "... ...on the evidence for this case, from the wreck ... of this tragic accident, which was investigated by the civil investigation aviation branch, not by the RAF, is that the engines, the FADEC, the fuel system were all in the normal working condition... There isn't a shred of evidence that there was any technical malfunction on this Chinook."

However findings in the AAIB report on the crash of ZD576 reflect the uncertainties of the investigators. Unlike the report into the Chinook operated on behalf of Shell Oil, which was decisive, the AAIB report on the ZD576 contained few unqualified conclusions about the state of the equipment.

The senior investigator Tony Cable chose his words with care, reflecting the fact that many of the findings were more speculative than concrete. This is highlighted by the following comments from his report:

"***Indications*** were found of controls positioned at 25% aft stick, 23% left stick, 77% left yaw and full collective thrust at impact, possibly initial impact but ***not positively determinable*** ... "thorough assessment of ***most*** flight control hydraulic system components was possible and revealed no signs of pre-impact failure or malfunction....

"***Most*** flight control system actuators ... remained functionable ... fire damage prevented assessment of the functionality of No 1 DECU [Digital Electronic Control Unit – part of FADEC] and had destroyed its memories of the operating program and exceedance fault history ...

"The No2 DECU remained ***partially*** functionable ... "***available*** evidence ***indicated*** normal Automatic Flight Control System Operation ...

"***possible*** utility hydraulic system abnormalities were ***suggested*** by ***some indications*** ... "engine condition and the ***available evidence*** of instrument indications and control setting ***suggested*** normal operation of both engines at the time of the accident ***... "Few reliable signs of cockpit and cabin instrument indications at initial impact were found .***.. Hydromechanical Assembly [part of the FADEC] internal settings confirmed correct operation for ***most*** HMA elements ...

"An excessive null error in a transducer of the No 1 Automatic Flight Control System computer had ***possibly*** been present pre-impact, but would not have resulted in ***significant*** performance degradation ... ***Almost all*** parts of the flight control mechanical systems were identified with no evidence of pre-impact failure or malfunction, although the ***possibility*** of a control system jam ***could not be positively determined*** ... a radar altimeter transmitter component fault, ***very*** pre-existing, caused abnormal transmitter behaviour ... the fault had the ***potential*** for causing erroneous height indication.

Investigators also found that some of their findings were apparently contradictory. Not all of these inconsistencies appear to have understood fully by the Mod.

For example the Mod said in a statement that the pilots, in the emergency, had "demanded emergency power levels from the engines." This echoed a letter from the Air Chief Marshal Sir William Wratten (a critic of Tapper and Cook) who told the magazine Aerospace International that the AAIB found that the Chinook's two engines were at "high power settings."

The remarks by the Ministry and by Sir Wratten are consistent with a Boeing simulation which indicated that in the last few seconds the pilots had suddenly seen the Mull and were trying to climb at high power out of trouble.

What the Ministry, and Sir William appear not to realise, however, was that the Air Accidents Investigation Branch found that: "Both powerplants were operating at similar ***intermediate*** power levels."

The confusion arises, perhaps, because the AAIB also found that, ***on the available evidence***, the Chinook ZD576 crashed at high speed. Indeed the AAIB said the transmission system showed that there was "evidence of high speed rotation."

An examination of the rotors found that they had been "rotating at speed at the time of the strikes."

Also, the control settings at the time of impact showed that the pilots had the collective lever at its maximum height. This tells the FADEC system that the pilots require considerable power to tilt the rotor blades at a maximum angle of attack, so giving the Chinook the maximum lift. With the collective in such a position, it might be expected that the engines would be delivering high power or maximum power, but apparently they weren't.

A Boeing simulation of the crash, which was reported by the AAIB, showed that, unusually, the rotors were *under*speeding, at 91%.

Another uncertainty was the condition, post impact, of the warning instruments in the cockpit which had been the source of several incident reports in the weeks prior the crash. The AAIB said the initial impact "meant that little reliable evidence was available from the cockpit instruments."

There was a further dimension of doubt in the AAIB report. In the case of specialised equipment there was a reliance on contractors to provide the test facilities, the knowledge of how their equipment worked, and what significance could be attached to any faults found.

For example the engines were examined externally in detail at the AAIB in Farnborough but were strip examined at Textron Lycoming's plant at Stratford, Connecticut (at a time when the Ministry of Defence was suing Textron over the accident in 1989).

The Hydro-mechanical assembly, part of the FADEC, was taken to, examined and tested by Chandler Evans, one of the FADEC subcontractors. The AAIB and a representative from Textron Lycoming were also present.

This investigation, said the AAIB, showed that the "***majority*** of the Hydro Mechanical Assembly subsystems acted normally both prior to and during the accident. The AAIB added: "... the evidence indicated that both engines were ***probably*** operating normally at the time of the accident." The AAIB went on to say that the No 1 hydromechanical assembly was found to be working in the FADEC's reversionary full "back-up" mode which was "as expected when power supplies fail."

The No 2 hydromechanical unit had suffered relatively little impact or fire damage. There were a number of fuel leaks but once some o-rings damaged by the fire were replaced by testers, the "unit subsequently completed the functional test ... with no ***significant*** anomalies found.

The AAIB said of the engines that, apart from a turbine nut, "no sign of pre-impact anomaly was found."

Ministers would say later quote the AAIB's apparent exoneration of the engines as implying that the FADEC must have worked properly, though, according to Malcolm Perks, this is an assumption which requires a leap in logic.

Perks is one of the world's foremost independent FADEC specialists. He worked for Rolls-Royce where he supervised the design and development of the first digital control for the Rolls-Royce Gem 43 engine. From 1998 through 1994 he was head of Head of technology at Rolls-Royce Aerospace Group and later head of Unit Engineering for Control Systems during the development of a FADEC system for large-engine aircraft such as the Airbus A330 and Boeing 777.

"The FADEC gives the instructions to the engines and they do what they are told to do," said Perks. "But if the engines are working normally that does not necessarily indicate that the software instructions are correct."

If you instruct a robot to jump off a cliff and it does so, there may be nothing wrong with the robot, only the instructions.

If you examined the wreckage of the robot afterwards and said that there was no evidence of technical malfunction you'd probably be right. The robot had responded in exactly the way it was programmed to react. It's the instructions you would need to look at ... and if those instructions are in the form of computer code and that code mistakenly tells the robot to jump off the cliff, then that's a design or programming error. Either way, the robot can be seen, on the face of it, to have behaved normally.

Asked whether the AAIB, or the subsequent RAF Board of Inquiry had fully understood the logic that underpinned the design of the FADEC, the Ministry of Defence said in a statement:

"Whether the Board of Inquiry team or the AAIB had or did not have a full understanding of the design logic of the FADEC system is irrelevant. From the AAIB it is clear that particular attention was paid to the FADEC but it was discounted as a possible cause given that the evidence from the wreckage proved that the engines were running normally at the point of impact."

The fact that the condition of the engines is not necessarily an indicator of whether the FADEC was functioning properly or not has been reinforced by some serious real-life problems with some engines equipped with FADEC.

When a spurious signal led to the FADEC systems on British Airways' Boeing 747 jets to enter an uncommanded power down, effectively shutting down all four engines, the engines themselves were, at the time working normally, but under incorrect instructions.

When an Airbus A320 crash landed at Warsaw because the engine's FADEC-controlled reverse thrust system and other braking systems failed to operate, it was found by investigators that everything on the aircraft had worked perfectly in the sense that the braking computers and sensors did what they were designed to do.

It was the programming of the software and the sensor's settings which had prevented the brakes from working under certain circumstances that had not been predicted.

The extent to which the Chinook's FADEC systems were understood, or could have been understood by the AAIB investigators is unclear, given the time they had. Tony Cable, the senior inspector of air accidents (engineering) at the AAIB who signed the report on the crash of ZD576, would later tell the Scottish Fatal Accident Inquiry that investigators were seeking an "expeditious" result.

He was asked at the inquiry whether it would have been possible to have the DECUs checked by a body which was independent of the manufacturers.

"No I don't think so in this case."

"Why is that?" asked Aidan O'Neill a lawyer for the Tapper family.

"I think it was far too specialised for that," said Cable. "The normal procedure in many, many cases is to take the equipment to the manufacturer, agree in advance what is to be done with it and to witness and direct the investigation of the particular piece of equipment, using the manufacturer's facilities which are commonly specialist facilities."

"So specialised that only the manufacturers could check whether or not a DECU was functioning?" asked O'Neill.

"Certainly with any degree of convenience. If had time I might have found somebody else but certainly to get an expeditious result I would certainly go to the manufacturers and have no qualms about doing so."

The Mod and the defence ministers Dr John Reid and John Spellar had, on several occasions, highlighted the thoroughness of the AAIB investigation into FADEC. For example on 21 April this year John Spellar wrote to the MP Robert Key, citing the depth of the AAIB's examination of FADEC. Spellar said: "...In its report to the RAF Board of Inquiry, the Air Accidents Investigation Branch (AAIB) states: 'In view of reports of a number of ongoing service difficulties experienced with the operation of FADEC, the Engine Change Units [sic] and FADEC were examined in some detail."

However Tony Cable, the senior investigator at the AAIB who studied the ZD576 wreckage, did *not*, by his own repeatedly-expressed admission, have a full understanding either of the FADEC's DECU system or of the series of problems which were reported by Chinook Mk2 pilots in the weeks before the crash on the Mull of Kintyre.

Indeed he disclosed under questioning at the Fatal Accident Inquiry that he had not been informed of all the FADEC-related incident reports in the weeks before the crash of ZD576.

He did not know, for example, about an incident involving ZD576 on 21 April 1994, less than two months before it crashed on the Mull of Kintyre. An internal RAF incident report said there had been a 40% torque-split and a corresponding change in engine noise [part of the FADEC's normal function is match the torque between the engines], but the same report said that engine indications were normal and it added: "No fault codes indicated on DECU." The incident was not mentioned in the AAIB report which showed a table of Chinook ZD576's FADEC-related faults dating back to January of 1994.

Cable was asked at the Scottish Fatal Accident Inquiry by Tapper's lawyer O'Neill why the report of the incident was not mentioned: "Because that didn't come to my attention," replied Cable.

O'Neill then asked: "So that was not reported to you by the body or people who gave you the DECU service history [of the ZD576]?

"Yes, that is correct. I don't believe I inadvertently missed out information that I had. To the best of my knowledge everything I know is in the table here [in the AAIB report].

So an incident which had led to an engine on the ZD576 being removed and put into quarantine a few weeks before the crash was not considered important enough to tell air accident investigators.

What Cable was told about the fault history of the ZD576 appears to have been limited. "No," he told the Fatal Accident Inquiry, "I don't think there is enough information from these brief [incident] reports to draw many conclusions..."

Also apparently withheld from the AAIB and Cable, it appears, was information about the legal action against Textron over the near destruction of the Chinook in 1989 because of a faulty design of the FADEC.

The AAIB's investigator Tony Cable gave no indication in his report, or in cross-examination later at the Scottish Fatal Accident Inquiry, that he had any knowledge of the EDS-Scicon report which had found 485 abnormalities in less than 20% of the FADEC software code.

He also no indication in his report, or in cross-examination later, that he was shown a report in which the Aeroplane and Armaments Experimental Establishment had deemed the FADEC software "unacceptable. "

Nor, it appears, is there any indication that the AAIB was given the reports which showed that concern about the FADEC went beyond that of the A&AEE. The Assistant Director of Helicopter Projects had, a few weeks before the crash, raised a series of questions about the FADEC, including the matter of outstanding safety case issues.

Cable was asked specifically at the Fatal Accident Inquiry whether he was made aware of the history of problems with the Chinook's FADEC. "Not in detail," said Cable, "I was made very well aware on many occasions during the investigation of ZD576 that the FADEC was a major concern of quite a number of people in the Air Force in relation to that accident, yes."

Although ministers referred repeatedly to the AAIB as the independent fount of expertise on the FADEC in relation to the crash of ZD576 Cable made clear during the Fatal Accident Inquiry that what he had been told about the operation of the DECU systems was limited.

When asked whether he knew the meaning of the fault codes F1, F2, B2 and E5, found in the DECU of a Chinook during engine start-up in March 1994, three months before the crash of ZD576, Cable said: "No, I don't. Offhand no."

In answer to other questions about the DECU and FADEC-related incidents in the weeks prior to the crash of ZD576 he replied:

"... I would not know sufficient about the DECU and the software and so forth therein to say..."

" ... I have no intimate knowledge of the....probably the software would be the item of interest here..."

"... To replicate the conditions or clearly any form of intermediate fault with any system is potentially going to be quite difficult to find the cause thereof ..."

" ... Whether the engine fail caption in these cases relate to the DECU is unclear to me. I think from what I know of the situation there is a good chance that they do. I don't know if that is the only possibility ..."

" ... Yes. I don't know if these are software problems. I say that that would be an area I would tend to concentrate on..."

"... I am by no means an expert on the system. I would have suspected yes, but I would need to check the details of the system. What the caption would be – I am not clear whether it would be an engine failure or a DECU. It would presumably depend on the situation. I know insufficient about the system, basically."

"... I am quite unclear as to whether one would have expected captions [warnings] had the system been working correctly, apart from the event that caused the torque split, or whether one would have expected the DECU faults to show up ..."

"... I don't know enough about the system, for example as to whether the power inlet temperature detection can directly trigger an "Engine Fail" warning and whether in the circumstance it will register a fault on the DECU. You would need someone who knows the system more intimately than I do to answer that... No I don't know enough about the system to know whether this is necessarily an indication of DECU problems. It may be."

Although Cable's report contained a table of incidents involving ZD576's DECU service history, taken from information supplied by the RAF, some incidents were not mentioned. They included an apparent torque mismatch on 26 April 1994, which ended up with the engine being replaced.

At the Fatal Accident Inquiry in Scotland, O'Neill, for the Tapper family, wondered why the incident had not led to any fault code appearing on the DECU. O'Neill asked Cable: "It could also be a fault in the DECU because it is not seeing these faults, but you don't know enough about the DECU to comment on that?"

Cable replied: "That is correct."

However Cable knew enough about the DECU to know that the device did not always detect every fault. Cable made this clear when he was asked whether the hexadecimal display of the DECU would show only "88" if it had no faults.

"If it *detected* no faults," he replied.

Cable was also able to comment on the number of abnormalities in the FADEC software, which he said appeared "reasonably high."

Asked whether an aircraft with the kind of the history of risk and faults would have been allowed to fly passengers in a civil aviation context he said he could not answer that but added: " ... the rate of fault, the judgement of overall risk of various states of failure and associated hazards from that is something that would require a great deal more information. I must agree with you: there is a reasonably high level of abnormality activity going on. Whether this is normal for this type of aircraft I could not say."

The level of abnormality was not perhaps the issue. The AAIB's comment once more raised the question: Should Tapper, Cook and their passengers, have been allowed to fly in a helicopter which had newly-fitted safety-critical computer systems that had shown ***any*** abnormalities.

*** * * * ***

Although the AAIB report was written before its author Tony Cable had fully understood the fault codes in the FADEC, ministers were to attach great importance to his findings.

Almost every year after the crash MPs, particularly Robert Key, would ask about the FADEC on the Chinook which crashed on the Mull of Kintyre. Usually he would be given a quotation from the AAIB report.

For example the defence minister John Spellar, in a letter to the MP Robert Key in April 1999 said of the surviving DECU: "The AAIB reported that 'no anomalies had been detected during the last flight and no unusual faults or excedences had been recorded over its life."

What Spellar did not say was that, later in the AAIB report, it was made clear that the assessment that the memory indicated "no anomalies" and "no unusual exceedences" was a judgement made by the manufacturers of the DECU.

The AAIB report said: "Both the fault codes and the level of exceedances were considered by Textron Lycoming and Chandler Evans to be reasonably normal for a typically operating system."

Was it reasonable to ask any contractor to identify possible serious problems with their own systems in the shadow of a major fatal accident, or to say whether the fault codes in their critical engine control system were of disturbing significance, even if they were?

It may also be worth noting that the AAIB's finding that the fault codes found on the DECU of ZD576 were normal has two overt caveats: "reasonably" normal and a "for a typically operating system." The judgement of what was reasonable was one made by the manufacturers. Also the phrase "typically normal system" assumed that the fault codes were being viewed in the context of an overall system which was working normally.

To put this into a wider context, the codes found in the DECU of the Chinook which was severely damaged at Boeing's flight test centre at Wilminton, USA, were all "soft" faults; that is they were not of such significance that the pilot should have been concerned.

Yet, in that case, the "E5" fault code in the DECU combined with the loss to the DECU of the remaining signal of the Chinook's rotor speed to bring about an uncontrolled rotor overspeed.

In the surviving DECU of Tapper and Cook's ZD576 an E5 fault code was found.

The AAIB did not make its own assessment of the significance of the E5 code. It described an assessment by Chandler Evans and Hawker Siddeley who said that it resulted from a power interrupt and was a "typical nuisance fault."

Had the E5 fault code not appeared in the DECU of the Chinook in the 1989 accident in the US, the aircraft would not have been severely damaged.

The Mod points out that the software was changed after the 1989 accident to ensure that, whenever "E5" was displayed on the DECU, indicating that it had latched out one of the signals, the computer system would not "disconnect" that signal permanently. It could re-acquire the earlier "latched out" signal in the event that the remaining sensor's signal was lost.

In short the Ministry was implying that an accident such as the one in 1989 at Boeing could not happen in exactly the same way again.

Four years after the 1989 incident and in the period before the crash of ZD576, however, it was apparent that engine overspeeds were still occurring. At the RAF's Board of Inquiry into the crash of ZD576, Squadron Leader David Morgan said: "The unforeseen malfunctions on the Chinook HC2 (mark 2) of a flight critical nature have mainly been associated with the engine control system FADEC. They have resulted in undemanded engine shut-down, engine run up, spurious engine failure captions and misleading and confusing cockpit indications."

The then Squadron Leader at RAF Odiham Robert Burke, a senior unit test pilot on the Chinook, said that he had experienced two engine overspeeds for no apparent reason and that no fault indication had been found afterwards on the DECU's displays.

The Ministry of Defence says that, while there may have been problems with FADEC before the crash of ZD576, there was no evidence of problems on its last flight.

This needs to be examined in the light of what the AAIB actually found. There were two DECUs on ZD576, one for each engine. Each DECU's memory comprises random access memory which is lost when power is shut off. But each DECU also has non-volatile Erasable Programmable Read-Only Memory which means that the fault data it detects stays in memory whether power is lost or not.

In the wreckage of ZD576, the DECU of No 1 engine was found generally intact. It was taken to Hawker Siddeley, the subcontractors which helped to write the software for the Chinook's FADEC systems. There was a problem reading the non-volatile memory. Attempts to read the memory were also made by a specialist defence organisation and some data was, in theory, found to be recoverable but the exercise was abandoned because data loss was so extensive.

The AAIB, which had not been present for some of the tests but had issued directions relating to them, reported that "data loss was probably consistent with the effects of ground fire exposure" and the loss was "probably irretrievable."

Ministers would later suggest that it did not matter that one of ZD576's DECUs was in effect destroyed in the crash. They suggested that it would be possible to tell that it was working by examining the surviving DECU on ZD576.

Reid told the Defence Committee in reference to the FADEC that "... if one was working normally the other one was working normally."

However technical documents written by Textron-Lycoming, Chandler Evans and Hawker Siddeley indicated that this was not part of the design.

Each of the two DECUs was assigned to the engine it helped to operate. The DECU on each engine was designed to operate independently of the other DECU, and athough there was limited sharing of information, the fault codes of one were not displayed on the other.

Therefore, with the damage to the No1 engine's DECU, information about the instructions that the device had fed to that engine, and any faults it might have had, were lost.

The fact that the engine itself was assessed by the AAIB as having shown no evidence of pre-impact malfunction was not an indication of the DECU's performance. To give a crude example, if a car crashes at high speed because the accelerator pedal became stuck, no fault would necessarily be found with the engine which had performed as it was instructed to do. The fault would lie with the accelerator which, in simplistic terms, was one of the functions of the FADEC system.

The No 2 DECU was also found "apparently intact," said the AAIB. The non-volatile memory on this DECU was readable, and ministers have pointed out that no fault codes were found from the last flight.
The No 2 DECU found in the wreckage of ZD576 was taken to the software manufacturers for their assessment. While there were no fault codes found in the "last-flight" section of the FADEC, a number of cumulative fault codes were present. The AAIB listed all these codes, but qualified its table by adding the comment that the assessment of the significance of the codes had been made by Hawker Siddeley and Chandler Evans.

The codes included:

A1: an abnormal torque signal outside 20 to 150%.
DB: a general channel failure of the reversionary (back-up lane)
E5: a difference in the signals from the two sensors that measure engine turbine speed.
F3: a difference in the sensors that measure the engine's gas generator speed.

The AAIB said: "Both the fault codes and the level of exceedances were considered by Textron Lycoming and Chandler Evans to be reasonably normal." The contractors had assessed all the codes as caused by power interrupts or other apparently minor problems. The "E5" fault code was described by Hawker Siddeley and Chandler Evans as a "typical nuisance fault."

Yet power interrupts were the particular problems that had plagued the FADEC during development in the 1980s. In 1987, a report written by Chandler Evans gave details of the results of a test of the FADEC. "Power interrupt testing in both primary and reversionary yielded poor results." And although an improvement was expected in the next set of FADEC tests, a report a year later, in 1988, said of power interrupts: "Results were similar to those encountered during phase 1 (in1987)."

Also the AAIB was unaware of the potential significance of the E5 code which was found on the surviving DECU of ZD576. It was the pre-existence of an E5 code that had contributed to the destruction of a Chinook at Boeing flight test facility at Wilmington, USA.

Therefore the AAIB REPORT needs, perhaps to be put into the following context:

- Investigators, by their own admission, did not fully understand the DECU, or all the ways that it impinges or does not impinge on the cockpit warnings and other systems.

- Investigators did not know the full meaning of the fault codes on the DECU which survived the crash of ZD576.

- The assessment of the fault codes as being minor and the level of exceedences being normal was made by the contractors.

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- Investigators by their own admission did not have a full understanding of the history of the FADEC's problems.

- Investigators were not told of the some of the incidents that had affected the performance of ZD576's engines and systems prior to the accident.

- Investigators and the Fatal Accident Inquiry in Scotland were not told, during their inquiry into the Chinook's FADEC systems, that an "E5" fault code had been the key to the near-destruction of a Chinook in 1989.

- Investigators gave no indication in the AAIB report that they had been given access to a report by the military computer company EDS-Scicon which found 485 anomalies in less than 20% of the FADEC code. The Fatal Accident Inquiry in Scotland was not given the EDS-Scicon report.

- Investigators gave no indication that they had seen a report by the Aeroplane and Armament Establishment in which the A&AEE had found the FADEC software "unacceptable." The report was not shown to the Fatal Accident Inquiry in Scotland.

- Investigators and the Fatal Accident Inquiry were not given access to the Mod's foremost independent FADEC experts, Malcolm Perks, who was working for the Ministry of Defence at the time of the crash of ZD576. He was the Ministry's expert witness in a case against the FADEC's contractor Textron-Lycoming.

- Investigators and the Fatal Accident Inquiry were not given access to the RAF Odiham's senior unit test pilot, Squadron-leader Robert Burke, who had a particular knowledge of the Chinook from a "users" perspective. Burke says that investigators were not allowed access to him because he was given specific instructions to stay away. "I was approached," said Burke, "by air force technicians assisting the accident investigator at the AAIB, to explain certain anomalies with control positions. When this was discovered, I was told specifically that I was not to answer any questions or say anything about this accident and not to talk to Mr Cable, the AAIB investigator who had called me up several times by phone."

- The AAIB uncovered contradictory evidence and inconsistencies which even the Mod and ministers do not appear to have fully understood.

- The AAIB in studying the complexity of the FADEC and other equipment on board ZD576 was looking for a "expeditious" result according to its senior investigator.

- Ministers in repeatedly quoting the AAIB report would rarely if ever give the context or draw attention to the provisos and qualifications contained in the AAIB's report.

More important than any of this, however, is that the AAIB did not address, nor was it supposed to address the issue of whether the release of the Chinook Mk2 into service was made prematurely. The A&AEE had said it regarded a re-write of the FADEC software in a verifiable form to be essential prior to it recommending a release to service of the aircraft. The AAIB had, itself, commented on the number of abnormalities in the FADEC software, which, said the senior investigator Tony Cable, appeared "reasonably high."

Yet all this proved of no significance for the pilots of ZD576. Tapper and Cook had believed all along that the Chinook Mk2 was not ready to enter operational service when they were instructed to fly it on June 2 1994. Their fears about the FADEC system had some substance. The RAF Board of Inquiry would hear of the "unforeseen malfunctions on the Chinook HC2 of a flight critical nature" which "have mainly been associated with the engine control system."

The same inquiry would conclude that there could have been technical problems on the last flight of ZD576, and that these problems might not have left any evidence. The Boards said that: "... distraction by a technical malfunction could have been a contributory factor in the accident."

But none of the evidence, as Tapper and Cook had suspected, would point decisively to a technical malfunction capable of causing the crash.

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Chapter Seven

Summary of Chapter Seven

Ministers contend there were no technical malfunctions on ZD576
Ministers say FADEC software is not safety critical
Manufacturers say FADEC is safety critical
Controversial nature of crash simulations
Technical data not taken into account in Mull of Kintyre crash simulation
Evidence in crash points to technical problems on ZD576
Function of the FADEC system
How software can cause malfunctions yet leave no trace of doing so
Investigators fail to test key instruments for evidence of engine overspeed
Possible technical problems that could have caused crash
US Army provides new evidence on causes of Chinook crashes
Evidence of problems on ZD576, consistent with US Army crash experiences
Evidence not considered by the RAF Board of Inquiry
RAF Board of Inquiry does not rule out technical malfunction as crash cause
RAF Board of Inquiry report doesn't blame dead pilots
RAF Board of Inquiry finds pilots guilty of gross negligence
Fatal Accident Inquiry in Scotland does not agree with negligence verdict
RAF refuses to reopen its investigation
RAF briefings mislead questioners
AAIB and Fatal Accident Inquiry unaware of MOD claim over faulty FADEC systems
Other information withheld from inquiries
Ministers give incorrect information to Defence Committee meeting on Chinook
Defence Committee examines flying restrictions on Chinook
Defence Committee told of FADEC-related overspeed incidents
Minister John Reid disparages Boscombe Down
Misleading information given to Defence Committee
Information withheld from the Defence Committee
Defence Committee reports it cannot find compelling evidence to blame the design of Chinook Mk 2 or components for crash
Was there a cover-up?

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That Jonathan Tapper and Rick Cook were unhappy about flying in the Chinook Mk2 is not in doubt. Their fathers, together with specialists who have studied the evidence such as Malcolm Perks and retired Squadron Leader Robert Burke, maintain the aircraft should not have been released into service by 2 June 1994.

But what evidence, if any, shows that there was a technical malfunction, or combination of problems that were capable of causing ZD576 to become uncontrollable?

None exists, according to a succession of ministers who appear to have had consistent briefings by their officials. Defence minister John Reid told Channel 4: "How do we know they were in control as they flew into the cloud? Because all of the evidence from this particular and specific case suggests that the ... engines, indeed the rest of the FADEC, and the rest of the Chinook was operating normally…"

Asked how he could be so certain of what was happening on ZD576 shortly before the moment of impact, Reid replied:

> " ...Well of course you can say to anyone that you can't prove a negative ... I cannot find evidence yet, nor has it been presented to me, which would justify over-ruling a Board of Enquiry of experienced RAF personnel which was based on a judgement by experienced Civil Aviation Authority investigators, who were considering concrete evidence from this specific case..."

So Ministers had ruled out the possibility that the Chinook was out of control in the moments before the crash. They went further. They suggested that the Chinook Mk2 was not capable of going out of control as a result of a FADEC problem. They also said that there had been no incidents anywhere where the performance of the FADEC had resulted in any safety-critical incidents involving the Chinook.

Reid told Channel 4: "... it [FADEC] is not only used in the Chinook but in a number of other aircraft. To my knowledge there has not been a serious accident in all the Chinooks which has been linked to a FADEC malfunction..."

On a separate occasion, in January 1998, Reid wrote to Nicholas Soames MP, assuring him of the integrity of the FADEC by quoting the contractor. Reid's letter said: "Textron-Lycoming added that, of all the units flying in the US Army and with other countries, there has been no known safety related FADEC software caused accidents."

During the Defence Committee hearing into the Chinook in March 1989, Reid said that of all the FADEC faults: "... "none of them have been safety critical to my knowledge."

However none of Reid's comments ever included any mention that the incident in 1989 in which an RAF Chinook had gone out of control, was due to the FADEC's faulty design. Reid also suggested to the Defence Committee that FADEC was incapable of causing the Chinook to go out of control. "Flight safety critical is very carefully defined as the failure of a component which would – not could – prevent the safe, continued flight and landing of an aircraft. With that very carefully definition, FADEC software is not flight safety critical because in the event of a total failure, the aircraft would be able to land safely."

There is no suggestion that Reid, Spellar or any other ministers ever intentionally misled MPs but the quality and accuracy of the briefings they received from their officials is open to doubt.

As recently as April this year, ministers were suggesting that FADEC could not have caused any serious problems. Indeed it was suggested that the engines themselves were not safety critical.

In a letter to Robert Key MP, Defence Minister John Spellar said, "... the design of the FADEC system and the design of the aircraft itself ... would enable it to auto-rotate safely to the ground in the unlikely event that ...each FADEC robbed both engines of power."

No mention was made in any of the ministerial letters to MPs, or the statements to Parliament by the Ministry of Defence, that if the engines on a Chinook failed in cloud, over a mountain range or sea, the helicopter might not be able to land safely.

Also ministers, when commenting on the evidence as reported by the Air Accidents Investigation Branch, did not take into account the fact that the AAIB was, itself, unaware of all the evidence.

The AAIB was unaware at the time of the crash on the Mull of Kintyre of the litigation between the Ministry of Defence and the Chinook's engines and FADEC contractors Textron Lycoming.

Had the AAIB seen the paperwork on the Mod case against Textron, it would have seen not only that the faulty design of the FADEC was ***capable*** of causing a Chinook Mk2 to go out of control but had ***led*** to a Chinook Mk2 going out of control in 1989.

Also, there is no evidence that the AAIB was shown a report by Boeing which demonstrated the various ways in which problems with the FADEC, combined with other failures, could have catastrophic implications.

In addition, the AAIB did not have access to Squadron-Leader Robert Burke, the RAF Odiham test pilot who was one of the most experienced pilot-users of the new Chinook Mk2, and who had experienced what he says was a multitude of problems including engine runaways. He says that he was ordered specifically not to talk to

Tony Cable, the AAIB's senior investigator. This is despite the fact that Cable had approached Burke on more than one occasion.

Cable went on to admit that he did not have a full understanding of the FADEC system when he was conducting his inquiry. Could all this explain why, in conducting simulations of the crash on the Mull of Kintyre, there were assumptions made on the basis that, in approaching the Mull, ZD576 was fully under control?

* * * * *

The investigators of the crash of ZD576 were without the help of Robert Burke or Malcolm Perks, and were partly reliant on the contractors for help in determining whether their computer equipment was functioning as it should have done.

However, in this technological age, they were not bereft of new tools to facilitate their inquiries. The computer simulation – looking to the untrained eye much like a video game – has emerged as one of the most potent and credible means of showing not only investigators but a wider audience, such as politicians and regulators, what happened in the last few seconds of a flight.

Few if any of the computer simulations which have been carried out after large-scale fatal crashes have pointed to a technical malfunction as the main cause. Some of the most notable simulations, including one conducted after the Mull of Kintyre crash have, however, pointed towards the pilots being to blame.

After the crash on the Mull of Kintyre, Boeing, the Chinook's manufacturer, created a simulation which appeared to show the pilots, in the last 2.9 seconds, pulling up suddenly to avoid the hill. The assumption was that, prior to this, the aircraft had been flying almost straight towards the fog of the Mull of Kintyre, as if the pilots had had a death wish.

There was no suggestion in the simulation that the pilots may have been distracted by warnings, spurious or genuine, as they approached the Mull.

The Ministry of Defence said in a written statement that Boeing had restricted the data used in the simulation to "evidence which was considered to be positive." As the state of the cockpit instruments could not be relied on, they appear not to have been used, so no allowance was made for spurious or genuine cockpit warnings, of the type that had plagued the Chinook in the weeks before the crash of ZD576. In reference to the simulation, the Ministry's statement said: "The instruments could have been subject to appreciable shock loading on impact and could not in all cases be considered as reliable evidence, unless corroborated by other evidence."

Nor was any data used which might have implied an engine or rotor overspeed. The Ministry statement said that: "Boeing did not use the rotor or engine indications as criteria to meet in the simulation."

It is common for simulations to be created by the manufacturers, and overseen by investigators whose inquiries have provided much of the data for the exercise. Whether they are selective with the data they use, and what emphasis they give to the information they decide to use is, however, the subject of controversy.

Rudi Kapustin, a former investigator with the National Transportation Safety Board, the equivalent of the AAIB in the USA, watched a simulation following a major air crash in Texas in 1985. "I don't know whether it was the first time it was used or not but video
animation was used to portray this flight going in and the lightning. But that's a bit of Mickey Mouse. I mean, you can put the lightning anywhere you want to on an animation."

The simulation was used to "convict" the dead crew of a Lockheed Tristar which crashed at Dallas Fort Worth airport in 1985, killing 137 people. It had been a perfect day, not a cloud in the sky, but shortly before the Tristar landed the crew had seen some bad weather in front of them.

One member of the crew had remarked (and it was picked up by the cockpit voice recorder) about lightning in the distance. Whether that lightning was in front of the aircraft or to the left or right some distance away was not made clear. Also, other aircraft had landed satisfactorily in front of the Tristar, and no real-time weather reports indicated there would be any severe windshear (a sudden downdraft of air).

Not perceiving any particular threat the pilots decided to land rather than go around again. On the final phase of their approach, they encountered the worst form of turbulence, a severe microburst, which has been likened to a high-pressure air hose forcing downwards on the aircraft.

"The downburst velocities were way, way beyond the capability of the aeroplane to climb out of," said Kapustin. "They simply could not arrest the sink rate."

The airplane crashed just short of the runway on a road, struck a car, decapitated the driver, and bounced into the airfield. One woman who survived was seen by firemen walking in a muddy field, her feet turned up, parallel with her legs. All that was keeping her upright was the mud.

As in the case of the Mull of Kintyre crash, there was a desire to show who was to blame. During the litigation, a video animation was presented which showed a straight-sided column of blackness while, on either side of the column, was blue sky. The black column, in which nothing could be seen but lightning, sat almost symmetrically on the runway which was surrounded by green fields. The plane was depicted as flying with purposeful and dark deliberation into a malevolent black void from which it was obvious that nobody could safely return.

Yet, in reality, the state-controlled authorities had told the pilots to expect nothing more than "just a little rainstorm" and that other planes had been landing safely. Kapustin said the government meteorologists were not present at the time of the landing, a back-up weather facility was not functioning and air traffic control did not tell the pilots how bad the weather was.

"Of course the government got off scot-free in the litigation," said Kapustin, who was the investigator in charge. "but that's how it is when it gets to litigation. I think whoever tells the most convincing story, right or wrong, wins. I wasn't happy about that."

The computer simulation by Boeing of the Mull of Kintyre crash was of the last 2.9 seconds. The parameters used in the production of the Boeing simulation assumed what the AAIB called "initial steady flight conditions." The simulation suggested that the pilots pulled up suddenly. For the short period before the last 2.9 seconds, the RNS 252 Tactical Air Navigation System was used to show the ZD576's flightpath.

Regarding the RNS 252, The Parliamentary Under-Secretary of State for Defence, The Earl Howe, wrote to Lord Chalfont, saying: "... the Board (of Inquiry) had the benefit of data downloaded from the aircraft's Tactical Air Navigation System from which it was able to derive an accurate picture of the Chinook's flightpath ..."

However the RAF Board of Inquiry said, in reference to the Chinook's flightpath, that the "preserved data" in the Tactical Air Navigation System and other navigation equipment "contained relatively little information concerning the previous history of the flight, the computers are primarily required to retain only data pertinent to ongoing calculations..."

Also the manufacturer Racal, in a report to the AAIB said: "The equipment is not designed to provide historic data…"

Racal was able to extract some data about the last few seconds. This provided, among other things, a position for the Chinook about one mile from the Mull. It appears that, on the basis of this and some other information, a simple line had been drawn between the point a mile from the Mull and the crash site. From this it was supposed that the Chinook, instead of making a left turn, had flown an almost straight line from a point a mile out to sea to the fog on the Mull.

In his letter to Lord Chalfont, the Earl Howe said of ZD576 that it: "... proceeded directly towards the Mull at very high speed, climbing only gently until the final few seconds."

However the RAF Board of Inquiry concluded that it was "unable to positively determine the sequence of events leading up to the accident."

There was criticism by computer experts and pilots about what data had been used and what had been discarded. No account was taken of the possibility that the aircraft could have been out of control, weaving and undulating in the last few seconds.

"From two main scraps of information – a waypoint change and a calculated height about 15 to18 seconds before impact – there was a dovetailing of information to suit the theory that the aircraft was under control, which wasn't necessarily the case," said Andy Fairfield, a former Chinook pilot in the Special Forces and currently a commercial airline pilot.

Boeing was not the only company to produce a simulation. A similar computer modelling exercise was undertaken by an organisation which was independent of Boeing but this simulation was carried out not on a Chinook or even a tandem-rotor helicopter.

Yet they were apparently convincing computer simulations.

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The first few lines of the report by the Air Accidents Investigation Branch into the Mull of Kintyre crash referred to the Boeing simulation.

The AAIB investigator reported that the simulation had indicated that the pilots, at the point of impact, had been trying to pull the aircraft up as much as possible. This suggested that the pilots had encountered the Mull at the last moment and were trying a last desperate manoeuvre. In keeping with this theory, the cyclic "joystick" lever was pulled back, which would have raised the nose.

The theory was also supported by the position of the collective lever which is like a handbrake in a car. It was near to, or at its maximum height. This suggested that Cook had turned the rotor blades into a sharp angle into the air, to ascend, a manoeuvre which would have called for considerable power from the engines.

What did not necessarily fit the theory was that the engines were not at maximum power. The AAIB had reported that, at the point of impact, the powerplants were "operating at similar intermediate power levels."

There was another problem with the simulation: the position of the pedals, which keep the aircraft pointing straight, and stop it drifting sideways.

It appears that Cook had pushed the pedal 77% towards the stop.

The minister Dr John Reid would say in 1998 that his understanding of the pedal positions was that they were "commensurate with a reasonably sharp left turn to the left, having seen the Mull to the right in front."

However the unit test pilot and Squadron Leader at RAF Odiham at the time of the crash, Robert Burke, says that the pedals are not used for turning but to keep the aircraft under control. Left and right turns are the function of the "joystick-style" cyclic lever. Taking the helicopter up or down on a vertical axis is the job of the "handbrake-style" collective lever.

The pedals are for keeping the aircraft from slipping into a sideways position or, in cruder terms, preventing the back of the helicopter skewing around to the front. In short they stop it from becoming uncontrollable.

Burke says that the pedals are sensitive to the slightest touch. Movements of less than 5% are normally sufficient to keep the aircraft under control. "A pedal position of 77% suggests to me that the aircraft may not have been under control."

In this context, it is of note that in 1998, when a Chinook in the USA suddenly became uncontrollable and turned upside down (see part 1), the pilots had fought unsuccessfully with the pedals to prevent the back of the helicopter coming around to the front – what the US pilots described afterwards as a "dramatic" yaw rate.

However the pedal position was not considered important by Boeing in its simulation of the Mull of Kintyre crash. In fact it left out the pedal position from its calculations.

The Mod would suggest later that the pedal movement indicated a possible "quick-stop" manoeuvre whereby pilots try to turn the aircraft sideways, using the fuselage as a wind buffer. Pilots know, however, that this can only be effective at less than 45 knots. The Chinook at the time of impact was estimated to have been going three times as fast as this. "It would be tantamount to suicide at this speed to try and turn the aircraft sideways," said one former senior Chinook pilot.

Also, it was assumed that the near-maximum height of the collective lever indicated a last-minute attempt by the pilots to climb steeply. No consideration appears to have been given to the possibility that the pilots may have been dealing with the start of an engine overspeed, the "cure" for which is to pull up on the collective lever to load the rotors and bring down their speed ... the side-effect of which is an unwanted increase in height.

And, while ministers have repeatedly pointed to the AAIB report as evidence that there was no ***evidence*** of technical malfunction capable of causing the crash, neither was there evidence to prove that the pilots flew with a reckless disregard for their lives, and for all the lives on board, towards the fog on the Mull, in an aircraft which was otherwise behaving perfectly.

Retired Squadron Leader Robert Burke believes that a temporary rotor overspeed, or the start of an overspeed of the type seen many times before the accident, or control jam (which was not discounted by the AAIB), is as likely a cause of the crash of ZD576 as pilot error.

The Ministry of Defence and ministers deny this saying that strip examination of the engines and the hydromechanical showed no signs of pre-impact failure or malfunction.

Indeed ministers have quoted regularly from the AAIB's report, in relation to the condition of the engines recovered from ZD576, to corroborate their assertion that both the FADEC systems must have been working properly at the time of impact.

This was said as recently as April and May this year in two separate letters written to MPs Robert Key and Martin O'Neill by the Defence Minister John Spellar. The Minister used almost identical words in assuring the MPs that FADEC could not have been a factor in the accident.

In both letters, Spellar cited the AAIB report as suggesting that the engines were working normally. Then Spellar's letters ceased to quote directly from the AAIB report and instead added a comment that the AAIB did not make: that from the state of the engines it was possible to deduce how the FADEC was functioning.

> "...The [AAIB] report," said Spellar, "goes on to say that: 'Strip examination of the engines indicated that both were running at high speed with turbines hot at the time of impact, and revealed no signs of pre-impact failure or malfunction that could have affected the operation of either engine.' Thus, as the evidence available indicated that the engines were working normally up to the point of impact, it was reasonable to conclude that FADEC could not have been a factor in the accident..."

However, as mentioned earlier, even if the engines and hydromechanical unit had been working perfectly before the crash – or rather had worked as they were designed to do – this would not necessarily indicate how the FADEC was functioning.

The FADEC is a fuel control system. It sends signals to regulate the flow of fuel to the engine, and hence its power output, after taking into account the instructions from the pilot, and sensors which indicate the speed of the engine and rotor operating conditions. It does this through the software which has the ability, through the signals it receives and sends, to increase or decrease engine power.

At one extreme it can run down an engine to idle. At the other extreme it can cause an engine to run up to maximum power. But because the software is not like a lightbulb which fails visibly, all the potential faults with it cannot be seen simply by delving into the code.

That's because the faults often lie with the design, not the code itself. Therefore software and aviation engineers, and other specialists, have come together to set down international standards.

This is because the only way that independent assessors can have confidence in safety-critical software is by checking not only the code itself but the standards that have been applied when the code was written and tested.

The standard of the documentation is no less important to assessors of safety-critical software, than diagrams are to the architects of a large building. Malcolm Perks, one of the world's foremost independent FADEC specialists, makes the point that without the correct documentation, it may be impossible to know how the software is supposed to fit together, whether it is safe, and whether there are parts there that should be there and are not, or vice versa, which may affect the integrity of the design.

If, to use an earlier analogy, a robot unexpectedly walks off a cliff because of a bug in the software which controls its motors and mechanisms, an examination of the wreckage is likely to show that the motors and mechanisms were working perfectly. The problem would be with the software which may be embedded in electronic chips and therefore invisible to the unaided, naked eye.

It would be the software which instructed the motors and mechanisms to behave the way they did. It is likely that that the only way the bug could be detected and corrected is by a thorough investigation of its software.

It would be illogical in this instance to say, in examining the wreckage of the robot, that because its motors and mechanisms were working perfectly at the point of impact, there was nothing wrong with the software which controlled the motors and mechanisms.

Similarly, if an all-electronic car crashes at high speed into a wall because a bug or design fault in the software-controlled accelerator pedal causes it to stick, perhaps even temporarily, an examination of the wreckage is likely to show that the engines were working perfectly. They had performed exactly as directed by the software which controlled the accelerator pedal.

It would be illogical to say that, because the car's engines were working perfectly at the point of impact, then the software controlling the accelerator must also have been working.

This is because the fault lay in the software, or the design of the software.

In the same way, it was equally illogical for Spellar to say that because all the signs were that the Chinook's engines were working at the point of impact, it was reasonable to conclude that FADEC could not have been a factor in the accident.

* * * * *

The possibility of an overspeed on ZD576 needs to be weighed against all the various software and other mechanisms designed to stop overspeeds happening.

Yet these are complex systems because they must also prevent the opposite happening: the engines thinking that the rotors are overspeeding and wrongly reducing the power output.

As mentioned earlier, an overspeed on a Chinook can be more dangerous than an engine cutting out. This is because an overspeed can overstress the aircraft and cause its near destruction, as happened in the 1989 accident, or battling with an overspeed can distract a pilot for long enough to cause a crash. An overspeed can even cause the rotors to fly off.

Burke described one of the incidents in which he had contended with an overspeed. "The first thing that happened was I was back in the cloud with the engine at full speed with the thrust lever up to my ear. We were going faster and faster upwards and we were accelerating ... you're then into a major emergency situation."

Despite all the FADEC mechanisms to prevent a rotor overspeed, the RAF Board of Inquiry was told that overspeeds were a particular problem on the Chinook Mk2. Squadron Leader David Morgan told the RAF Board of Inquiry:

> "The unforeseen malfunctions on the Chinook HC2 (Mk2) of a flight critical nature have been associated with the engine control system FADEC. They have resulted in undemanded engine shutdown, engine run up, spurious engine failure captions and misleading and confusing cockpit engine indications."

And there ***is*** evidence in the wreckage of signs of a possible overspeed, although this does not appear to have been considered seriously by the AAIB.

Burke says the cockpit instruments which are important in providing early warning signs of a rotor overspeed are the torquemeters, the tachometers, and the engine emergency power warning.

The AAIB, however, did not test the torquemeters or the tachometers. The AAIB report said:

> "***Testing of the torquemeters and triple tachometers could not be attempted because of the lack of facilities but their functionality was dubious and testing was not considered critical."***

This lack of attention to the torquemeters was despite the fact that on 21 April 1994, a few weeks before the crash, a faulty torquemeter had caused the engine to be removed.

The aircraft in this case was ZD576.

Was the AAIB deliberately kept in ignorance of this incident?

Tony Cable, the AAIB's investigator of the crash, told the Scottish Fatal Accident Inquiry that he had been informed of incidents involving ZD576 ... but not the 21 April incident.

Was the Ministry keeping silent over any evidence that might show the susceptibility of the Chinook Mk2 at that time to incidents such as possible overspeeds?

The Mod responds to the suggestion that ZD576 may have been experiencing an overspeed by saying that the lighthouse-keeper on the Mull, who had a particular interest in helicopters, would have heard an increase in the noise of rotor "slap", and he had not noticed any change in the sound of the blades.

But the lighthouse keeper did not see the crash or hear the sound of the rotors for the entire period that ZD576 was in the vicinity. He told the Fatal Accident Inquiry in Scotland that he was sitting in the living room of his lighthouse at 5.55pm and had heard the sound of a helicopter, which he knew to be the sound of a Chinook. He said he went outside and although he did not see the aircraft he heard it approaching for about "two, to two and a half minutes."

He said that although he did not hear the sound of the Chinook for the entire time, what he did hear did not sound unusual. However the Sheriff in the Fatal Accident Inquiry in Scotland was uncertain how much importance could be attached to the testimony of the lighthouse keeper, Mr Murchie, in relation to his hearing of the Chinook. "But in all circumstances," said the Sheriff, "it seems to me that there must be some doubt about the reliability of Mr Murchie's evidence as to what he heard of the aircraft and for how long he heard it."

Also the reliability of the lighthouse keeper's evidence can be weighed against the fact that it is the Mod's contention that there was a dynamic manoeuvre such as a call for maximum power and a sharp pull-up before impact ... yet the lighthouse keeper says he heard no change in the aircraft's sounds.

However a temporary overspeed should not in itself have caused the Chinook to crash into the Mull, though it could have caused an emergency and could have explained why ZD576 did not make a turn away from the Mull as expected. It would also explain why it entered cloud unexpectedly, the side effect of dealing with an overspeed being a climb.

Any study of large-scale fatal accidents, however, shows that many of them are the result of two or more simultaneous problems which in themselves are minor but which conspire together, in a way which nobody has predicted, to cause a catastrophe.

Apart from the FADEC, a particular problem with the Chinook was the detachment in flight of a part on the flying control assembly. The detachment of the part would, by itself, be of little concern.

It might cause the collective lever to go heavy, or the "joystick" cyclic lever to lurch to one side, such that it had to be physically held in place by the pilot.

However it *would* be a safety-critical problem if the loose part caused a flying control to jam. It might, for example, cause the aircraft to go straight on instead of making a turn as intended.

In this event the aircraft would be uncontrollable, says Burke. He points out that if a spring which is about 7 inches long came loose in the control closet, one of the most flight safety sensitive areas of the Chinook where a number of key controls come together, this could make the aircraft uncontrollable.

The Ministry says in response to the idea of a control jam that ZD576's spring assembly/inserts were last checked prior to the aircraft embarking on the fatal day's flying. It also refers to the rarity of accidents involving control jams. However the incident involving Bric Lewis' Chinook which overturned shows that control jams can happen. There was another entirely separate incident reported by the US Army. As the pilot of a newer class of Chinook turned to land "the flight controls locked up in yaw axis to the left." As the pilot wrestled with the controls "no movement of controls occurred." No caution lights illuminated on the caution panel. The US Army newsletter added: "After approximately 30 seconds the flight controls broke free.."

Had such an incident occurred on ZD576, a wait of 30 seconds before the controls became free might have been too long...

The AAIB report into the crash of ZD576 said that the method chosen by the manufacturers to attach parts to the flying control assemblies "appeared less positive and less verifiable than would normally be expected for a flight control system application."

The report also said on the same matter: "Most attachment inserts on both flying control system pallets had detached, including the collective balance spring bracket that had previously detached from ZD576's thrust/yaw pallet, with little evidence available to eliminate the possibility of pre-impact detachment."

A large spring had become detached on ZD576's collective lever on 10 May 1994, a few weeks before the crash.

Had Cook and Tapper experienced a control jam, it would explain why the left turn was not made and why the Chinook apparently headed straight for the Mull.

Into this murky pool of uncertainties, there was yet another potentially serious problem which should have been taken into account but wasn't. It is a problem which has not so far been considered by ministers, the Mod, nor indeed by the families.

The US Army (which has more Chinooks by far than any other country) has reported in its newsletters that there have been movements of the flying controls that have occurred for no apparent reason and have left no obvious visible clues after the incident. The only clues to these uncommanded control inputs had been the fact that the pilots had survived to say what had gone wrong.

Had the pilots of ZD576 experienced an uncommanded control input, which had stopped the aircraft from making a left turn and had caused it to head towards the Mull, they would not have been able to explain what had happened because there were no survivors. There would not necessarily be any clues in the wreckage, if the US experiences are anything to go. Pilot error would therefore be assumed.

Yet there was a clue in the wreckage of ZD576.

As part of its study of Chinook incidents the US Army requested information from pilots and others about incidents similar to the one in 1998 (reported in part 1) in which a Chinook had, without any command from the pilots, turned upside down.

The cause of this 360-degree "barrel-roll" was not established decisively and the US Army said that computer simulation was not sophisticated enough to "produce the exact manoeuvres of the incident aircraft; therefore no absolute cause and effect has been established."

As a result of its request for more information on similar incidents, the US Army found that there had been a number of uncommanded flight movements, where the controls in effect seize command of the aircraft without any input from the pilots.

It went on to list as the first cause of these incidents: "contamination of hydraulic fluid." A separate bulletin said that action would be taken to remove contaminants from flight hydraulic systems on the Chinook.

So what does this have to do with the crash of ZD576 on the Mull of Kintyre?

Tucked away near the back of the AAIB report, on page 50, a defect is revealed which appears to have gone unnoticed since the crash.

The paragraph reveals that there was contamination of the hydraulic systems on ZD576.

The AAIB says: "Strip examination revealed no anomalies apart from the ... considerable quantity of very small metallic particles in residual fluid ...and the presence of four fine metal slivers" up to 0.2in long on the actuator which helps to control yaw movements. The AAIB report said there were no indications that this had contributed to the accident but at that time, in 1994, the experiences in the US concerning the uncommanded control inputs with a suspected cause of contamination of hydraulic fluid was not known. That evidence emerged only in 1998 and 1999.

Yet the AAIB had not overlooked the significance of the contamination of the hydraulic systems.

> "These features," said the AAIB, "did not appear to have been associated with the effects of the accident and suggested pre-impact hydraulic system contamination..."

So serious was the potential of the problem to cause malfunction that the AAIB listed the contamination in its list of nine recommendations. It called for measures to monitor.... "hydraulic system debris."

Therefore the AAIB's investigators, after the crash of ZD576, had reached the same conclusion as the US Army. The US had investigated incidents of uncommanded movements of the flying controls that left no visible traces of the cause. Both organisations had concluded that action was needed to monitor hydraulic system debris.

The difference was that the US Army had not accused two pilots of gross negligence on the basis that there was no evidence of technical malfunction.

In the case of ZD576 evidence existed which did not rule out the possibility that the pilots may have been struggling to control yaw at a time when the aircraft may have been unresponsive to control inputs, as in the barrel roll of a Chinook in the USA.

Can it now be said, in the light of these newly-detailed technical problems on ZD576, that there is no doubt whatsoever that the pilots were to blame for the crash?

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Within a day of the crash of ZD576, the RAF Board of Inquiry began its work. Nobody could have doubted the thoroughness of its investigation, on the limited technical evidence available to it.

When its report was issued in 1995, the document mirrored the AAIB report in as much as the RAF investigators mentioned nothing about the 1989 accident involving an RAF Chinook Mk2 at Wilmington in the US.

Nor did the RAF inquiry report mention anything about the EDS or the A&AEE reports on inadequacies in the Chinook Mk2 FADEC system.

It did not draw attention to the dangers inherent in contamination of flight control hydraulic systems. Also there was little credence attached to the possibility that one of the crewmembers on ZD576 may have been trying to set an emergency signal on the "IFF" transponder in the seconds before impact.

Yet the RAF report was an objective one, based on the evidence available. It took lengthy and detailed statements from serving RAF officers, including pilots.

Several witnesses to the RAF Board of Inquiry and the later Scottish Fatal Accident Inquiry, believed that Tapper and Cook had seen the Mull and had decided to turn left, and had entered this "waypoint" change into the navigation computer system.

However in the 15 and 18 seconds before impact, the Chinook had, for reasons which could not be ascertained, flown straight on, towards bad weather on the top of Mull, at high speed, with nothing approaching enough climb to fly over the land.

If nothing else this would have put Tapper at risk of breaking the icing restrictions, and therefore the terms of the Chinook's release to service. Tapper had sought advice on this restriction and been warned against breaking it. Squadron leader Robert Burke at RAF Odiham, who knew Tapper, says that he would not have broken the restriction. He was the "most by the book pilot I knew" says Burke.

Indeed the idea that the pilots had elected to fly into bad weather on the Mull, instead of turning left to remain below cloud in visual flying conditions, was attacked by Group Captain Crawford, the station commander of RAF Odiham.

He told the Inquiry in a written statement:

> "I find this difficult to believe; such actions would go against all the crew's instincts and training. Moreover it is the very antithesis of the professionalism and careful planning that had gone before." He added in his statement that the idea that the crew could have been deceived into thinking their climb rate was sufficient to fly over the Mull was "incredible."

He added:

> "Whilst tackling this issue the Board were unable to totally discount the following factors: spatial disorientation or visual illusion; an unregistered technical malfunction; human factors. Any of these or a combination of them could in my view have sufficiently distracted the view from the task of turning away from the Mull to caused them to inadvertently enter cloud and then fail to take the correct procedure for an emergency climb in a timely manner. The Board consider engine control system malfunctions and it is particularly relevant to note that at this stage ... spurious ENG FAIL captions, lasting on average 7-8 seconds were an increasingly frequent occurrence. These are now well understood but at the time they were not."

> "Had such an indication occurred it would have caused the crew considerable concern particularly as they were over water with no obvious area for an emergency landing. Such a warning would also have required urgent and very careful check of the engine instruments and Flight Reference Cards."

Evidence was given to the RAF inquiry about some of the FADEC problems and other malfunctions.

> "The Board reviewed the technical malfunctions and air incidents which had occurred with the Chinook HC2 (Mk2) in RAF service and considered whether any could have played a part in the accident. The Chinook HC2 had experienced a number of unforeseen malfunctions mainly associated with her engine control system, including undemanded engine shut down, engine run-up, spurious engine failure captions and misleading and confusing cockpit indications."

> "The Board found no evidence that any of these malfunctions had occurred on Chinook ZD576's final flight. Nevertheless an unforeseen technical malfunction of the type being experienced on Chinook HC2 which would not necessarily have left any physical evidence, remained a possibility and could not be discounted."

The Board concluded that technical failure was unlikely to have been a direct cause of the accident but said it was "possible that a technical malfunction or indication could have provided a distraction to the crew."

The possibility of two or more simultaneous problems such an "Eng Fail" warning and a temporary overspeed does not appear to have been considered.

However, in its summary the Board said that in the absence of a definite cause of the accident and the lack of a cockpit voice recorder, "the Board found it particularly difficult to determine what part human failings had played in the accident..."

> "The Board could find no evidence that Flt Lt Tapper had not approached and prepared for the sortie in anything other than a thorough and professional manner. The Board was unable to positively determine the sequence of events leading up to the accident and therefore concluded that although it is likely that Flt Lt Tapper made an error of judgement in the conduct of the attempted climb over the Mull of Kintyre, it would be incorrect to criticise him for human failings on the available evidence..."

> "The Board concluded that Flt Lt Cook could not be criticised for failing to identify any errors. The Board concluded that there were no human failings with respect to Flt Lt Cook."

In its recommendations the RAF Board of Inquiry hinted at the RAF's lack of understanding of the fault histories of the FADEC system.

> "The Chinook HC2 Engine DECUs record significant amounts of engine operating data which can be used for engine health monitoring. The data is cumulative and, if not extracted and recorded on a regular basis in order to associate with specific operating periods, progressively loses its value. In contrast to the US Army, the Royal Air Force does not extract and make use of this data."

One facet of the RAF's Board of Inquiry which went largely unnoticed is that it registered in official inquiry documents that pilots were experiencing difficulties of a flight critical nature involving the engine control system, in the period before the crash of ZD576.

So here was further evidence that pointed to the fact that the Chinook Mk2 had been released prematurely into operational service.

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The conclusions of the RAF Board of Inquiry were signed on 3 February 1995, by three Board members: two squadron leaders and the Inquiry's President, a wing commander. Their report then went to the Board's reviewing officers, Air Chief Marshal Sir William Wratten and Air Vice Marshal J Day who were part of the Inquiry. A month later, in March 1995, Day signed a statement which contained his views on the Inquiry report.

If there was any possibility that Tapper and Cook's families would – could – begin to regain possession of normality after their losses, Day laid waste to every particle of hope.

"When the aircraft crashed it was flying at high speed well below safety altitude in cloud in direct contravention of the rules for flight under Visual Flight Rules or Instrument Flight Rules," said Day.

He added that the aircraft could have climbed to safety at 2,800 feet, He commented on the fact that the icing limit existed and suggested that this explained why the crew wanted to fly under visual flight rules. He made no reference, however, to the fact that to overfly the Mull would have been against every instinct and training of the crew.

He said that any distraction to the crew was not such a strong possibility that it would have "been likely to prevent such an experienced crew from maintaining a safe flight."

"Therefore," he continued, "unlike the Board and the Officer Commanding RAF Odiham, I reluctantly conclude that the actions of the crew were a direct cause of this crash."

Of Tapper he said his failure was not an honest mistake while exercising the degree of skill that could have been expected of him. "To the contrary Flt Lt Tapper did not exercise appropriate care and judgement," said Day.

He added: " ... while aware of the difficulty of attributing negligence to deceased aircrew I am nevertheless forced to conclude that Flight Lieutenant Tapper was negligent to a gross degree."

Of Cook he said that, as an experienced Chinook captain, he should have recognised the dangerous environment into which he as flying.

> "He continued to fly the aircraft directly at the Mull at high speed, at low level in poor visibility. I therefore cannot avoid the conclusion that Flight Lieutenant Cook was also negligent to a gross degree. It is incomprehensible why two trusted experienced and skilled pilots should as indicated by all the available evidence, have flown a serviceable aircraft into cloud-covered high ground."

His short report mentioned none of the evidence which showed that the pilots had intended, in the last 15 to 18 seconds, to fly over the Mull rather than make a left turn. Nor did he make any specific mention of the problems that could seize command of the aircraft from the pilot; seize it for only for a few seconds perhaps, but that was all it took to nearly destroy a Chinook at Wilmington in the USA.

And Day made no mention any of the incidents that were described as flight critical during the RAF Board of Inquiry, such as engine runaways.

Nor did he mention the possibility of control jams, uncommanded control inputs, the safety-related issues raised by the Assistant of Helicopter Projects or the fact that the A&AEE had said that they regarded the re-write of the safety-critical FADEC software in a verifiable form to be essential prior to recommending that the Chinook have release to service.

There was not a hint of a suggestion that the crew may have entered an emergency code into the IFF transponder.

Indeed Day concluded that "... the Inquiry found no evidence of technical malfunction..."

This comment did not take into the Board's finding that "... an unforeseen technical malfunction of the type being experienced on Chinook HC2 which would not necessarily have left any physical evidence, remained a possibility and could not be discounted."

* * * * *

A month after Day's judgement, there appeared a similar statement by Sir William Wratten, the Air Chief Marshall.

> "Without the irrefutable evidence which is provided by an Accident Data Recorder and a Cockpit Voice Recorder, there is inevitably a degree of speculation as to the precise detail of the sequence of events in the minutes and seconds immediately prior to impact," he wrote. "What does emerge from the inquiry, however, is that there is no evidence whatever of any combination of possible minor problems, or any major difficulty, which would have so taxed the skills of the crew that they had no option other than to keep flying towards high ground in speed at low level in deteriorating conditions of cloud and visibility.... Why they ... elected to ignore the safe options open to them and pursue the one imposing the ultimate danger, we shall never know ....there is not even a hint of circumstances which would have been beyond their professional skills to accommodate ... I therefore agree ... that the actions of the two pilots were the direct cause of the crash. I also conclude that this amounted to gross negligence."

The pronouncement was highly unusual. It was common, after military crashes, for dead pilots to be blamed. Indeed it was statistically the norm. However it was unknown in recent years for pilots to be found guilty, formally and seemingly irrevocably, of gross negligence.

For dead pilots to face such opprobrium, the rules state that there should be no doubt whatsoever of their negligence.

As with Day's judgement, there was not a suggestion in Sir William Wratten's statement that the pilots were flying in good visibility, the sun glinting off their aircraft's fuselage, and would have remained in good visibility had they stayed at approximately the same height and made a safe left turn as indicated on the navigation computer.

In effect Day and Sir William had, in tandem, suggested that the pilots, for no apparent reason, had changed their minds about a left turn and had decided to continue to fly straight on, climb a little and head fatally towards the cloud on the top of the Mull: an action that the station commander at RAF Odiham had described as incredible... not something even a junior crew would do, let alone one qualified to fly Special Forces missions.

Neither Day nor Sir William appear to have considered the possibility that ZD576 could have been afflicted by an uncommanded control input. At that time - indeed throughout the 1990s - such incidents were not uncommon though the US Army has learned much more about them in the last two years.

> ***One thing the US Army has learned is that uncommanded movements of the flying controls do not always leave any evidence of technical malfunction.***

The two senior officers seemed to regard the new FADEC-equipped Chinook as a machine with as much transparency in its behaviour as the Tiger Moth biplane. Rather, it was - is - a recondite machine with highly complex safety critical software which has not always behaved predictably.

And so, with the strokes of contumelious pens, Day and Sir William vilified the reputation of the two pilots. They found certainty where their three colleagues, a few weeks before, had expressed doubt.

Condemning the pilots directed attention away from the decision by senior RAF and Ministry officials to put two reluctant pilots in charge of an aircraft type that had, the day before, been effectively grounded by airworthiness assessors at the Aeroplane and Armament Experimental Establishment.

"They'd lost all these people and they had to blame someone," said Sarah Cook. "They did not want the blame to fall on ineptitude higher up the scale. So they made the pilots scapegoats, as far as I am concerned and an awful lot of people are concerned."

Not so much as an eddy of blame swept its way towards those who had brought the Chinook Mk2 into service before it was ready.

Instead the blame ended up huddled into a tiny, corner of wracked defencelessness: the memories of the families of the two dead pilots.

It was just as Flight Lieutenants Jonathan Tapper and Rick Cook had predicted a few days before the crash...

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From the point of view of some officials at the Ministry of Defence, one of the most inconvenient facets of the crash of ZD576 was that it happened in Scotland. There would therefore have to be an independent inquiry, a Fatal Accident Inquiry, headed by a sheriff over whom the Ministry would have no control.

The Inquiry, in a temporary courtroom near Glasgow, gave a chance for the lawyers of the families of those killed in the crash to question the evidence put forward at the RAF Board of Inquiry.

The disdain that the Ministry had for the inquiry can been seen in the concluding comments of the civil head of the Fatal Accident Inquiry, Sheriff Sir Stephen Young. "I have to say that my task in acquiring this knowledge (about the Chinook) was not made any easier by the manner in which evidence was presented by the Crown to the inquiry."

He explained:

> "For example it may be thought rather odd to have expected the court to understand two and a half days of very detailed technical evidence from Mr Cable ... about his investigation of the wreckage of ZD576 before any evidence had been led to demonstrate clearly what a Chinook Mk2 helicopter was meant to look like, and how it was meant to work, when it was entire.
>
> "Indeed it was only just before lunch on the ninth day of the inquiry that questions were for the first time asked of Mr Cable in cross-examination about how it is that a Chinook Mk2 helicopter can actually be made to fly forwards, upwards, downwards and to the side through the air."
>
> "Likewise, while there were among the productions for the Crown in excess of 60 photographs of the wreckage of ZD576, there were only six photographs of a complete Chinook Mk2 helicopter. Of these two were of the exterior of the aircraft.... In the general photograph of the cockpit the cyclic sticks could be seen in broad outline and with a practised eye the top of the right hand collective lever could just be discerned. The AAIB report contained a few diagrams ... which were of very little assistance in understanding the basic design and construction of the aircraft..."

The Ministry of Defence argued at the inquiry that it was not up to the court to endorse or reject the findings of gross negligence. In conclusion, however, Sir Stephen said:

> " In the event it has not been established to my satisfaction that the cause of the accident was that found by the Board of Inquiry and it would not be for me to comment further upon what others may or may not have said on the matter."

The Ministry's view of Sir Stephen's inquiry could also be detected in a "question and answer" briefing written by Ministry officials for its spokespeople.

If asked to comment on the Sheriff's determination, spokespeople were to say: "We will clearly need time to digest the content of the very lengthy (120-page) report before making a substantive comment."

Yet the same briefing note makes it clear that the Mod would be in no way influenced by the report, whatever it contained.

If asked whether the RAF would reconvene its Board of Inquiry in the light of the report, spokespeople were to say: "No. The RAF Board of Inquiry comprised members with first hand knowledge of Chinooks who conducted an exhaustive investigation. Neither the Sheriff's determination nor his personal views alter the conclusions of the RAF Board of Inquiry."

If asked why, if the Sheriff had not apportioned blame, how could the RAF? … the suggested reply was:

> "The extremely thorough Board of Inquiry eliminated any structural or technical malfunction as the cause and concluded that the accident was caused by the action of the two pilots. Unfortunately they continued to fly towards the high ground of the Mull of Kintyre below a safe altitude in bad weather conditions."

If asked why the RAF was so sure, in the absence of flight data and cockpit voice recorders, that there was no technical malfunction the reply was:

> "Data from the Tactical Air Navigation System (TANS) enabled the Board to derive an accurate picture of the flight path, establish that the aircraft was climbing, confirm speed and impact and conclude that the aircraft kit was functioning properly."

This last reply in the briefing note was inaccurate to the point of raising the question of whether the Ministry cared about the facts. The Tactical Air Navigation System was able to give some limited navigation information relating to the last moments of ZD576 but it could not conclude that the aircraft kit was functioning, says Andy Fairfield .

Not even a purpose-designed accident investigation tool such as a flight data recorder could, even with hundreds of checks or parameters, necessarily determine whether every piece of aircraft kit, from the software in the FADEC to the reversionary valve stepper motor/gearhead was functioning correctly and was, for example, without a design fault.

The Ministry's spokespeople were also briefed on what to say if asked why the RAF was continuing to fly the Chinook Mk2 at a time when Boscombe Down had suspended trials flights.

The suggested reply:

> "Test flights were intended to extend the aircraft's operational flight envelope. The Chinook HC2 (Mk2) had already been cleared for routine squadron flying subject to a few restrictions. The Chinook HC2 which crashed was operating within these restrictions."

It was an artful reply in that it did not answer the question. The reply suggested that, if the Chinook was flying within the weight and icing restrictions, it was safe.

However the weight and icing restrictions did not address at all the issue of uncommanded control inputs, engine run-ups, the safe-case concerns of the Assistant Director of Helicopter Projects or the fact that the A&AEE had wanted the software rewritten prior to it recommending a release to service.

The briefing note was a taste of things to come. From 1995 onwards defensiveness, inaccuracy and disingenuity would characterise statements made by ministers and their officials about the FADEC and the crash of ZD576.

*** * * * ***

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

The cover-up

Following the crash of ZD576 there had been reports by the Air Accidents Investigation Branch (AAIB), the RAF Board of Inquiry, and the Fatal Accident Inquiry in Scotland.

The search for the truth did not end there. MPs, particularly Martin O'Neill, Menzies Campbell, Robert Key, and James Arbuthnot, have continued over the last five years to doggedly seek answers to questions about the accident, the problems before the crash and in particular the FADEC system.

Some of the parliamentary replies to questions about the Chinook's computer systems appeared to assume that anything that was said by the Mod could not be credibly disputed because only the Ministry has all the facts.

On this basis – a basis of no genuine accountability - the Mod and ministers have made some outlandishly illogical assertions.

Why were some of the replies so wide of the truth? One could assume that officials made innocuous mistakes in briefing ministers. However many of the answers carried in them a vein of consistency and assertiveness.

For example the Ministry has said repeatedly over the past five years that the Chinook's software was not regarded as safety critical. This is despite the fact that the A&AEE had said in 1994 that Boeing had considered the system to be safety critical.

Finally, in April 1999, the defence minister John Spellar, answering a direct question by Robert Key MP about whether Boeing had considered the FADEC system to be safety critical said:

> "They did so, but assessed that the risk of catastrophic failure was mitigated by the design of the FADEC system and the design of the aircraft which would enable it to auto-rotate safely to the ground in the unlikely event that ... each FADEC robbed both engines of power."

Earlier, in a written statement to the House of Commons Defence Committee in 1998, the Ministry of Defence said***:***

> ***"Boeing did not consider the FADEC to be flight safety critical because the engines on the Chinook are not considered to be safety critical."***

Apart from the incongruity in the two statements, the notion of the engines on an aircraft not being safety critical because it can glide safely to earth without them is disingenuous.

If both engines failed when the aircraft was over a mountain range, sea, in cloud or at a time when considerable engine power was needed to fly out of trouble, the consequences could involve easily be catastrophic.

Many of the examples which show the difficulty of obtaining the facts can be seen from the comments made by the then Defence Minister Dr John Reid when he appeared before the Defence Committee in March 1998. So many of his statements were incorrect or left MPs with an incorrect impression that it is worth examining them:

> "Let me tell you that up until the accident at the Mull of Kintyre there had been five failure incidents reported ... during the first year of warranty that is May 1993 to April 1994, five faults occurred during 950 flying hours. None of them related to software, none of them .. all of these are what were called soft faults and as such had no effect on the operation of the FADEC ... The fifth fault was an electrical power interlock ... I am sorry to go into such detail but I ... thought you would want me not only to give you the number of FADEC incidents but also the details of this so you could satisfy yourselves on that aspect."

What was noteworthy about this answer was the exactitude of the dates chosen: May 1993 to April 1994. If April 1994 itself were excluded there were indeed five FADEC-related incidents which affected the Chinook Mk2.

> ***What Reid did not say was that there were a further six incidents in an eight-week period from the end of March 1994 before the crash of ZD576. Five of these related to one aircraft in particular ... ZD576.***

The incidents are listed in the RAF's incident reports.

Reid's assertion that all the faults were "relatively trivial" and were "soft" faults, needs to be put into context. The DECUs on the Chinook Mk2 which was almost destroyed in 1989 because of a defect in the design of the FADEC, showed only "soft" faults after the incident. Soft faults are those that are not serious and involve no pilot action.

By looking at the FADEC's fault codes after the accident, it would not have been possible to see the seriousness of the problem that had occurred.... a problem so serious that, had the pilots not pulled the emergency "T" handles, the rotors could have flown off, possibly slicing through the aircraft.

Also the term "soft" fault does not convey fully the fact that after one of the incidents on 21 April 1994, a jet engine on ZD576 was removed and replaced.

Among the functions of the FADEC system is to balance the torque between the aircraft's two engines but on this occasion there was a torque split of 40% (which was later put down to a faulty torquemeter). The meter measures torque, and torque signals are fed to the FADEC system to help balance torque between the two engines.

There had been a torque split during the 1989 overspeed accident.

Reid asserted that the faults were "relatively trivial" but did not explain that four of the five incidents he was referring to had arisen because an "Eng Fail" warning had appeared in the cockpit, indicating a possible engine failure.

In a two-engined helicopter this is not a trivial matter as it implies that a series of checks must be carried out – and if this is necessary at a time when there is another serious failure on board, there could be a full emergency.

> ***It was later discovered that the Eng Fail warnings were spurious, but this could not have been assumed by the pilots at the time.***

As Gp Capt Crawford told the RAF Board of Inquiry: " ... it is particularly relevant to note that at this stage of the Chinook Mk2's service spurious Eng Fail captions ... were an increasingly frequent occurrence. These are now well understood but at the time they were not. Had such an indication occurred [on ZD576] it would have caused the crew considerable concern..."

Sometimes the answers given by Reid to the questions from MPs were plainly incorrect. Reid has said several times that the Ministry's legal action over the 1989 accident at Boeing was due to negligence in the testing and not because of the faulty design of the FADEC system.

Referring to the accident in 1989, in which a Chinook Mk2 was nearly destroyed, Reid told the House of Commons Defence Committee:

> "It was not – I repeat it was not – on account of the failure of the software. Let me explain to the committee what happened. In the course of the testing procedures we supplied Boeing and Textron Lycoming with a Chinook helicopter which they were testing on the ground for a range of things..."
>
> "In the course of doing that [simulating small arms fire damage] one of the plugs they pulled out effectively was the FADEC; they disconnected the FADEC and another one was disconnecting the fuel control... the engine ran out of control and it ruined the engines. We sued them for negligence in their testing procedures. We did not sue them because of a failure of the FADEC software. This is one of the misconceptions that has unfortunately been allowed to flourish."

> "So there was a case, the Board of Inquiry were aware of the case, but the case was essentially against Boeing and Textron Lycoming for negligence in their testing procedures, not against the software. I hope that is a full answer and I hope that clarifies things."

Reid's account of the litigation was re-iterated as recently as 15 May this year by the Defence Minister John Spellar when he wrote to MP Martin O'Neill. Spellar was explaining to O'Neill why the Air Accidents Investigation Branch had not been told at the time of their inquiry into ZD576 about the litigation involving the aircraft's FADEC and engines contractor Textron Lycoming.

> "Thus, as the evidence available indicated that the engines were working normally up to the point of impact," said Spellar, "it was reasonable to conclude that that FADEC could not have been a factor in the accident and therefore the action taken by the Mod arising out of the faulty test procedures in the early days of the the system's development programme could have no relevance to the investigative process."

In fact the Ministry of Defence case against Textron-Lycoming ***was*** based on the inadequacies of the FADEC system, rather than negligence in the testing procedures.

It appears, however, that Reid had not been shown a copy of the official claim by the Government of the United Kingdom of Great Britain and Northern Ireland, acting through the United Kingdom Defence Procurement office, Ministry of Defence, against Textron Inc.

The claim left no doubt that the Mod was suing Textron over the faulty design of the FADEC system.

The formal Mod claim, submitted by the Government of the United Kingdom through the British Embassy in Washington DC, states:

> ..."The FADEC system, in short, was constructed by Textron in such a way that the loss of both N2 signals would cause a catastrophic engine runaway, unless the flow of fuel to the engine were somehow reduced ...

> ... "In the design, development manufacture and testing of the FADEC system, Textron was negligent and failed to use the care and skill contractually required of it ..."

> ... The FADEC system provided by Textron failed to provide adequate overspeed protections required under the Contract and Specification R-1209.
>
> ... "Contrary to the Specification, the design of the DECU was such that the loss of certain "sensor inputs" into the DECU (i.e., the loss of the N2a and N2b engine speed signals) in the course of ground testing did not produce any of the system responses required by the Specification..."

Also, a separate report submitted to the US arbitration authorities by the UK government over the 1989 overspeed incident claimed:

> ...a "failure to conform to technical requirements of contract"
>
> ... that the FADEC failed to accommodate loss of inputs
>
> ...that the FADEC was not airworthy
>
> ... that the computer software was not adequately documented.
>
> ... that the subsystems hazard analysis was inadequate
>
> ...that development tests on the FADEC hardware were inadequate
>
> ....that because the tests were incomplete they did not lead Lycoming to identify the fatal N2 logic flaw
>
> ....that the software design was not adequately verified or documented
>
> ... The almost total reliance of the Lycoming-designed FADEC on the DECU software for engine and aircraft safety constituted a flawed system design.
>
> ..."that had Lycoming properly responded to information that it had, or ought to have had, it would have corrected the flaw before it caused damage."

That was there no doubt that there was a defect in the design of the FADEC can be seen from the reaction of the contractors to the overspeed incident. They assessed the cause of the accident as being the combination of a pre-existing "E5" fault code in the DECU which had caused the loss of an engine speed sensor, and the simultaneous loss of the remaining speed sensor when a "PL3" cable was disconnected.

Yet, as mentioned in part 3, the assertions by Reid and Spellar that the 1989 legal case was about the negligence in testing procedures, was not an allegation which materialised out of thin air. It was the position adopted by Textron's insurers as they sought to fight the UK's government's case. It was the argument advanced by the United States Aviation &Underwriters, insurers for Textron-Lycoming.

In denying the UK government's claim for compensation in respect of the 1989 accident, the underwriters said:

> "Our investigation has revealed that the overspeed incident resulted from an intentionally induced dual point failure. This failure involved an "E5" difference fault followed by the disconnection of the PL3 connector. This dual point failure was never contemplated by the contract between Textron Lycoming and the Mod, and was clearly outside the scope of the approved test plan."

The letter from the underwriters continued...

> "it was a dual point failure, testing for which was not contemplated by the contract for the development of FADEC. The requirements of Specification 1209 paragraph 11.1 do not address dual point failures ... prior to ground testing all contractually required analyses and simulations were conducted fully and properly..."

However Textron lost the arbitration hearing and in November 1995 it paid the UK government just over $3m in compensation.

Therefore Reid and Spellar, in stating the UK government's position against Textron, had actually cited Textron's defence to the Ministry's accusations. This is despite the fact that the Ministry's successful case against Textron was based on the claims that it was the FADEC software which was at fault, rather than simply negligence in the testing procedures.

It may also be worth looking at Spellar's explanation for the AAIB not being told about the litigation against Textron. He said that because the action taken by the Mod arising out of the 1989 accident was because of faulty test procedures then it could "have no relevance to the investigative process."

This indicates that the Ministry of Defence made a judgement about what information to give the AAIB on the basis of its assessment of relevancy. In this case it decided not to tell the AAIB about the 1989 accident on the basis that it was nothing to do with FADEC, although the case against Textron was primarily over the design of the FADEC.

Reid in his replies to the Defence Committee also went on to say that the Scottish Fatal Accident Inquiry had not been told about the case against Textron Lycoming because "for reasons which will be obvious from what I have said , that it [the legal case] was essentially about negligence in testing procedures and not with the software, it was not regarded as highly relevant to the inquiry."

So neither the AAIB nor the Scottish Fatal Accident Inquiry were aware that, at the time of the crash of ZD576, the Ministry of Defence was in the process of taking legal action against the US company which was responsible for the supply of the engines and the FADEC system on the Chinook Mk2. (bold italics) The AAIB and the Scottish Fatal Accident Inquiry were also unaware that it was the faulty design of the FADEC that had led to the near destruction of a Chinook in 1989.

They were kept in ignorance despite the fact even though both organisations were, among other things, investigating the FADEC systems in the light of all the reported incidents .

Had news emerged about the Ministry's case against Textron-Lycoming, it would have shown not only that the faulty design of the FADEC system had caused an accident, but that FADEC was capable of causing an accident of a safety critical nature.

During the past five years ministers and the Ministry of Defence have argued that FADEC has not caused any safety critical accidents and is not capable of causing one.

As mentioned before, the Ministry said in a written statement to the Defence Committee last year: "Boeing did not consider the FADEC to be flight safety critical because the engines on the Chinook are not considered safety critical."

Reid told the Defence Committee: "There are a lot more faults which occurred a lot more regularly – and some of them more safety critical – than FADEC. I think what has given FADEC this interest is the case we took against Textron Lycoming which people assumed to be because of the software but, as I explained earlier, was actually due to negligent practices."

His adviser at the Committee, Colonel Barry Hodgkiss, told MPs: " ...FADEC is not flight safety critical because in the event of a total failure the aircraft would be able to land safely."

Also Reid told David Harrison, in an interview for Channel Four: " ...to my knowledge there has not been a serious accident in all the Chinooks which has been linked to a FADEC malfunction..."

This point was further made in a letter from Reid to the MP Nick Soames dated 22 January 1998. Reid quoted Textron Lycoming as saying:

> "...of all the units flying in the US Army and other countries there have been no known safety-related FADEC software caused accidents."

Indeed it was this incorrect basis – that there had never been any serious accidents which had involved FADEC – which had contributed to the decision to approve the Chinook Mk2 in November 1993 for safe flight.

This position was set out in a Ministry of Defence paper to the Defence Committee last year. The paper explained, among other things, why the Chinook was certified although the A&AEE had made it clear that it wanted a re-write of the software in a verifiable form before it would recommend an airworthiness release.

> "The RAF," said the Ministry statement, "in conjunction with the Procurement Executive took account of the US Army's experience both in ground testing and flight testing the FADEC and noted that no flight safety critical problems had been experienced. Therefore, while the views of Boscombe Down were carefully considered, these were weighed against the flight safety criticality of the FADEC."
>
> "In view of the fact that the Chinook has two engines each fitted with FADEC it was accepted that in the unlikely event of a FADEC failure in both primary and reversionary modes, the aircraft could still be flown safely on one engine ... but even in the unlikely event of all power being lost the Chinook is designed to descend in a controlled manner."
>
> "With this in mind the RAF and the Procurement Executive (of the Ministry of Defence) agreed that the Chinook Mk2 could be cleared for safe flight within certain parameters."

So, in clearing the Chinook Mk2 for safe flight the RAF and the Ministry of Defence took into account the fact that there had been no flight safety critical problems with FADEC *as used by the US Army*.

Apart from the fact that the US Army did not have the same version of FADEC as the RAF, it is perhaps extraordinary that the Chinook was cleared for safe flight partly on the good experiences of the US Army but ignoring that the RAF had almost lost a Chinook because of a design fault in the FADEC which led to an uncontrolled and dangerous overspeed.

The cover-up of the real reasons for the 1989 case against Textron-Lycoming sustained the claim that there had been no known accidents involving the Chinook's FADEC. It also helped to sustain the claim that, because there had been no known accidents involving the FADEC in the US Army, the Chinook could be released to service as airworthy, despite the concerns of the A&AEE at Boscombe Down.

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RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

In April this year it emerged that, not only were details of the Ministry of Defence's case against Lycoming kept from the Air Accidents Investigation Branch and the civil Fatal Accident Inquiry in Scotland, but may also have been kept from the RAF's own military Board of Inquiry into the crash of ZD576.

Asked by the MP Robert Key whether the RAF Board of Inquiry knew of the litigation between the Ministry of Defence and Textron-Lycoming, Spellar replied:

> "It is not possible now to establish if investigators were informed at the time of the case."

So, at a time when the RAF Board of Inquiry was taking evidence, under oath, on, among other things, incidents such as engine overspeeds involving the FADEC system, it may not have been told of an overspeed accident involving the faulty design of FADEC, which led to the Ministry claiming millions of dollars from the contractors of the FADEC.

And the litigation was going on at the time the Board of Inquiry was convening.

*** * * * ***

The 1989 accident was not the only matter on which information was kept from investigators or ministers answered questions in Parliament by stating as the UK government's position the views of the FADEC's contractors, even when the contractor's opinions were at odds with those which had been expressed in writing within the Ministry of Defence.

The Scottish Fatal Accident Inquiry was, during its inquiries, kept in ignorance about the EDS-Scicon report which found 485 anomalies in less than 20% of the FADEC code and concluded that such a number of anomalies was a characteristic of poorly developed code.

It was also remarkable that the Mod was determining what evidence it would give to the investigators on the basis of its subjective test of relevancy. If the defendant in a criminal court were allowed to prohibit the production of any evidence which he regarded as irrelevant, there would be no critical evidence produced at all …

But was this the intention? …

*** * * * ***

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

When the defence minister, Dr John Reid, MPs, civil servants, radio TV and newsprint journalists, filed into the House of Commons committee room for the hearing on the Chinook, a paper was made available which showed the total number of aircraft accidents between 1992 and 1997.

There was only one Chinook on the list of more than 50 aircraft including the Tornado, Harrier, Jaguar, Wessex, Chipmunk and Gazelle. The one Chinook crash was ZD576 in June 1994.

Reid told the televised hearing of the committee:

> "... There is a very long list here, which you will see. There is one Chinook on that list..."

However the list covered only a five-year period, form 1992 to 1997.

When an MP said he thought there had been a Chinook accident prior to 1992, Reid replied:

> "I am going to come onto that. It is outside this period. As far as I am aware, despite the fact that the Chinook is flying with us and with the Dutch and with the United States and elsewhere in the world, there has been prior to that [ZD576] one Chinook accident."

This "one" previous accident was explained by one of Reid's advisers at the Defence Committee, Air Vice-Marshal Jenner, who said: "There has only been one previous Royal Air Force accident. That was in 1988."

At this, Robert Burke, the RAF Odiham unit test pilot, was shaking his head in disbelief. He wrote a note which was later passed to MPs. In addition Mike Tapper, the father of Jonathan Tapper, wrote a letter to the Defence Committee saying that the "Air Marshal is quite simply wrong."

After the proceedings the Air Vice-Marshal corrected his statement and accepted there had been eight accidents and provided the hearing with a statement about them. By the time this correcting statement was published, however, the televised proceedings and the media coverage of the proceedings had long since past.

There had in fact been eight Chinook accidents in the period prior to 1992. Seven of those accidents involved the mark one Chinook. All of them except the ZD576 had happened in the period between 1984 and 1991.

So the Ministry of Defence's paper for the Defence Committee and for journalists which showed only one Chinook accident in the period between 1992 and 1997 ... that of ZD576 ... was correct because the other eight accidents happened before 1992.

Also the Ministry at the hearing did not refer to the Chinook accidents in the USA where there had been 116 serious accidents between 1994 and 1998, including seven fatal crashes. One of the fatal crashes, in March 1996, involved one of the few US Chinooks fitted with FADEC.

The details of this March 1996 accident are being withheld by the US Army for reasons of national security. However, with reference to this US crash of a newer Chinook in 1996, there was a local newspaper report in the US in February this year that Boeing had agreed to pay $4.4m in compensation to the widows of the military personnel on board the Chinook MH-47E.

The paper said that the widows had been told originally that the crash was due to pilot error.

* * * * *

The Defence Committee last year also looked at why, if the Chinook software was so safe, there was a weight limit in case one engine failed because of the FADEC system. One MP Crispin Blunt said: "So we went through an expensive upgrade from a mark one to mark two and we reduced its performance because Boscombe Down say we cannot trust the software that controls the engines?" Reid replied:

> "No, they do not say they cannot trust it. They say they cannot read it, which is a different thing. They can neither trust nor distrust it because the tools they have – I hope you will want to explore the whole of the Boscombe Down side and FADEC which you have referred to – they cannot actually read it."

This was not the case, however. The Aeroplane and Armament Experimental Establishment (A&AEE) at Boscombe Down had made it unequivocally clear in its memos and reports that it was able to read the software. A memo by the Electronic Assessment Section at Boscombe Down dated 29 April 1994, less than two months before the crash of ZD576, says that the A&AEE found a "very large number of errors" in the code.

Had it not been able to read the code it would not have been able to find errors. The A&AEE in its report goes on to mention in considerable detail how the code in both the primary and reversionary back-up modes perform, and also mentions the dangers of the engine overheating.

Lest there should be any doubt that the A&AEE had read the software, the memo continues:

> ... "While A&AEE did review the reversionary lane code and a proportion of the primary lane, it was found to be unacceptable."

So Reid at the committee hearing was suggesting that Boscombe Down had only a technical problem reading the code, which had the effect of drawing questions away from what inadequacies the A&AEE had found when reading the code.

* * * * *

Reid went to tell the committee that:

> "The United States use the Chinook and are satisfied and trust the software, because they use a different method of testing the software. The Dutch similarly..."

What Reid did not say was that that the RAF's version of FADEC was not exactly the same as any of those used by the US Army, Army Reserves and the National Guard, which together bought 435 Chinooks. The US Army bought a more powerful engine which had a custom-built FADEC. It is similar but not the same as the FADEC system used by the RAF. Textron claim that the software for the two engines is 99% similar and the Mod says they are 95% similar. However the exact differences in terms of the software have never been published.

In theory, a minor difference in software – less than one per cent – can potentially make a big difference to the way that software behaves.

In April 1994, less than two months before the crash of ZD576, the Assistant Director of Helicopter Projects in April 1994 questioned – in fact he said it was a "critical issue - " the fact that Textron was claiming that all testing of the US version of the engine and FADEC were valid to support the testing of the RAF's version of the engine. He sought more information on this.

The Assistant Director also said that the flight testing on the RAF version of the engine, at 45 hours, "would appear to be low."

Reid had referred to the satisfaction of the Dutch with the FADEC software ... but the Dutch did not acquire the FADEC-equipped version of the Chinook until long after the crash of ZD576 – and then after there had been modifications.

* * * * *

Reid also sought at the Defence Committee to disparage evidence from Robert Burke, who was the squadron leader at RAF Odiham at the time of the crash of ZD576. Burke was not Hollywood's idea of a test pilot, being someone who flies an aircraft to the limits of its capabilities.

He was instead a senior unit test pilot who tested the Chinook when it had had a service, maintenance overhaul or an upgrade such as the change from mark one to mark two status.

Now retired, he has nearly 8,000 military helicopter flying hours of which nearly 4,000 were flight testing, and 1,500 of which were flight testing Chinooks. He was a pilot with by far the most flight testing hours on the Chinook. The dangers of his job are obvious. As he was sometimes flying faulty aircraft, there was a considerable risk of loss of life.

Burke lost "quite a few friends" in a number of fatal Chinook crashes which happened during flights to test a recent maintenance service or upgrade.

A few days before the Defence Committee hearing, Burke had made assertions in Computer Weekly that there had been two engine overspeeds and instances in which the DECUs had not shown any fault codes.

In response to the mention of Burke at the Committee hearing Reid said:

> "First of all Mr Burke has had a lot of experience though to my knowledge he never operationally flew a Chinook Mark-2 in his life, although he is a man of considerable experience on Chinooks. I read with interest that Mr Burke said on one occasion that there were two (I think he said) safety critical incidents ... I have had my records checked. No such incidents were ever reported to the best of my knowledge. If he did experience these not only should he have reported them, but under the terms of reference of the job he carried he was obliged to report them."

Reid said that if further evidence came to light about the incidents, with the dates and details, he would have them investigated. "So all I say is that while it is easy to quote supposed facts from supposed experts … when I check out these facts I find that they do not appear to stand up ..."

After the hearing Burke supplied details of the two overspeed incidents, and the Ministry of Defence, in its paper to the Defence Committee, confirmed that it had found details of one of the incidents. It had been recorded in Burke's own handwriting.

Burke says the incidents happened at Boeing in Philadelphia where he was performing the role of a co-pilot. It was the captain's responsibility to report the overspeed incidents, but because of their seriousness, Burke wrote hand-written reports, which were given to the UK Chinook liaison officer. Burke says that the captain also filed reports on the incidents which happened within 24 hours of each other. During the second incident there were representatives from Boeing and Lycoming present.

One of Reid's advisers at the Defence Committee hearing, Air Vice Marshal Jenner, made comments which did little to enhance Burke's credibility in the eyes of MPs. Jenner made the distinction between a "real" test pilot and Burke.

The Air Vice Marshal told the committee:

> "I think I should make the important distinction between a unit test pilot, which Mr Burke was, and a true test pilot at Boscombe Down."

Jenner said how a "real" test pilot takes an aircraft to its limits in "very hazardous circumstances" at times.

> "A unit test pilot is there to take aircraft normally out of routine maintenance and make sure that the maintenance that is being carried out is correct..."

Reid did not leave it there. He turned to the Air Vice Marshal and asked: "... In the gradation of expertise of pushing something to its limits, where would Mr Burke's expertise come in that spectrum?"

The question went unanswered because an MP, Menzies Campbell, interrupted Reid and told him that in effect the question was pointless.

Reid was then asked again why the Chinook Mk2 was flying with software that could not be validated by Boscombe Down.

The minister then disparaged Boscombe Down. Menzies Campbell asked: "As a layman you are telling the Committee, I think, that an upgrade of an existing aircraft is flying with software in relation to the FADEC that cannot be validated?

Reid replied: "No, cannot be validated *by Boscombe Down*; scientists in that section of Boscombe Down."

Another MP, John McWilliam, interjected. "Just on that point Dr Reid, did you say earlier in your opening statement that they could not validate it because they could not read it?

Reid replied: "They cannot read it ..."

Campbell then asked if that was a satisfactory situation.

"No, in an ideal world," replied Reid, "they would have the tools to read the software."

What is the date, asked Campbell, when the Royal Air Force, the Ministry of Defence, expects Boscombe Down to be able to read the software?

Reid replied: "I do not think Boscombe Down have shown any indication of changing their methods is the answer to that."

Later Reid said of Boscombe Down's comments relating to the interaction between the primary and reversionary lanes of software in the FADEC: " ... the advice from Boscombe Down is not necessarily accepted by others who are in the field..."

This disparagement of Boscombe Down was highly effective. In its report on the verbal evidence given by Reid, the Defence Committee concluded that:

> "We are concerned by the failure of Boscombe Down to give final approval to the FADEC software. We conclude however that this is a management failure, and we are persuaded by the evidence that this absence of approval raises no safety-critical implications."

This Committee was not to know that, shortly before the crash of ZD576, the matter of outstanding "safety case" issues in relation to the FADEC was being mentioned not by Boscombe Down but by the Assistant Director of Helicopter Projects - the person appointed as the Project Manager for the Chinook. In a memo dated 29 April 1994, the Assistant Director said:

> "It is important therefore to understand and take full account of A&AEE's views, since the strength of counter-arguments will be crucial to our commercial position in future negotiations to revise the FADEC software in pursuit of a satisfactory resolution of all safety case issues."

The Assistant Director reported to the Director of Helicopter Projects who, through a chain of command delegated down from the Secretary of State for Defence, was responsible for issuing a release into service of new or modified aircraft.

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Reid also told the committee that if, within the 18-tonnes weight restriction, there was a problem with the FADEC and one engine were to fail, "one engine would allow the Chinook to do everything that it could do with two engines."

However this appears to have been Textron's view, which did not coincide with that of the Assistant Director of Helicopter Projects who wrote in his April 1994 memo: It is disturbing to see Textron claiming that one control system is not flight critical on a twin engine helicopter. Clearly they do not appreciate how often in flight twin engine helicopters have no flyaway capability on one engine."

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Reid went on to re-iterate to the Committee that the United States was happy with the software, but without mentioning how few of their 435 Chinooks (about 25) were fitted with FADEC.

> "It may also seem absurd that the United States are perfectly happy – they have a huge fleet of Chinooks – and they are applying the standards of NASA. I would have thought that if applying the standards of reading which are applicable to sending rockets to the moon is sufficient to verify something, that we would have been able to, but the situation is, as Mr Campbell described, we have not been able to do that at Boscombe Down..."

Reid also suggested to the committee that because Boscombe Down could not read the software (although in fact they could) they would not be able to verify the FADEC systems on other aircraft. He also stated, wrongly, that the Chinook's FADEC system was going on the Concorde.

His comments came after an MP John McWilliam asked whether Textron can read its own software.

> "I think to the question you are asking the answer sounded a bit daft, that Textron cannot read it. Yes they can read it but they cannot read it in the way which Boscombe want to read it which is based on the nuclear industry. Because when people design things they do not necessarily design them with a view to them being read by a particular system."

> "Everyone else who looks at this is apparently satisfied. This software is going on the Airbus 320 and the Airbus 340, it is on the Boeing 767 and the 777, British Airways are putting the same FADEC system on the new Concorde, so presumably Boscombe Down would not be able to verify – and I am presuming this - the software which is going to be on Airbus, Concorde and some of the biggest international [air] liners in the world. That puts it in perspective. That is the problem we have. Their tools cannot apparently read this software."

Nobody from Boscombe Down was able at the hearing to intervene and tell the committee what was in their confidential reports.

The conclusions to be drawn from their reports was that it was that true that the FADEC code was not amenable to being tested with automated tools such as MALPAS and SPADE.

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However that did not mean that the code could not be read. It could be read – and it had been read.

The A&AEE said it had reviewed the software and had found it "unacceptable." It said that it had found "numerous errors" in its reviews.

However this was not the reason it found the software to be unverifiable. Its reports cited what it saw as a lack of testing and the fact that what analysis had been done, gave the A&AEE little confidence in the code.

Safety-critical software does not have to be written in such a way as to make it easy to read by automated tools, although it helps. Boscombe Down said that the code does need to be sufficiently simple and traceable to be understood by an independent team of verifiers. That is why it regarded the code to be unverifiable, and "therefore unsuitable for its intended purpose."

This does not appear to have been understood by Reid who, several times, told the Committee that Boscombe Down could not read the FADEC code.

> " ...One aspect of the software has not been validated in practice but it is giving us ten times more reliable a system than before," said Reid. "It is flying all over the world in Chinooks, it has been accepted by the Americans and the Dutch ... It is not ideal I admit that but it is not within my powers to say to Boscombe Down: 'Please go and get something which can read this' because apparently for reasons which are above my computer knowledge and probably anyone around the Committee, they cannot read this particular piece of software which is used in a whole range of aeroplanes which are flying all around us, all the time."

Reid's statement gave the impression that the Chinook software was in use in every modern aircraft and that the only problem anywhere was the fact that Boscombe Down could not read it.

In fact the Chinook's FADEC software was not used in a whole range of aeroplanes. Malcolm Perks says: "FADECs are designed by different companies to do different jobs, on different engines, with different designs of computers and with different software. Rolls Royce use FADECs made by Lucas Aerospace, the big two American aero-engine companies, Pratt & Whitney and General Electric, use American companies for their FADECs."

The principles behind the FADEC are common but the software designed for the Chinook could not be simply transposed into other aircraft, any more than a 24 valve engine designed for a Vauxhall motor car would be the same as a 24-valve engine in a Fiat, Rover, Ford or Saab. Even the FADEC designed for the RAF Chinook engines was different to the software which was used in the Chinook engines in the USA.

Yet Reid would go on to say:

> "As I said earlier the similar system is in Boeings, it is in Concorde for the future it is on the Queen's flight, it s on the 767s, 777s and I cannot, I think, give you any more details in layman's terms than that but I will answer any other points."

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The committee were also given the incorrect impression that no aircrews had expressed concern about the FADEC. An MP Julian Brazier asked what were pilots told when they raised safety issues and was there a catalogue of pilots raising concerns about the Chinook?

Air Vice-Marshal Jenner, sitting next to Reid, told MPs at the hearing that concerns could be raised in a number of different ways.

> ... "Our records show that that there were of course routine faults raised and those were the ones we have talked about already. There were no confidential reports at all relating to the computer FADEC on the Chinook and there is nothing we can find in any of the flight safety meetings at station level to say that the crews had any concerns on those flights. I can assure you that if crews did have any concerns on the FADEC ... they would have been made."

However the Committee was not told that two pilots in particular had raised concerns about the engine control system on the Chinook.... Flight Lieutenants Jonathan Tapper and Rick Cook.

A witness at the RAF Board of Inquiry, Lieutenant Ian Kingston Royal Navy, had said under oath:

> "The concerns they had with reference to the Chinook HC2 (mark 2) I believe did worry both pilots in two ways. First was the uncertainty of how the aircraft's Automatic Digital Engine Control system would perform during operational sorties in Northern Ireland and what sort of emergencies or situations the present amount of spurious and unexplained incidents would lead to." The second related to levels of manpower regarding Special Forces.

Indeed the concerns of pilots more generally was raised formally in the conclusions of the report of the RAF Board of Inquiry. "The Chinook HC2 had experienced a number of unforeseen malfunctions mainly associated with the engine control system, including undemanded engine shutdown, engine run-up, spurious engine failure captions and misleading and confusing cockpit indications."

In addition, Squadron Leader David Prowse told the RAF Board of Inquiry that Tapper was so concerned about the limited operational capabilities of the Chinook Mk2 that he had "requested permission for an extra HC1 (mark one) to be in Northern Ireland for an additional period."

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For the families of Flt Lts Tapper and Cook, the incorrect impressions given to the Defence Committee seemed endless. For example, the Committee's report said that visual flight rules required pilots to see clearly five kilometres ahead of them, which was not necessarily the case on the last flight of ZD576.

However this rule applied to faster aircraft rather than helicopters where the minimum distance under visual flight rules was one kilometre.

In the end the Committee said: "We have considered the evidence suggesting that the crash of ZD576 pointed to fundamental flaws in the design of the Chinook Mk2 or its components. We have found no compelling evidence to support these claims."

The Committee's conclusion was entirely understandable. On the evidence that was made available to MPs, they could not have found that there were fundamental flaws in the design of the Chinook Mk2 or its components.

However the Committee had been shown barely any evidence at all. Much of what it was shown, was misleading, inaccurate or wrong.

In the course of our investigation, we have had access to and studied hundreds of pages of documents, most of which relate to concerns, problems, and questions relating to the Chinook Mk2.

Few if any of these documents were shown to the Air Accidents Investigation Branch of the Department of Transport, the Scottish Fatal Inquiry into the crash of ZD576, or the House of Commons Defence Committee.

It is important to stress that there is no suggestion that Reid, Spellar or any other minister intentionally misled MPs or covered up information but there is doubt over the quality and accuracy of their briefings by officials.

If there has not been a cover-up of the seriousness of the problems involving the Chinook Mk2 and its FADEC system, a cover-up of the decision to release the helicopter into service before it was ready, a cover-up of the decision to compel pilots to fly an aircraft that they were reluctant to fly and at a time when trials pilots had suspended flying, and a cover-up of the technological and design faults that could have played a part in one of the most notorious military accidents in recent years, what else can it be called ... ?

RAF JUSTICE

How the Royal Air Force blamed two dead pilots and covered up problems with the Chinook's computer system FADEC

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