Maintenance test flying – an accident waiting to happen?

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ABSTRACT

This paper focuses on maintenance test flying as pertaining to commercial jet aircraft. Aircraft maintenance manuals or regulatory prescriptions require aircraft to be test flown prior to being released to service, following specific maintenance, repair, overhaul or modification events. Further, such flights might be conducted to accept or return aircraft as demonstration of their serviceability. Similarly, test flights to verify aircraft performance are at times required.

Such maintenance test flights are mostly conducted by pilots rated to fly those aircraft primarily in commercial line operations, typically with no or little training on such specific maintenance or performance test flight procedures or techniques. The international regulatory environment remains in flux with discussion ongoing.

In conducting such flights a pilot is exposed to activities outside the normal aircraft standard operating procedures up to the edge of the operational flight envelope. Whilst not intentional, abnormal aircraft behaviour can nevertheless result in inadvertent flight outside the envelope with a consequential potential loss of control. History has shown that the predominant cause of fatal accidents during maintenance test flying result from complex loss of control scenarios not recovered or not recoverable. This raises the question of adequacy of pilot training.

Maintenance test flights are a necessary component for the industry to maintain its exceptional safety standards and minimising loss of life. But such flights in themselves remain demonstrably one or two orders of magnitude more risky than commercial flights.

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1.0 INTRODUCTION

'In little more than one lifetime, aviation has transformed itself from a high risk activity fit only for barnstormers and daredevils into a routine part of modern life'.

Tony Tyler, IATA Director General and CEO[1]

Since the first commercial flight about one hundred years ago, the aviation industry has grown itself into a global enabler where the airlines now transport more than three billion passengers per year, about 44% of the world population[1].

The industry has achieved this by prioritising safety and by continuously learning from its mistakes. From around 35 fatal accidents per million flights in 1959 on the worldwide commercial jet fleets the rate has reduced to a ten year average ending 2011 of 0·39 per million flights[2], whilst the number of flights increased by 22% over this ten year period from 2002 to 2011[2].

Commercial jet aviation started in the early 1950s with the introduction of the de Havilland Comet in 1952, followed by the Boeing 707 and Douglas DC-8 entering service in 1958 and 1959 respectively.

Table 1
Accident Summary by Type of Operation[2]

Type of Operation	All Accidents 1959-2011	All Accidents 2002-2011	Fatal Accidents 1959-2011	Fatal Accidents 2002-2011
Passenger	1,424	317	483	63
Cargo	252	74	76	13
Non-Revenue	122	13	44	3
Total	1,798	404	603	79

Between 1959 and 2011 the worldwide commercial jet fleets experienced 603 fatal and 1,195 non-fatal accidents, total of 1,798, versus 79 fatal and 325 non-fatal accidents, total of 404, for the period 2002 to 2011[2]. The average number of fatal accidents per annum is reducing whilst the number of flights per annum steadily increases, yielding a greatly reduced accident rate. Additionally, the ratio of fatal versus non-fatal accidents is equally reducing.

For non-revenue flights on commercial jet aircraft there were 44 fatal and 78 non-fatal accidents over the review period with 3 fatal and ten non-fatal accidents for the last 10 years under review[2]. Non-revenue flights include maintenance test, ferry, positioning, training and demonstration flights, i.e. flights that don't earn revenue but are conducted in support of overall commercial operations. A further break down of the analysis into the separate non-commercial activities was not provided.

This discussion paper aims to focus particularly on the risk of maintenance test flying as required on commercial jet aircraft.

2.0 ARE MAINTENANCE TEST FLIGHTS NECESSARY?

A maintenance test flight can be classified as a non-revenue flight typically carried out by flight crew for whom normal duties are line flying. Recently, such flights are also being referred to as a Functional Check Flights or Maintenance Check Flights. Regardless of terminology, the purpose is to test the correct functioning of aircraft systems either, typically:

(a) After a significant single major rectification or modification maintenance event;

(b) After a major base maintenance check during which the aircraft gets disassembled and then reassembled;

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(c) For the acceptance or return of an aircraft;

(d) When required by the regulatory authority; or

(e) When required by the aircraft maintenance manual (e.g. for multiple engine changes or for flight control changes).

Independent of regulatory and/or maintenance manual requirements, though, it seems instructive to evaluate the practical necessity for maintenance test flying.

The Aviation Safety Network[3] on its website, since 2002, lists 49 aircraft accidents or incidents involving commercial jet aircraft on revenue flights which are directly attributable to incorrect or inadequate maintenance procedures or to aircraft technical complications. These aircraft had been released to revenue service as being airworthy.

Whilst these accidents are equally on the decrease since the start of the jet age, they have not been eliminated in its entirety. Human error remains ubiquitous throughout the industry. Naturally such statistics only reveal the extent of actual occurrences, not those that have been prevented by intervention measures. Statistics on successful preventions are either just not available or they are buried within the reportable incident data warehouses of numerous regulatory authorities, without the link necessarily being established to what could have happened but did not. The propensity for recording and reporting negativities, even if ultimately used for learning and safety advancement, heavily outweighs reporting successes.

Representative statistics on reportable maintenance occurrences exists but, although freely available on the Internet on international official websites, may not necessarily be referenced without the express permission of the publishing authority. Suffice it to say that the ratio of high risk versus all reportable events appears to be at least one or two orders of magnitude higher. Consequently, it can be deduced that only a minute fraction of those flights experiencing technical difficulties end catastrophically. The majority are recoverable within existing flight crew procedures and training but may be commercially disruptive, resulting in aircraft diversions or groundings. Maintenance test flying very fundamentally seeks to prevent the majority of such occurrences from reaching revenue generating commercial operations. Whilst the risk of human error in the maintenance environment persists, however small, the necessity for maintenance test flying remains.

During major maintenance events an aircraft gets disassembled, serviced, refurbished, repaired (where necessary) and then reassembled. Critical systems such as flight controls, engines, etc. are all being maintained/serviced. The necessity to subsequently test fly the aircraft is similarly justifiable as the necessity for production test flying. It could even be argued that maintenance test flying creates a higher level of necessity given the infrequency of major maintenance events (every five to eight years depending on type) versus a production assembly line. Interestingly, though, production test flights are typically conducted by qualified test pilots whilst maintenance test flights generally are performed by line pilots.

3.0 ACCIDENTS/INCIDENTS DURING MAINTENANCE TEST FLIGHTS

Appendix A lists a number of maintenance test flight accidents reviewed for this paper[4,5,6]. Although the statistical discussion above restricts itself to commercial jets, appendix A also lists several propeller driven aircraft accidents as these serve to further illustrate the loss-of-control prevalence in these accidents, as discussed later.

The list is by no means exhaustive. There are numerous incidents where aircraft were recovered that do not necessarily reach the public domain. The two B737-700 incidents on 12 January and 19 May 2009 refer. The first incident led to a special bulletin[7] shortly after the incident given the extent of the loss of control and difficulties in recovery, followed by a full bulletin the following year[8]. The second incident only finds mention in the full bulletin on the first incident.

These two incidents resulted from what is colloquially referred to as a manual reversion check, intended to demonstrate aircraft controllability with hydraulic assistance removed. Given the high aerodynamic loads on flight controls, correctly rigged balance tabs are decisive in being able to control the aircraft. One tenth of a degree inaccuracy can have a marked impact on controllability[8].

These two particular incidents are by no means unique[8]. The author has had his own experience of an incorrectly rigged balance tab during a maintenance test flight. Such incidents, though, in addition to the above, comprehensively demonstrate the necessity of maintenance test flying: An in- flight loss of all hydraulics on an aircraft fitted with only dual hydraulic systems would result in a fatal hull loss if the aircraft does not remain controllable for the line crew, necessitating an in-flight validation of the correct balance tab rigging prior to release to commercial services.

The table in Appendix A lists nine fatal hull losses of commercial jets and a further five of propeller driven aircraft, since 1959, total of fourteen. Of these, one was as a result of a mid-air collision with another aircraft, two weren't specified, one was a Controlled-Flight-Into-Terrain (CFIT) and nine (64%) were as a result of a loss-of-control (LOC) scenarios from which the crew were unable to recover.

Of the 79 fatal accidents between 2002 and 2011 involving commercial jets 18 (23%) resulted from LOC and a further 18 from CFIT[2]. The CFIT phenomenon has largely been addressed, at least for aircraft of sufficient size, through the installation of reactive Ground Proximity Warning Systems (GPWS) and more recently predictive Enhanced GPWS, together with crew training. Meanwhile LOC is fast becoming recognised as a primary risk to the safety levels of the industry. Airlines such as South African Airways are developing specialised training for line crews on LOC even before the expected regulatory prescriptions are activated.

Maintenance test flying has added one fatal hull loss since 2002. This needs to be viewed in perspective. An aircraft in the category of an Airbus A320 or a Boeing 737 will typically operate between 600 and 2,500 flights per annum. A planned maintenance test flight occurs following a heavy maintenance check every five, six or eight years, as applicable. Thus, a planned maintenance check flight occurs once every 3,600 to 20,000 commercial flights. Even if an aircraft requires one or two additional maintenance test flights (for other reasons) per major maintenance interval, the ratio remains at least one maintenance test flight per 1,200 to 1,800 commercial flights. In this context, even one maintenance test flight fatal hull loss out of 79 fatal hull losses seems extreme.

Not surprisingly then, even without more detailed analyses, it appears that the heightened risk of maintenance test flying is real and is significant. This is widely acknowledged and recognised by the Industry[9]. Intuitively the risk will be higher than on a commercial flight, given the nature of the activity. Nevertheless, has everything possible been done to mitigate the risks involved?

Commercial aviation relies heavily on the adherence to Standard Operating Procedures (SOPs) to achieve the remarkable safety levels the industry enjoys today. Pilots are taught to operate in the middle of the operating flight envelope. In this context the operating flight envelope is as stipulated in the aircraft flight manual respectively aircraft operating handbook. The design flight envelope is established by experimental test pilots during aircraft type certification, including inter alia fully stalling the aircraft at the one extreme and testing for flutter behaviour at the design speed at the other. The operating flight envelope lies well inside the design flight envelope.

Line pilots get taught to stay well away from the edges of the operating envelope. They are taught to recover at the first sign of an impending stall, typically at stall warning or stick shaker activation. Fly-by-wire technology takes this one step further, from warnings to protections, and prevents the aircraft from entering a stall (normally). Thus, line pilots do not generally get exposed to a full stall of their aircraft. Nor is such exposure readily realisable. Full flight simulators are not very representative of the aircraft outside of the operating envelope, as the underlying data is not readily available. On the other hand, performing such training on actual aircraft is risky, prohibitively expensive and disruptive to an airline's flight schedule.

Maintenance testing seeks to verify the correct functioning of the various aircraft systems, including warning and/or protection systems. Recovery procedures such as wind shear or terrain escape manoeuvres rely on the correct functioning of such warnings respectively protections, necessitating in-flight testing prior to release back to commercial services.

During maintenance testing the aircraft thus necessarily needs to be flown to the edge of the operational flight envelope. Typically, this requires activities outside of those intended in the SOPs. Since maintenance test flying is generally not a regular activity even for those designated to perform such flights, a crew can quickly end up outside their comfort zone. Unfamiliar activities increase work load, even at monitoring level, reducing the capacity to recognise or distinguish between intended non-standard activities and unintended abnormal system response.

Whilst never intentional, the possibility of ending up outside the operational envelope exists when there is a failure of a system, as evidenced by the A320 accident in 2008 and many of those accidents preceding it. This then begs the question whether pilots conducting maintenance test flights are adequately equipped to deal with envelope excursions?

The accidents listed in appendix A might suggest not. Nine out of the fourteen accidents listed were as a result of loss of control, typically placing the aircraft outside the operational envelope and always at the low end of the speed scale. At least seven of the nine accidents resulted in a stall that was not recovered. Admittedly, one or two of these might not have been recoverable (but preventable in the first place), but inability to recover from a stall does seem to stand out. Would recovery have been possible on most of these accidents had the crews received more training on fully identifying and handling their LOC situation?

Admittedly, most of these accidents resulted from LOCs aggravated by additional contributors. The A320 accident in 2008 illustrates[10]: During high altitude flight two of the three angle-of-attack sensors froze, as a result of moisture in the sensors, at a relative low setting. When conducting low speed protection checks the auto-trim system, as per design, gradually moved the horizontal stabiliser to a full nose up position. As the aircraft approached the stall angle-of-attack the remaining angle-of-attack sensor recognised the stall onset. Unable to provide the intended protection due to the other two angle-of-attack sensors frozen into a lower position, the aircraft reverted to direct law as per design, thus disabling the auto-trim system. The crew, however, seemingly did not recognise the change in flight control law. The Captain reacted conventionally to the stall onset with the approach to stall recovery technique, applying maximum thrust.

In normal flight control law, which the crew is used to, a pitch up due to a thrust increase is negated by the flight control laws, with the aircraft approximately retaining the required pitch value. In direct law, however, the aircraft reacts conventionally to the thrust increase from the under-wing engines, inducing a further nose-up moment, which, in combination with the full nose-up trim, resulted in the LOC. No attempt was made to trim the aircraft manually or to reduce thrust in order to regain control. It appears that the crew were not aware of their aircraft status. The manufacturer subsequently changed the recommended stall recovery technique to primarily focus on unstalling the wings with the thrust application becoming secondary (but ultimately still necessary) to the recovery.

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Again, had the crew been adequately trained to deal with such a situation? Internationally, there appears to be a drive to introduce upset recovery training programs to deal with the LOC threat. Will this training be sufficiently detailed to equip those line pilots performing maintenance testing to deal with such events?

Incidentally, another operator a short while later similarly experienced frozen angle-of-attack sensors, except that in this instance all three sensors were frozen. There was no reversion to direct law and the crew recovered successfully at the onset of buffet[9], in accordance with the standard training received.

A seemingly worse situation of the loss of all three angle-of-attack sensors versus just two actually presented the crew with a better situation for recovery, demonstrating the complexity inherent in modern large transport aircraft.

4.0 THE REGULATORY ENVIRONMENT

The South African Civil Aviation Authority (SACAA) requires test flights to be performed following inter alia major repairs, modifications or maintenance. Such test flights are to be conducted by pilots with the appropriate test flight rating[11]. The Regulations in Part 61 further refer to Class I, Class II and post-maintenance test flight ratings.

Under Part 61 Subpart 19 POST MAINTENANCE TEST PILOT RATINGS the requirements for the issue of Class I and Class II test pilot ratings is stipulated with the Class I having to have successfully completed a recognised test pilot course. The Class II applicant must satisfy the Director of the SACAA that he has adequate knowledge of test flying techniques. No mention is made for the requirements of a post maintenance test pilot rating. The privileges of such ratings are not listed.

There is confusion within the local industry, such that the debates on the way forward are healthy and rigorous. Nevertheless, there is recognition for the need of some form of additional qualification for pilots performing maintenance testing.

The European Aviation Safety Agency (EASA) seemingly has adopted a different approach. Although acknowledging the safety concern around maintenance test flying they have adopted the view that maintenance test flying is, in fact, not test flying[12]. 'Functional Check Flight'[13] or 'Maintenance Check Flight' seems to be the new terminology[14]. Within EASA latest developments[15] would seem to indicate, though, that 'Functional Check Flight' and 'Maintenance Check Flight' are being defined differently, with the 'Maintenance Check Flight' specifically being seen as required after maintenance activity.

Regulations around the conduct and qualification requirements for such Functional Check Flights or Maintenance Check Flights are only expected around 2014 to 2015, whilst EASA chose to first address the need for regulations pertaining to the conduct of test flights[13] such as during aircraft certification. The Notice of Proposed Amendment 2012-08[14] does aim to address Maintenance Check Flights and only recently closed for comment.

Other authorities also recognise the risks inherent in Functional Check Flights. The UK CAA's Safety Regulation Group has published the CAA Check Flight Handbook to guide in the conduct of maintenance test flights[16]. Although the UK CAA does not require specific ratings, they do require pilots to be acceptable to the UK CAA, and, for heavier aircraft, to have flown a test flight with a UK CAA test pilot. No specific mention is made, for instance, of any specific additional training over and above the normal line pilot training.

5.0 THE INDUSTRY RESPONSE

1994 and 1996 saw the last accidents on large commercial jet aircraft during test flying for a period of 12 years until the 2008 accident occurred. The 2008 accident was rapidly followed by several incidents of a nature serious enough to have the potential for further accidents, prevented by the crews involved.

The industry took note. There are now several short introductory courses to maintenance test flying available on the market, including the Airbus Technical Flight Familiarisation (TFF) Course, which the author has attended. Such courses are necessary steps in the right direction, focusing on proper planning and prevention through a structured approach to each test sequence, including establishing pre-determined sacrosanct limits. They do hold short, though, of training the recovery from developed complex loss of control scenarios, focusing rather on not getting into such situations in the first place. Although conceptually correct, this cannot fully guarantee that LOC events will not happen in future.

Admittedly, with current technology available, simulation of flight outside of the operational flight envelope is not necessarily representative of aircraft behavior, starting with an absence of the necessary data to program flight simulation devices accordingly. Further, physical constraints prohibit the effective simulation of sustained high flight load sensation to the crew.

An aircraft can be flown by alternative means as at least two crews demonstrated successfully, the DC-10 in Sioux City in 1989 and the A300 in Baghdad in 2003[5]. In both instances the aircraft lost all hydraulic systems with the crew reverting to the use of thrust only to control their aircraft in pitch and roll. Neither crew had training for such a (very rare) eventuality. Should there be training for maintenance test flight crews to deal with such situations?

The Flight Safety Foundation [9] equally got involved. At the International Air Safety Seminar 2009 in Beijing the risk associated with maintenance test flights was topical. In 2010 the Flight Safety Foundation established a steering team which led to a dedicated Functional Check Flight Symposium in Vancouver, in February 2011.

Here equally, the designation of such flights was the first topic, the term 'Functional Check Flight' being adopted. The principle that flight tests are performed by manufacturers, flight checks are performed by operators seems to have been applied. Unfortunately, such an approach does not really solve the grey area between the two, following, for example, a major aircraft modification, not necessarily implemented by the manufacturer, but within regulatory constraints.

The symposium recognised a number of items[9]:

- Functional Check Flights represent a higher risk than normal flight.
- Operators need to adopt industry best practices including personal selection, qualifications /training and organisational structure.
- Regulators need to develop sensible, well defined regulations together with industry to address the conduct of Functional Check Flights.
- Manufacturers need to provide operators with more up to date information on Functional Check Flying.

Again, these are all steps in the right direction. But what is the industry best practise? The symposium saw a number of presentations from operators on how they approach Functional Check Flying. The operators presenting at the symposium all operate large fleets with designated pilots who perform numerous functional check flights annually. Does that represent industry best practise? What do smaller operators do who often have multi-year gaps between such flights? The EASA Notice of Proposed Amendment 2012-08[14] suggests a 24-month recency

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requirement, which would have to be achieved through recurrency training with the associated cost implications.

Operators historically often had to develop their in-house functional check flights programs as evolutions, for example, of experiences on aircraft acceptances from the manufacturer or from another operator, customised to local conditions and biased by in-house occurrences/experiences. These evolutionary processes are not necessary effective as subsequent industry experiences or the impact of aircraft modifications/upgrades do not necessarily find their way into such programs. Such programs then easily become out-of-date until the next set of aircraft acceptances. The operator necessarily is reliant on manufacturer support in this regard and the appropriate programs are starting to become available.

The discussions at the symposium did not elaborate on high LOC component of maintenance test flight accidents.

6.0 CONCLUSIONS

Since the start of the commercial jet age, the industry has made huge strides in safety improvements, reducing the fatal accident by three orders of magnitude.

Maintenance test flights, maintenance or functional check flights, whatever one may wish to call them, remain a necessary component of retaining the industry's exceptional safety records. Transfer of risk to non-revenue flying (and the essential crew only), in order to protect against the ubiquitous nature of human error, safes lives and prevents schedule disruptions.

Contrary to the principles of making flights as safe as possible through well-structured and strict adherence to Standard Operating Procedures (SOPs) a pilot during maintenance test flying necessarily needs to deviate from such SOPs for the purpose of testing, and needs to operate near the edges of the operating flight envelope. Yet such a pilot's main activity remains line operation with strict adherence to Standard Operating Procedures and operations in the middle of the operational flight envelope. In so doing gaps are opened in the 'safety net' and the line pilot finds himself faced with situations, through the testing process, not normally experienced during line flying where expected aircraft behaviour may not be as readily distinguishable from non-normal behaviour. At the extreme, this can lead to a loss-of-control situation outside the operational flight envelope beyond the pilot's ability to recover, as evidenced by the accident history of maintenance test flights.

The ratio of fatal accidents of revenue flights versus maintenance test flights between 2002 and 2011, 78 versus one, compared to the ratio of number of revenue flights versus maintenance flights, in excess of 1,200 to one, suggests that the risk of a maintenance flight fatal accident is one to two orders of magnitude higher. Exact numbers are not required. Rather, recognition of the significantly heightened safety risk is.

The regulatory environment remains in flux around this topic with no clear guidance or consistency on training, experience and/or licensing requirements for maintenance test flights. Instead the focus appears to be, for now, to derecognise such flights from maintenance test flights to maintenance check flights so as to separate such activities from other test flight activities. Proposals on the requirements, privileges and limitations for conducting maintenance check flights are being tabled for industry comment.

The industry has responded to the recent incidents/accidents on large transport aircraft involved in maintenance test flying. The manufacturers have started making maintenance test flight programs available. Functional/maintenance check flight training courses are also becoming available. Such courses appropriately focus on planning and on prevention, including LOC avoidance, through early recognition and strict observance of predetermined limits for each critical test sequence.

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They stop short of addressing recovery from complex loss of control scenarios. In the absence of regulatory enforcements such courses remain voluntary.

The risk of exposing crew to actual complex loss of control scenarios predictably reduces through such training. However, even after having been exposed to and having applied such training, the risk remains that a complex Loss of Control situation, once entered, might not be recovered.

7.0 RECOMMENDATIONS

Whilst progress is being made on addressing the risks associated with maintenance test flights, there is still a long way to go. Industry best practises remain to be more clearly defined. Regulatory oversight needs to be established. Crew training/experience/qualification requirements remain to be finalised.

Once all these elements have been addressed respectively resolved, the question ‘Has enough been done?’ remains. The ability to recover from complex ‘Loss of Control’ events, although recognised as a primary concern by the industry generally, remains an open topic currently not addressed in any focused way within the spectrum of maintenance test flying. This needs to change. Discussions around this, at a minimum, are necessary.

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APPENDIX A: MAINTENANCE FLIGHTS ACCIDENTS/ INCIDENTS

Date	Aircraft Type	Brief Description
25 Oct 1962	TU-104B	Crash on take-off due to rudders installed incorrectly
22 Oct 1963	BAC 1-11	Aircraft entered a stable stalled condition from which recovery was not achieved
17 May 1986	Yak 40	Crash during test flight
2 Apr 1992	DC-9	Crashed into sea
26 Jul 1993	CRJ100	Sideslip manoeuvre ended in a deep stall with no recovery. Anti-spin parachute separated from aircraft
30 Jun 1994	A330	Simulated engine failure on take-off resulting in excessive pitch up with no recovery
22 Dec 1996	DC-8	Inoperative stick shaker, stall with inappropriate recovery techniques, crashed in mountainous terrain
10 Oct 2000	CL 604	Excessive take-off rotation with aft centre of gravity resulting in a stall with no recovery
8 Nov 2002	A340	Impact with ground equipment during landing following an unplanned and inadequately briefed manoeuvre
27 Nov 2008	A320	Stall due to angle-of-attack sensor blocked. Test was performed during approach, unable to recover.
12 Jan 2009	B737-700	Manual reversion check. Rapid pitch down with LOC eventually recovered, speed reached 429 kts Recovered.
19 May 2009	B737-700	Manual reversion check. Rapid pitch down. Recovered.
6 Nov 1967	Britannia 175	Loss of instrumentation resulting in a loss of control, not recovered.
19 Jan 1973	Vickers Viking	Loss of orientation in marginal weather conditions, crashed in mountainous terrain
25 Aug 1992	Metro III	Replacement of primary flight control cables, roll to right after take-off not recovered.
27 Aug 1992	DHC-4T Caribou	Too steep climb with roll to the right after take-off - no recovery. Possibly control locks not removed.
5 Feb 2006	Shorts 360	Mid-air collision

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