# Maintenance Mistakes and Systems Solutions

*This article by Alan Hobbs, a BASI[*] human performance investigator, was published in Asia-Pacific Air Safety in March 1999.*

**Human factors is not just about people: it is also about improving systems. While the focus of this article is on airline maintenance, there are also lessons for general aviation.**

Ask someone about the threats to the airworthiness of an aircraft and they will probably mention metal fatigue, corrosion, excessive wear of components or other results of ageing and use.

Yet today, as aircraft become increasingly reliable, we have reached the point where the actions of the maintainers themselves lie at the heart of many airworthiness problems. According to Boeing, around 15% of major aircraft accidents involve maintenance error.

Human errors, and the frustration, sleepiness, misunderstandings and memory lapses which produce them, are powerful forces affecting the quality of maintenance and hence the airworthiness of aircraft.

There is now a worldwide effort to understand more about the human side of maintenance problems. This article deals with just a few of these issues.

Maintenance errors can have a significant impact not only on safety, but also on the financial performance of large and small operators alike. A single in-flight turn-back of a Boeing 747, with the need to accommodate passengers overnight, can easily wipe out $250,000 of profit. It has been estimated that in the USA, maintenance error could cost airlines one billion US dollars per year![1]

The term 'human error' is used throughout this article in recognition of the fact that most aviation accidents do involve human error at some point in the chain of events. However, we need to recognise that these errors (or unsafe acts) tend to be just one link in a chain of events. A useful framework to use when considering human factors issues is the Reason Model of accident causation illustrated.

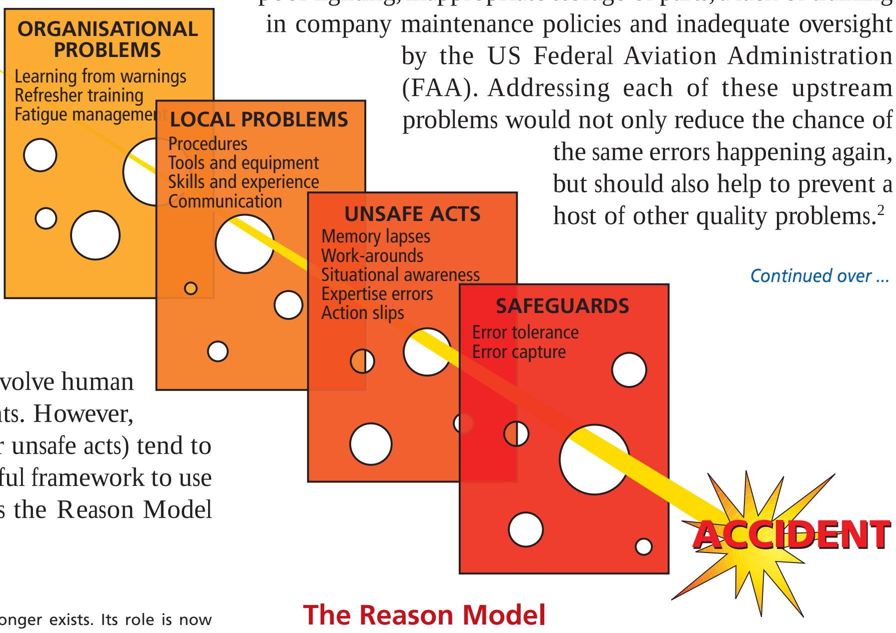
Unsafe acts are not just problems in their own right, but can be seen as *symptoms* of wider problems. For example, in March 1994 the number one engine and pylon of a 747-200 rotated downward during the landing roll and contacted the runway. There were no injuries to passengers or crew. The aft fuse pin on the pylon diagonal brace had migrated from its fitting and was found loose in the pylon structure. The type of pin fitted to this aircraft was normally secured in place by two retaining devices, but on this occasion, neither of these retainers could be found.

Approximately 10 hours after the accident, the missing retainers were found in an unmarked cloth bag on a work stand near where the aircraft had recently undergone a C-check. The C-check had included an inspection of the diagonal brace fuse pin lugs on the two outboard engines.

It was never established who had made the errors that culminated in the accident; however, finding the people responsible may not have helped prevent future accidents. The most important lessons learnt from this accident were not about individuals, but about the way maintenance was organised and carried out.

The US National Transportation Safety Board (NTSB) identified a range of system problems including an error-producing work environment, potentially dangerous scaffolding, poor lighting, inappropriate storage of parts, a lack of training in company maintenance policies and inadequate oversight by the US Federal Aviation Administration (FAA). Addressing each of these upstream problems would not only reduce the chance of the same errors happening again, but should also help to prevent a host of other quality problems.[2]

*Continued over ...*




**The Reason Model**

*BASI (Bureau of Safety Investigation in Australia) no longer exists. Its role is now performed by ATSB (Australian Transport Safety Bureau).

... continued from previuos page

## Unsafe Acts: What Goes Wrong?

In order to understand the types of errors made by maintenance engineers, the Bureau of Air Safety Investigation (BASI) has collected information on over 120 maintenance unsafe acts from interviews with airline engineering personnel and from incident reports received during a study of the regional airline industry. Most of the unsafe acts were corrected before the aircraft flew, or resulted in only minor consequences.

Over 80% of the unsafe acts of maintenance mechanics fell into one of five types:

### Memory Lapse: 24%

Memory lapses do not generally happen randomly, but often occur when a person is interrupted to go and do something else. Juggling maintenance tasks on several aircraft is a common situation, which can lead to a memory lapse.

Being the only person on shift, I was responsible for both hangar and line maintenance. There was a fuel quantity problem on a […]. I had to move fuel plumbing to gain access. I was distracted from my task by heavy commitments with line defects. I forgot to check the tightness of the B-nuts causing the aircraft to develop a potentially disastrous fuel leak.
– De-identified incident report.

### Work-arounds: 23%

Typically, work-arounds involve performing a task without all the necessary equipment, or in a more convenient manner than in the approved procedures. However, some are more serious, as in the case of workers faced with time pressure who decide not to document their actions or decide not to perform all the required steps in a task. On their own, work-arounds may not necessarily result in an incident, but serious problems can result when other people are not aware that someone has taken a shortcut, or when a work-around is followed by an error.

It was a Friday afternoon and I was about to knock off for the weekend. I decided to do one last-minute job and tighten the nose-wheel steering cables on a twin-engine aircraft. Not having an appropriate flagged rig pin, I used a bolt through the aircraft floor to hold the rudder pedals in neutral. It got dark and everyone was anxious to go home, and I was holding them up. At the end of the job I signed off the Maintenance Release but forgot to remove the bolt. On the Monday I was asked if the aircraft was ready and I said 'yes'. The aircraft was flown for a whole day checking out a pilot, with landings every 20 minutes. If they had feathered an engine or there had been an engine failure they would have been in real trouble, as the limited rudder movement was from this bolt flexing in the floor structure.
– De-identified incident report.

Maintenance mechanics are often faced with the pressure of being informed by companies to follow the procedures, but at the same time are encouraged to get work done to deadlines. One mechanic summed it up this way: "Management tell us to follow the procedures to the letter, but then they tell us not to be obstructive and to use common sense." A recent European study found that a third of maintenance tasks involved a deviation from official task procedures.[3]

*"Maintenance engineers are like torque wrenches: they need to be re-calibrated from time to time."*

### Situational Awareness: 18%

Situational awareness errors occur when the mechanic starts work without first gaining an accurate picture of the situation being dealt with. Often, they don't realise that the situation is different from normal, as when a mechanic activates hydraulics without noticing that cockpit controls have been moved while the hydraulics were off. In other cases, an engineer may not be aware of work being done by other workers on the same aircraft.

### Expertise: 10%

Errors of expertise happen when someone doesn't have the knowledge, skills or experience to do all aspects of their job. As might be expected, errors of expertise tend to involve less experienced workers. The fact that 10% of errors are of this kind could indicate deficiencies in training.

### Action Slips: 9%

Action slips occur when someone accidentally does something unintentionally. Slips tend to occur on routine, highly familiar tasks.

A mechanic accidentally put engine oil into the hydraulics system of an aircraft. Oil and hydraulic fluid were stored in nearly identical tins in a dark storeroom.
– De-identified incident report.

## Local Problems: Why do Things go Wrong?

The BASI analysis of maintenance incident reports found that for incidents which had airworthiness implications, the most common factors in the work area at the time of the incident were:

### Confusion, Misunderstandings, or Differences of Opinion About Procedures

It is not unusual to find that workers have a fairly limited understanding of a company's formal policies and procedures and instead follow informal practices developed on the job. Older, experienced workers will sometimes develop their own practices, which may be different from the approved procedures. Unworkable or inconvenient procedures prompt the sort of work-arounds described earlier.

### Communication Breakdowns Between People

In a recent survey, senior US maintenance mechanics were asked to describe the most challenging part of their job.

Their most common answer was "human relations or dealing with people".[4] Performing in a team requires more than technical know-how, and we often overlook the need to develop these important communication and people skills.

### Pressure or Haste

Since the early days of aviation maintenance, personnel have faced pressures to get aircraft back into service. However, as aircraft become more complex and operators strive to reduce the amount of time that aircraft spend in maintenance, pressure is a growing fact of life for maintenance engineers. A particular risk is that engineers faced with real or self-imposed time pressures will be tempted to take shortcuts to get an aircraft back into service more quickly.

Maintenance systems have built-in safeguards, such as independent inspections and functional tests designed to capture errors on critical tasks. By necessity, these error-capturing safeguards generally occur at the end of jobs, at exactly the time when pressures to get the aircraft back into service are likely to be greatest and the temptation to leave out or shorten a procedure is strongest.

In the recent BASI survey, 32% of mechanics reported that there had been an occasion when they had not done a required functional check because of a lack of time. At the time, such a decision may have seemed safe and reasonable; however, decisions made under pressure do not always stand the test of hindsight.

### Inexperience

Younger personnel need to know about the traps lying in wait for them, yet too often they are allowed to discover these for themselves.

### A Lack of Tools, Equipment, or Spares

Many work-arounds occur in response to lack of appropriate hardware or spares. It is understandable that airlines will try to reduce their stocks of expensive spares; however, in some cases relatively inexpensive spares such as O-rings are nil-stock items. Furthermore, a lack of major spares can lead to increased cannibalisation of parts from other aircraft, which in turn doubles the disturbance to systems and increases the potential for human error.

A common theme underlying these problems is that maintenance personnel may need training in human factors areas such as communication, supervision, and dealing with pressure and frustration.

The great benefit of human factors training is not only that people change, but that people can see the opportunities to change the systems in which they work. For this reason, managers, who have the most power to change things, should not be excluded from human factors training.

My company ran a human factors course for all mechanics in 1996. It was very informative and I learnt a lot of things I hadn't even thought about before. As a result, I have changed my attitudes and actions to increase my personal safety and awareness. This course should be given to all apprentices or new hires. It is invaluable.
– Survey comment.

## Organisational Factors: What are the Weaknesses in the Overall System?

Maintenance incidents can reflect a range of organisational problems. Three of the most important of these are dealt with below.

### Lack of Refresher Training

The regulations state that maintenance personnel must receive "proper and periodic instruction". However, in reality, few maintenance engineers receive refresher training once they have gained their licences. Without such training, non-standard work practices can develop or engineers can lose touch with changes in regulations or company procedures. One senior airline manager put it this way: "Maintenance engineers are like torque wrenches: they need to be re-calibrated from time to time".

### Lack of Learning From Incidents

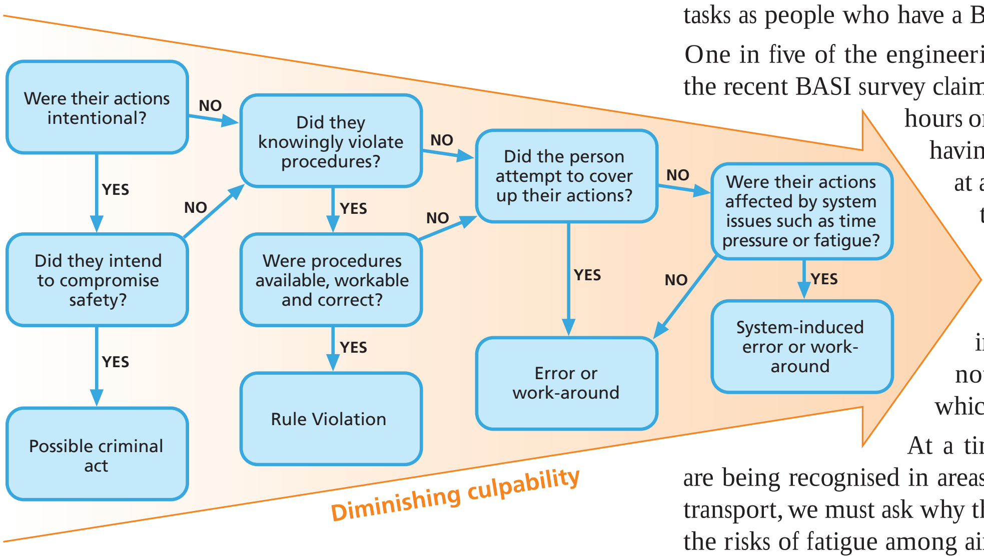
The conventional wisdom among safety experts is that for every accident there may be 30 or more previous minor incidents. When BASI interviewed maintenance engineers about incidents, it became apparent that before a serious quality lapse occurs, there are usually earlier incidents which could have acted as warnings of a problem.

Unfortunately we do not always learn the right lessons from these 'warning incidents', sometimes because they are never reported. It is never easy to admit a mistake; however, it is even harder when an organisation punishes people who make honest mistakes, perhaps by docking pay or placing notes on personnel files. A punitive culture within the company or the regulatory authority creates an atmosphere in which problems are quietly corrected and places barriers in the way of learning from our mistakes. In the recent BASI survey of maintenance personnel, 66% of respondents reported that they had corrected an error made by one of their colleagues without documenting it, in order to avoid getting them into trouble.

One action which managers can take to ensure that they hear about the 'warning incidents' is to have a clear 'responsibility policy', which outlines how the organisation will respond to maintenance incidents.

*Continued over ...*

The following diagram illustrates how a responsibility policy might work, although every operation will need to tailor such a policy to its own requirements. Needless to say, no policy such as this can be expected to function if the regulatory authority penalises those who report their mistakes.




**'Responsibility Policy'** (adapted from James Reason[5])

*Until the regulator's inspectors move away from the blame culture that is currently implemented, maintenance defects and incidents will always be covered up and hidden.*
*– Survey comment.*

Once an incident has been reported, the focus of an internal investigation should normally be on identifying system problems, not on identifying personal deficiencies of individuals.

There **may** be rare times when incidents are related to intentional acts of malice, but the great majority of maintenance mechanics do their jobs with diligence and integrity and most incidents reflect system problems, which go beyond individual workers.

*"After 23 hours of being continuously awake, people perform as badly on these tasks as people who have a blood alcohol concentration of 0.12%."*

An internal investigation that only results in recommendations directed at the level of individuals, (such as reminders to engineers to 'be more careful' or to 'follow procedures more closely') are sure signs that the investigation did not identify the system failures which led to an occurrence. There are now structured methods to help managers identify system failings in maintenance, such as the Boeing maintenance error decision aid (MEDA) system[6].

### Fatigue

There is probably no way to avoid the need for maintenance to be done at night; however, this does not mean that fatigue levels cannot be managed. Unfortunately, almost all night-shift workers suffer from a lack of quality sleep.

Recent Australian research has shown that moderate sleep deprivation of the kind experienced by shift workers can produce effects very similar to those produced by alcohol.[7] After 18 hours of being awake, mental and physical performance on many tasks is affected as though the person had a blood alcohol concentration (BAC) of 0.05%. Boring tasks, which require a person to detect a rare problem (like some inspection jobs), are most susceptible to fatigue effects. After 23 hours of being continuously awake, people perform as badly on these tasks as people who have a BAC of 0.12%.[8]

One in five of the engineering personnel who responded to the recent BASI survey claimed they had worked a shift of 18 hours or longer in the last year, with some having worked longer than 20 hours at a stretch. There is little doubt that these people's ability to do their job would have been degraded. An important point to note is that like people who are intoxicated, fatigued individuals are not always aware of the extent to which their capabilities have degraded.

At a time when the dangers of fatigue are being recognised in areas as diverse as medicine and road transport, we must ask why there are no regulations to control the risks of fatigue among aircraft mechanics.

## Safeguards: Reducing the Consequences of Maintenance Errors

### Minimising Consequences of Errors vs 'Working Without Nets'

Functional checks and independent inspections are examples of safeguards designed to capture errors before they cause harm.

However, there is another approach to managing error which is sometimes overlooked. This is to acknowledge that errors will occur from time to time and that we need to design procedures and systems that can minimise the consequences of such errors. Special maintenance precautions applied to extended-range twin-engine operations (ETOPS) are an example of such an approach. When an aircraft is being maintained in accordance with ETOPS procedures, the performance of identical maintenance actions on multiple elements of critical systems is avoided wherever possible. Engines, fuel systems, fire-suppression systems and electrical power are examples of ETOPS critical systems on aircraft such as the B767 and B737.

However, these precautions are not generally applied to aircraft with more than two engines, or to twin-engine aircraft which are not being maintained in accordance with an ETOPS maintenance programme.

For example, in 1995, a European-operated Boeing 737-400 was forced to divert shortly after departure following a loss of oil quantity and pressure on both engines. Both of the aircraft's CFM-56 engines had been subject to boroscope inspections during the night prior to the incident flight. High-pressure rotor drive covers were not refitted on each engine and, as a result, nearly all the oil was lost from the engines during the brief flight[9].

Several months after this incident a similar overseas incident occurred on a Boeing 747-400. Shortly after departing on an over-water flight, the crew noticed reducing oil quantities on the number one and number two engines. The aircraft was turned back to its departure point, where it arrived safely without any need for the engines to be shut down in flight.

After landing, oil could be seen leaking from the engines.

Boroscope inspections had been carried out on all four of the GE CF6 engines. This inspection normally involves removing and then refitting the starter motor from each engine, and in fact the starter motors were removed from the number one and number two engines in preparation for the job. Because the tool to enable the engines to be turned by the starter drive could not be found, the starter motors for engines 3 and 4 were not removed and all engines were turned by an alternative method. A lack of spares had led to a practice of not replacing O-rings when refitting starter motors. However, on this occasion a mechanic **did** comply with documented procedures and removed the O-rings from the number one and two starters. The workers who refitted the starters apparently assumed that the situation was 'normal' and did not notice that the O-rings were missing – a 'situational awareness' error.

This incident had a variety of causal factors, such as informal procedures which had evolved to work around the frequent 'nil stock' state of spares, poor lighting and inadequate leak check inspections. However, an important point is that because the aircraft had four engines, it was not protected by ETOPS standards. In essence, the mechanics were 'working without nets'. Had the job proceeded as originally planned, the starter motors would have been removed from all four engines, with serious consequences.

The extension of some ETOPS precautions to non-ETOPS operations would help to contain such maintenance-induced problems.

Boeing has encouraged operators as a general practice "to institute a programme by which maintenance on similar or dual systems by the same personnel is avoided on a single maintenance visit".[10] BASI has also published the following suggested safety action: "Where possible, the simultaneous performance of the same maintenance tasks on similar redundant systems should be avoided, whether or not the aircraft is an ETOPS aircraft".[11]

## Conclusions

Unfortunately, advances in aviation technology have not necessarily been matched by improvements in the way we organise the work of the people who maintain aircraft.

The remarkable aspect about maintenance incidents is that many of them share similar features. A relatively limited number of unsafe acts, such as work-arounds, memory lapses and situational awareness errors typically occur in the context of problems such as unclear or poor procedures, a lack of equipment or spares, communication breakdowns, time pressure and fatigue. Because unsafe acts are

Continued over ...

***GA Maintenance Comment***

As some smaller maintenance organisations often have additional human factors considerations that are specific to their operation, *Vector* sought comment from a New Zealand general aviation maintenance provider. They had this to say:

Engineers of smaller maintenance organisations are sometimes tasked with multiple roles. Sometimes, they not only have to carry out the day-to-day maintenance work on aircraft, but may also have to be either the CEO, Chief Engineer, Certifying Engineer or storeman at the same time. Changing between these roles can be stressful, and it increases the chances of introducing error.

An interruption, such as a business-related phone call to the CEO, while working on an aircraft could cause a memory lapse, the consequences of which need little elaboration. It is important that engineers in multiple roles are aware of such potential pitfalls and that they have strategies in place to minimise the risks.

Maintenance Controllers need to be mindful of the pressure they may be placing on their maintenance provider (especially a small business) when scheduling routine aircraft maintenance. An awareness of how much time is involved in each particular check, a good understanding of the scope of the work involved, and scheduling it well in advance within a realistic timeframe, does significantly reduce the amount of pressure on the maintenance provider.

The same is true when it comes to rectifying defects – Maintenance Controllers should be careful not to apply undue pressure to get the job done. Time pressure is an engineer's worst enemy.

A further problem that smaller maintenance organisations often face, unlike their larger counterparts, is carrying sufficient stocks of parts for the aircraft they maintain. Because of the diverse range of aircraft types that some smaller maintenance organisations can have on their books, it is often not financially economic to carry a full range of parts. This can mean an added time pressure when they have to be ordered in.

... continued from previuos page

generally symptoms of wider problems, human factors is not just about focusing on people but on the systems within which people work.

This article concludes with just five system-level improvements that may help to ensure safer maintenance:

- Introduce refresher training, particularly on company policies and procedures.
- Introduce a clear 'Responsibility Policy' to remove barriers that discourage people from reporting incidents.
- Introduce a fatigue management programme. This will almost certainly involve ensuring that workers get adequate sleep opportunities. If 12-hour shifts are being worked, a ban on extending shifts with overtime may be necessary.
- Introduce human factors training for management and workers.
- Minimise the simultaneous disturbance of multiple or parallel systems.

While striving for perfect performance by those maintaining aircraft, we should recognise that making mistakes is an unfortunate but unavoidable consequence of being human. ■

### References


1. Marx D. (1998) *Learning from our Mistakes: a review of maintenance error investigation and analysis systems,* FAA.
2. NTSB Special Investigation Report NTSB/SIR-94/02.
3. Eggerling U. (1998) Airbus Industrie, *Human Factors in Maintenance: the Need for Dialogue and Feedback,* Paper presented to Association of Asia Pacific Airlines Maintenance Human Factors Conference, Sydney February 1998.
4. Predmore S. and Werner T. *Maintenance Human Factors and Error Control* Eleventh FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. Washington, DC: FAA.
5. Reason J. (1997) *Managing the Risks of Organisational Accidents* Ashgate, Aldershot.
6. Rankin W. and Allen J. (1996) Boeing Introduces MEDA: Maintenance Error Decision Aid *Airliner* April-June, 20-27.
7. Dawson, D. and Reid, K. (1997) Fatigue and Alcohol Intoxication have Similar Effects on Performance. *Nature,* 38, 17 July, 235.
8. Williamson A. and Feyer A. Moderate sleep deprivation produces comprehensive cognitive and motor performance impairments equivalent to legally prescribed levels of alcohol intoxication.
9. Air Accidents Investigation Branch (1996) Aircraft Accident Report 3/96.
10. Boeing Service Letters *Dual System Maintenance Recommendations* 17 July 1995.
11. Bureau of Air Safety Investigation (1997) *Human factors in airline maintenance: a study of incident reports.*


# Check Before Tightening

A recent fatal helicopter accident, in which the pilot experienced severe control difficulties following a loss of hydraulic systems pressure, was found to have been caused by a leaking hydraulic supply line. The leak was due to a fatigue crack, which had been propagating for some time. The crack was probably due to a combination of factors: reversed bending stresses (exacerbated by vibration) on the tube in the area of the fitting, previous wear and tear, and the fact that the MS flareless fitting securing the supply line had been repeatedly tightened in apparent attempts to stop a slow leak. When and by whom the attempted rectification was carried out could not be established.

It is reasonable to expect that a licensed aircraft maintenance engineer would be familiar with the characteristics and limitations of the MS flareless fittings and would not have attempted to over tighten the fitting to stem a leak. The over tightening is more likely to have been performed by somebody with mechanical skills, but with no training in aircraft maintenance. The simple remedy is to replace a leaking line; the components are readily available and are not expensive.

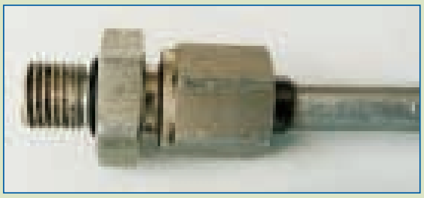
This accident highlights the susceptibility of MS flareless fittings to damage if over tightened. Ensuring that such fittings are tightened to the correct Maintenance Manual torque setting by an **appropriately qualified** aircraft engineer is vital. Suspect fittings or lines should always be replaced – doing so would have probably prevented this accident.

If you do discover a weeping flareless fitting on a hydraulic line and are unsure about the correct procedure to tighten it, then always refer to the aircraft Maintenance Manual **before** undertaking any work.

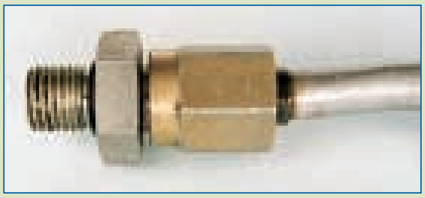
Further information on this topic can be found in the CAA Accident Report 01/44 on the CAA web site (**www.caa.govt.nz**) by clicking on **Accidents and Incidents/Fatal Accidents.** ■

*Properly formed (new) tube end: The 'ridge' visible inside the tube end is normal.*

*MS flareless fitting components: (Tube, MS 21921 nut, MS 21922 sleeve and MS 21916D reducer)*



*The damaged MS fitting: The nut has been filed to obtain further travel after it has bottomed out on the reducer.*



*The nut at the opposite end of the same line, for comparison.*

September / October 2002

# VECTOR

*Pointing to Safer Aviation*

## Maintenance Mistakes and Systems Solutions

**Trouble Checking**

**Transponder Basics**

**Erroneous ILS Indications**

CAA
CIVIL AVIATION AUTHORITY OF NEW ZEALAND