Abstract. This paper appeals for care with the language of aeronautical fatigue. Communication is as important as calculation. Bad words undo good engineering. It gives examples (including twelve troublesome words), suggests causes (including pride and insecurity), and offers help (including Plain English and Simplified Technical English).

1. Introduction

‘Sticks and stones will break my bones but words will never hurt me!’ is an old saying I often heard at school. But we know from everyday life that this is not true —words can hurt.

What about the words of aeronautical fatigue? Could they hurt us too?

2. The Hurt

Words have hurt us in the past. Here are just three examples:

Tenerife 1977
After two Boeing 747s crashed into each other, killing 583, the Dutch report said ‘misunderstanding has arisen from normal but ambiguous terminology’ [1]. The Spanish report recommended the ‘use of standard, concise and unequivocal aeronautical language’ [2]. The crash led to a major international effort to improve communication between pilots, and between pilots and air traffic controllers.

University of New South Wales 1976
This was a personal experience. While studying aeronautical engineering, for my thesis I designed a wing with another student who stressed it. By telephone (this was before fax and email) he told me the length I needed for a part of the spar. He told me the semi-span. I thought he meant full span. So my part was too short. Thankfully the wing broke on test, not in flight, so it only hurt my pride.

Ansett 2000
The incident that started my thinking for this paper. In 1997, a revision to Boeing’s Maintenance Planning Data for the 767 said at the front:

* Oral presentation
Revised Airworthiness Limitation section to reflect the reassessment of the ‘50-Series’ Supplemental Structural Inspection Program.

Ansett, then Australia’s second-largest airline, thought ‘50-series’ meant that these fatigue inspections did not start until 50,000 flights, the 767’s design service goal. So they put the revision aside. But ‘50-series’ was Boeing jargon for something else. The inspections should have started at 25,000 flights, a point which some of Ansett’s 767s had already passed. Ansett remained unaware for three years, until Christmas 2000. The immediate groundings for inspections and repairs stranded thousands of passengers. Ansett did not recover and closed in 2001. See [3].

3. The Words

Here are twelve words that are troublesome and could hurt us:

- initiation
- failure
- on-condition
- condition monitoring
- safe life
- fail-safe
- damage tolerance
- ageing aircraft
- structural integrity
- detectable
- supplemental inspection documents
- service history based inspections

Initiation

ASTM E1823–10 defines crack initiation as ‘the onset of crack propagation from a pre-existing macroscopic crack’—leaving us to then define onset [4]. For AFGROW, ‘initiation is defined by the strain-life data used in a given prediction’. For its ‘sample data’, it is a ‘2.5 mm (0.01 inch) crack’ [5], a common size ‘engineers have arbitrarily set’ [6]. Unfortunately, engineers do not always say which size they set, or even the ‘level of observation’ [7]. It could be a visual check, load drop-off, or separation.

While initiation works generally (‘notches initiate cracks’), spatially (‘the crack initiated here’) and metallurgically (‘initiation involves slip bands’), it is not definitive chronologically (‘the crack initiated then’), because it is not the ‘singular event’ that many think it is [8]. It is a multi-stage process. Better reflections of that are Schijve’s ‘initiation period’ [9] and Hoeppner’s nucleation [10].

Fortunately, civil rules do not use initiation to design aircraft or their inspections. Despite that, I have seen attempts to use initiation instead of critical for setting the inspection threshold. This error is unconservative if:

- critical precedes initiation (for strong brittle alloys as Hoeppner warns [11])
- critical follows initiation and the compressive zone (for cold expansion [12]).

(Thanks to Len Reid of Fatigue Technology, who convinced me at the Symposium that the second bullet was wrong. Even if a crack were to grow beyond the compressive zone (unlikely), into the tensile zone, the compressive zone would still resist its opening, and so still retard its growth.)
Failure

Failure is hard to define because, like initiation, it is usually a multi-stage process rather than a singular event. Where in the process do we draw the line—is it initiation, ultimate strength, limit strength or separation?

Safe lives for the wing of the Embraer Bandeirante once differed widely because some authorities thought its fatigue test failed at ultimate strength, and others at separation—much later. Bandeirante wings flew more hours less safely in some countries. It is even more serious if international differences cause operators to distrust all safe lives.

MSG-3 has a good definition of failure: ‘the inability of an item to perform within previously specified limits’ [13]. Let’s remember to specify those limits.

On-condition

MSG-2 defined on-condition as ‘repetitive inspections, or tests to determine the condition of...portions of structure’ [14]. However, many thought the word implied doing nothing, and hoping that damage will be obvious before it is dangerous. Another problem was the word sounding like condition monitoring (the next word in this list).

So, it was good when MSG-3 replaced on-condition by its maintenance tasks to ‘eliminate the confusion associated with the various interpretations of Condition Monitoring (CM), On-Condition (OC), Hardtime (HT) and the difficulties encountered when attempting to determine what maintenance was being accomplished on an item that carried one of the process labels’ [13].

Condition monitoring

MSG-2 defined condition monitoring:

For items that have neither hard time limits nor on-condition maintenance as their primary maintenance process. Condition monitoring is accomplished by appropriate means available to an operator for finding and resolving problem areas. These means range from notices of unusual problems to special analysis of unit performance. No specific monitoring system is implied for any given unit.

It could mean doing nothing, as many thought on-condition meant. It was just as confusing. So, MSG-3 replaced it by its maintenance tasks too.

Safe life

Safe life has many meanings. Some say it is a design property—a single load path. But we know there are single load paths that are damage tolerant and there are multiple load paths that have safe lives.

Some say safe life is a method of analysis—S-N curves and Miner’s rule. But we know there are safe lives that are set by fracture mechanics and tests.

Some say safe life is an assumption—of perfect material and manufacturing quality. But we know that the well-used S-N curves in FAA AC 23-13A [15] came
from fatigue tests of military fighters built in the Second World War—was their quality perfect?

FAR 25.571(c) defines safe life as ‘service life without detectable cracks’. It is vague because it does not specify the inspection method—and perverse because it discourages a good one. MIL-STD-1530C (3.29) is better: ‘that number of events such as flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design ultimate value due to fatigue cracking’. (FAA AC 91-82 [16] copies MIL-STD-1530C but is not a rule.)

Unlike on-condition and condition monitoring, MSG-3 kept safe life. But the emphasis is the associated maintenance task—discard—‘the removal from service of an item at a specified life limit’. It is clear what to do.

(I thought it was clear what to do with a safe life until an aircraft manufacturer told me they fatigue-tested a fuselage to find its safe life, but then did not publish it. They did not see a need for a maintenance task. So operators exceed it, unaware of the risk.)

Some prefer safety by retirement (SBR). But discard is simpler, shorter and, being in an international standard, more established.

**Fail-safe**

Fail-safe was a worthy goal—a structure can fail and stay safe; damage will be obvious before it is dangerous; there is no need for a maintenance task.

But even though the practice rarely met the promise, the word fail-safe still fostered complacency. In the 1970s, it hindered authorities wanting to mandate maintenance for fail-safe jets, such as the Boeing 707. It took until 1978, when the UK CAA’s Airworthiness Notice 89 required ‘structural audits’ [17]. In 1981, the FAA followed with AC 91-56 [18]. The results were the now familiar Supplemental Inspection Documents (SIDs)—more on those soon.

The complacency still hinders us. In 2007, Cessna issued a good SID for the 441 Conquest turboprop. In 2011, some operators still question the need for the SID’s inspections and limit of validity because of overconfidence in the 441’s fail-safety.

Fail-safe is no longer in FAR 25.571. Some lament losing the requirement for structure to survive large damage. Perhaps MSG-3’s emphasis on the maintenance task could help us again. Could we restore fail-safety to damage tolerance by restricting the inspection task to operating crew normal duties?

**Damage tolerance**

At ICAF 2005, Eastin and I argued that damage tolerance is not a design property or fracture mechanics, but ‘a method...for assuring safe inspection intervals’ [19]. Then, at ICAF 2007, Gallagher seemed to contradict us [20]. He said: ‘contrary to popular belief, the damage tolerance design approach was not created to support the development of an inspection program’. He said it was a design objective.

Both are correct in context. Eastin and I spoke for a civil rule, FAR 25.571(a)(3):
Based on the (damage tolerance) evaluations required by this section, inspections or other procedures must be established...

Gallagher spoke for a military rule, MIL-STD-1530C (3.8):

Damage tolerance is the attribute of a structure that permits it to retain its required residual strength for a period of unrepaired usage after the structure has sustained specific levels of fatigue, corrosion, accidental, and/or discrete source damage.

So, civil and military damage tolerance rules differ, as Eastin explains more fully in [21]. He concludes that ‘the use of the same words for different things can lead to confusion and needless debate. This has been the case with the words damage tolerance and fail-safe’.

I have seen ex-military engineers get so confused evaluating damage tolerance for civil aircraft that they ignore inspectability, so damage could be dangerous before it is detectable. Like fail-safe, the words foster complacency, so some think they do not need to inspect or repair damage-tolerant aircraft. And again, damage tolerance is not a maintenance task. Some prefer safety by inspection (SBI). But again, simpler, shorter and more established is MSG-3’s task: inspection.

Ageing aircraft

When is an aircraft an ageing aircraft? The FAA’s Aging Airplane Safety Rule says 15 years [22]. Australia’s Civil Aviation Safety Authority (CASA) says it is ‘the time they leave the production line’ [23].

Does definition matter? Not if we don’t need the words. ‘Ageing aircraft’ is just a new name for an old activity—continuing airworthiness. It is a fad. Unfortunately, some think it really is new. For example, a recent recommendation that an authority should have an Ageing Aircraft section overlooks that ageing aircraft are already core business for its Continuing Airworthiness Section. We would be wise to avoid such wasteful duplication and risky division.

The fad is passing. Ageing Aircraft conferences in the US and Australia are now Aircraft Airworthiness and Sustainment conferences—a good start.

Structural Integrity

ICAF 2011’s theme is ‘Structural Integrity: Influence of Efficiency and Green Imperatives’. But what do we mean by structural integrity? By definition and common usage, rarely is it wholeness and purity. Mostly, practically, all we mean is strength. If so, do we really need more jargon that is neither clearer nor shorter?

If we also mean stiffness—as rules like FAR 25.629 (d) require us to—we can say so. But, if not (and we rarely do), let it be clear.

Aircraft manufacturers and airworthiness authorities like structural integrity because it is a euphemism. Service bulletins and airworthiness directives warn more of ‘reduced structural integrity’ than of ‘failure’. The first causes less alarm, but the second causes more action.
Detectable
‘Damage tolerance evaluations’ to civil rules (like FAR 25.571) must assess ‘detectability’. But at ICAF 2007, Gallagher preferred ‘missability’. Asking about ‘missability’ instead of ‘detectability’ helps the optimistic among the inspectors to see the ‘glass half-empty’ instead of ‘half-full’, to answer for a probability of detection (POD) of 90% instead of 10%. Safety must consider psychology.

SID
Airworthiness Limitations (in the ALS) and Supplemental Inspections (in the SID) are the same inspections for the same safety. The only difference is their time of creation relative to type certification: the ALS before, the SID after. Yet operators obey the ALS more than the SID. It is the different words as well as different laws —many think ‘supplemental’ means ‘optional’. We are getting less safety than we had hoped from SIDs like those for Fairchild Metros [24] and Cessna piston twins [25]. Good lessons from ICAF are underused.

Service history based inspections
In AC 91-82 [16], the FAA’s service history based inspections differ from damage tolerance based inspections by not needing even a crude check of three basics of damage tolerance that Eastin and I argued are essential to assure safety [19]:
- detectable (or missable)
- dangerous (or critical)
- duration (or interval)
Service history, if available, can help us estimate them—but it cannot replace them. The dichotomy is false.

4. The Reasons
We might use bad words—or misuse good words—because we are:
- unaware—we do not see a problem
- unprepared—we do not see a solution
- uncaring—we do not want a solution.

The first one is obvious. The second I discuss in the next section. But the third—why would anyone not want their writing to be shorter, simpler and clearer?

Is it schooling—did your teacher specify the minimum length of your essays? If so, did you learn verbosity? Is it engineering—do we like our words complex like our numbers? Is it pride—is complexity more likely to impress? Is it insecurity—would you still be the expert if others understood you?
Is it laziness? Paradoxically, simple writing is harder. Eagleson says ‘it involves thinking—but if your thinking is muddled, your writing will be muddled too’ [26].

I do not judge—I am guilty of all.

5. The Help

The solution is *ergonomics*, the ‘science of work’, according to the International Ergonomics Association (IEA) [27].

**Ergonomics**

Ergonomics is more than office furniture and cockpit controls. The IEA defines three branches:

- *physical* ergonomics—‘human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity’ (includes office furniture and cockpit controls)

- *cognitive* ergonomics—‘mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system’ (includes communication)

- *organisational* ergonomics—‘optimization of sociotechnical systems, including their organisational structures, policies, and processes’.

In cognitive ergonomics, ICAO’s SHELL model has two interfaces [28]:

- liveware-software interface—written communication

- liveware-liveware interface—spoken communication.

For the first, ICAO warns that ‘delays and errors may occur while seeking vital information from confusing, misleading or excessively cluttered documentation and charts’. We once liked complexity in the cockpit (the more, the better!), but then we matured. We learned that increasing complexity increases error. We now strive for simplicity and clarity. Likewise, we should strive for simpler, clearer communication for aeronautical fatigue. To this end, three aids are Plain English, Simplified Technical English and Safety Management Systems.

**Plain English**

Eagleson describes Plain English as:

*The opposite of gobbledygook and of confusing and incomprehensible language. Plain English is clear, straightforward expression, using only as many words as are necessary. It is language that avoids obscurity, inflated vocabulary and convoluted sentence construction. It is not baby talk, nor is it a simplified version of the English language. Writers of plain English let their audience concentrate on the message instead of being distracted by complicated language. They make sure that their audience understands the message easily.* [26]
Gowers adds [29]:

*When experts are writing only for their fellow experts they may achieve their aim of conveying to their readers exactly what they intend to convey by the use of language which the rest of us find obscure or even quite unintelligible. ... This is not to say such writing always is clear, even to the intended readers. Its obscurities are sometimes due, not to the requirements of the subject matter, but to muddled thinking or mere pretentiousness; and for obscurities of this kind, as for any other misuses of language, the writers are not to be forgiven merely because they are writing for fellow experts.*


One lawyer, Asprey, in *Plain Language for Lawyers*, argues it is good for justice and for business [30]. But many lawyers resist for reasons similar to engineers.

In aviation, if Plain English improves clarity, it improves safety.

**Writing Plain English**

How do you write Plain English? Three helpful books are:

- *Writing in Plain English* by Eagleson (Australia) [26]
- *The Complete Plain Words* by Gowers (England) [29]
- *The Elements of Style* by Strunk (USA) [31].

More recent and for aviation is: *Writing User-Friendly Documents, A Handbook for FAA Drafters* [32]. Two of its applications to fatigue are:

- FAR 39, *Airworthiness Directives*.

**Simplified Technical English**

Simplified Technical English (STE) is a controlled language for technical documentation. It started for European aviation but other countries and industries now use it. Standard ASD-STE100 has ‘writing rules’ and ‘approved words’ [33].

Sometimes there is tension between STE and Plain English. For example, where Plain English would suggest ‘inspect’ as a verb, STE would want ‘do an inspection’ because it approves the noun but not the verb. But the irritations are only minor in a standard worth ICAF’s attention.

**Format**

Plain English and Simplified Technical English also concern format. Sadly, we arrange many of our fatigue and corrosion maintenance instructions like an old cluttered cockpit. Gallagher says the ‘root causes’ for ‘inspection misses’ include ‘confusing...documents and instructions’ [20]. We keep adding more clutter. It is easy to miss or misread an instruction—just as Ansett did.
Safety Management Systems
Since 2009, ICAO has required ‘that an operator implement a safety management system...that...identifies safety hazards...and aims to make continuous improvement’[34].

For a lot longer—since 1951—ICAF has been doing exactly that for technical safety hazards. A modern safety management system should remind us and help us to watch our words as well, as we ‘exchange information concerning aeronautical fatigue’ (ICAF’s aim).

6. Conclusion
The sentiment of ‘sticks and stones’ is wrong. The words of aeronautical fatigue could hurt us. Communication is as important as calculation. Let us not allow bad words undo our good engineering.

7. Recommendations
Here are three:
• Be aware—be a critic, especially of your own words
• Prepare—be a wordsmith, even if you find it hard, like I do
• Care—be the professional you are—in all things.

8. Quote
We spent over fifty years on the hardware, which is now pretty reliable. Now it’s time to work with people.

— Don Engen, FAA Administrator, 1986

9. References


[14] FAA, AC 120-17A, Maintenance Control by Reliability Methods, Appendix 1, USA (1978)


[16] FAA, AC 91-82, Fatigue Management Programs for Airplanes with Demonstrated Risk of Catastrophic Failure Due to Fatigue, USA (2008)

[17] CAA, Airworthiness Notice No. 89, Continuing Structural Integrity of Transport Aeroplanes, Issue 1, Civil Aviation Authority, Redhill, England (1978)


[31] Strunk, W.: The Elements of Style, New York, USA (1918)


[34] ICAO, Annex 6, Operation of Aircraft, section 3.3.4, Montreal, Canada (2001)
This book contains the proceedings of the 26th Symposium of the International Committee on Aeronautical Fatigue that was held from June 1-3, 2011 in Montreal, Canada. It contains more than 70 selected papers including the Plantema Memorial Lecture on a broad range of structural fatigue and related topics under the following headings:

- Airworthiness and Other Considerations
- Advanced Materials and Innovative Structural Concepts
- Fatigue Crack Growth and Life Prediction Methods
- Structural Health and Structural Loads Monitoring
- Full Scale Fatigue Testing of Aircraft and Aircraft Components
- Inservice Experience, Life Extension and Management of Ageing Fleets
- Fatigue Life Enhancement Methods and Repair Solutions
- Helicopter Fatigue and Damage Tolerance