

RUSTY DIAMOND

Could 'damage tolerance' be as useful for corrosion as it is for fatigue?

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For 23 years, Steve has regulated fatigue *and* corrosion for Australia's 12,500 hard-working civil aircraft. Many are the oldest of their type in the world. His views in this paper are not CASA policy.

Abstract: An experienced civil aviation safety regulator reviews if 'damage tolerance' could be as useful for corrosion as it is for fatigue. The answer is 'yes'. Operators, manufacturers and regulators could save time, money and lives. Examples, recommendations and draft regulatory guidance show how.

INTRODUCTION

How well are we managing corrosion in the civil world? Modern Corrosion Prevention and Control Programs (CPCPs) *are* a major improvement on the past. Crashes, like those in Annex 1, are less likely. But, look closely, and there are *still* simmering problems. There are *still* unnecessary risks *and* costs. There is *still* room for improvement.

At ICAF 2005, in *Rough Diamond*, Bob Eastin, my counterpart in the United States Federal Aviation Administration (FAA), helped me propose a simple damage tolerance model for fatigue. We light-heartedly called it the 'diamond' [1]:

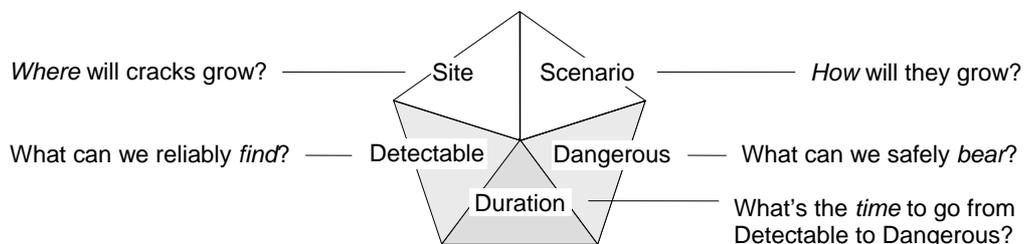


Figure 1: The diamond's five facets of 'damage tolerance'. In the civil rules, damage tolerance is a method to develop maintenance, not a prescription for fracture mechanics, rogue flaws or particular design. Many prefer the term 'safety by inspection', to avoid these unnecessary associations, but 'damage tolerance' seems entrenched.

Rough Diamond was so simple we feared it was simplistic. But, *Air Safety Week* praised it [2], the Royal Aeronautical Society reprinted it [3], and the 'diamond' still helps us understand and explain even complex situations. This sequel and companion, *Rusty Diamond*, reviews whether damage tolerance, with the same simple model, could also be useful for corrosion.



Figure 2: Corrosion doesn't look like fatigue. But, can we still manage it by damage tolerance?

The paper's three main sections are questions:

- Is there a problem?
 - Let's see if there *is* anything 'broke' to 'fix' (to rephrase Bert Lance)
- Is damage tolerance *applicable* to corrosion?
 - Let's see if corrosion *is* too different to fatigue (or, if it matters)
- Is damage tolerance *useful* for corrosion?
 - Let's see if it *is* the improvement we seek

The answers may surprise you.

Finally, as we use more composites (part of ICAF 2007's theme), are you wondering if corrosion is dead? Don't stop reading; we can't ignore corrosion yet. For a while, 'composite' aircraft will still have metal that is structural and corrodible by carbon fibres [4]. We try to separate them, but, even if we design well, we err on assembly. On the wing of one military transport, aluminium trailing edges corrode where the fasteners weren't properly sealed. And, on the fuselage of one civil airliner, workers ground off the fibreglass layer that insulates a carbon-fibre bulkhead from its aluminium frame, to improve the fit!



Figure 3: In 'composite' aircraft, one small slip during design or assembly can unleash the corrosive power of 'cathode-to-anode ratios' far higher than the 'lead' pencil marks we worried about years ago. 'Composite' aircraft are not very 'damage tolerant' for corrosion.

IS THERE A PROBLEM?

Let's look under three headings: 'division', 'duplication' and 'danger'.

Division

In the beginning, the US FAA made them equal: in the first civil rule for damage tolerance, corrosion was there, next to fatigue [5].



FAR 25.571

Damage-tolerance and fatigue evaluation of structure

General. An evaluation of the strength, detail design and fabrication must show that catastrophic failure due to fatigue, corrosion, or accidental damage, will be avoided throughout the operational life of the airplane.

Similar rules followed. Yet, we use them for fatigue, but not for corrosion. We hope that someone, somehow, is ensuring 'their' corrosion won't affect 'our' fatigue. In 2002, the FAA lamented this, and proposed a solution [6]. But, in 2004, they withdrew it! [7]

One problem is professional rivalry: engineers jealously guard fatigue and damage tolerance; mechanics do the same for corrosion. For the FAA, it's Aircraft Certification versus Flight Standards. For this paper, it's writing alone, because Bob Eastin covers fatigue and damage tolerance, but not corrosion. For large airliners, it's Certification versus MRB (Maintenance Review Board), FAR 25.571 versus MSG-3 [8], and Airworthiness Limitations versus MRB reports and CPCPs.

Another problem is the division between civil and military. The military are sponsoring far more research on corrosion and its interaction with fatigue and damage tolerance (with 'corrosion' and 'damage tolerance' even in the same sentence on one consultant's web site! [9]). The problem is convincing the civil world. Sharing conferences (like 'Aging', ASIP and ICAF) is good, but not enough: the jargon seems alien, the programs unaffordable.

Duplication

Division often means duplication. We waste time and money on the program when:

- We *assess* twice: materials; coatings; access; criticality; even loads;
- We *publish* twice: separate fatigue and corrosion programs that overlap; or
- We *teach* twice: the management principles, which are common (as we'll see).

Then, there is the waste of the program not working as *efficiently* as it could, because we didn't develop it as *scientifically* as we could.

Danger

Division means danger from corrosion if:

- We *guess*: because there's no scientific method or guidance;
- We *ignore*: the interaction with fatigue; or
- We *neglect*: if corrosion is not in the mandatory Airworthiness Limitations.



Figure 4: In the 1980s, division in CASA endangered Aero Commanders (left). The corrosion specialists let them fly for years with untreated exfoliation corrosion in their wing spars (centre). When the fatigue specialists found out, they stopped the practice, fearful that corrosion would worsen fatigue they were managing in the same spars (right – the arrows show a crack) [10]. We learned the lesson. One section now manages fatigue *and* corrosion.

So, is there a problem?

I don't want to exaggerate the division, duplication or danger. But, if they are unnecessary, aren't they unacceptable? 'Broke' or not, we could do better.

IS DAMAGE TOLERANCE *APPLICABLE* TO CORROSION?

Many damage tolerance experts say it *can't* be applicable, because corrosion is too different to fatigue. I have heard them say things like:

- Fatigue is scientific, but corrosion is not;
- Fatigue is predictable, but corrosion is not; and
- Fatigue is deterministic, but corrosion is probabilistic.

Given the division already mentioned, those views are understandable. Are they true? Although loads drive one, chemistry the other, both follow natural laws. So, *both* are scientific. As our knowledge of corrosion's science improves, so will its predictability (as for fatigue). Both fatigue and corrosion involve random variables (many of them), so *both* are probabilistic. As our knowledge of corrosion's statistical distributions improves, so will our risk analysis (as for fatigue). So, corrosion *is* more similar to fatigue than we often think.

Even if it weren't, would it matter? *I would like to suggest it wouldn't.* Damage tolerance is not unique to fatigue, or even aviation. Its method is universal. It can manage *any* deterioration, in *any* discipline. It is how I manage weeds in my lawn, how the pest inspector manages termites in my house, and how my gastroenterologist manages polyps in my bowel. So, corrosion *doesn't have to be like fatigue*, it just has to be *deterioration*. That's the *only* condition for it to be manageable by damage tolerance and the diamond's five facets (Fig. 1).

Obviously, we must know the diamond's two Ss:

- 'Site': *where* will it grow?
- 'Scenario': *how* will it grow?

Then, just as obviously, for every site and scenario, if we want to know how long the 'inspection window' will be safely open, we must know the three Ds:

- 'Detectable': what can we reliably *find*? (Or, what could we sometimes miss?)
- 'Dangerous': what can we safely *bear*?
- 'Duration': what's the *time* to go from one to the other?

Although the scenario may differ from fatigue, graphing it with the three Ds still looks like classic damage tolerance – *because it is*:

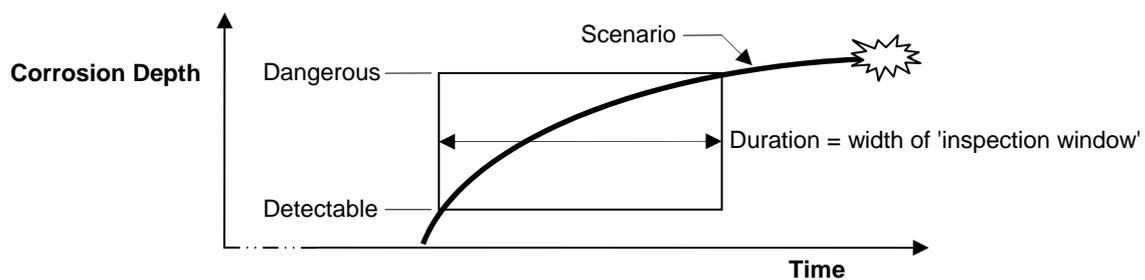


Figure 5: Classic damage tolerance for corrosion

Some points to note:

- Of course, like fatigue, there'll be lots of scatter.
- Those of us familiar with fatigue must look more broadly for sites. They are lavatories as well as laps; skins as well as spars, bilges as well as bolts.
- With prediction hard by analysis (for example, structural models can't yet show the 'hot spots' for corrosion), an experienced mechanic is essential on the development team.
- This is the simplest scenario, which doesn't consider the coating deteriorating or corrosion interacting with fatigue (more on those later).
- Corrosion scenarios are hard to predict, but we are learning [11]. There is now software, like ECLIPSE [12]. But, if we can't analyse the scenario, we should:
 - Test;
 - Manage within a part of the scenario we *can* analyse; or
 - Manage by a method other than inspection.
- Corrosion often slows as its products restrict ion flow, especially if it's confined. Arrest is total in fibre-metal laminates, like GLARE, when corrosion hits the fibres.
- Like fatigue, what is 'detectable' depends on factors like method, lighting, size, distance, congestion and cleanness (including *inhibitor* – the term I use to avoid TLAs – three-letter acronyms – like CPC for corrosion preventive compound).
- We must be able to analyse the residual strength of corroded structure. One paper is [13].

IS DAMAGE TOLERANCE *USEFUL* FOR CORROSION?

In this section, I would like to show examples of how I think damage tolerance and the diamond method could be useful, under these headings:

- Considering the interaction with fatigue;
- Lessening corrosion;
- Preventing corrosion (by inspection and by restoration);
- Exposing uninspectability;
- Investigating service experience;
- Extending an inspection interval;
- Flying with corrosion;
- Unifying structural maintenance development;
- Balancing structural maintenance development; and
- Consolidating the research.

Considering the interaction with fatigue

We all know that corrosion and fatigue can worsen each other. David Hoepfner told us how at ICAF 2003 [14]. Another classic was Walter Schutz's Plantema Memorial Lecture at ICAF 1995 [15]. The diamond helps us start a checklist:

- Site
 - Could corrosion promote fatigue where stresses are normally low?
 - Could fatigue promote stress corrosion, or crack coatings or sealants?
 - Could corrosion *inhibitor* change crack sites by lessening frictional load transfer? [16]
- Scenario
 - Could corrosion - *or the inhibitors we use* - quicken fatigue scenarios?
- Detectable
 - Could corrosion - *or the inhibitors we use* - hide cracks?
- Dangerous
 - Could corrosion weaken residual strength for fatigue?

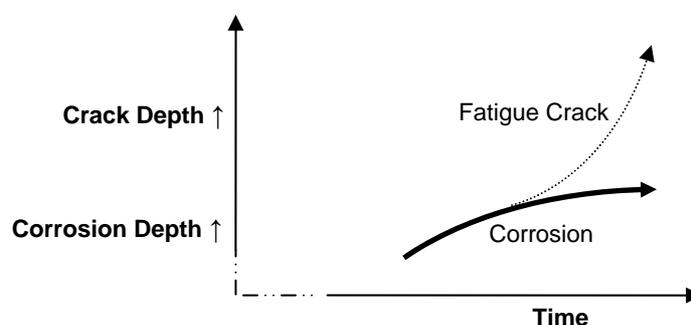


Figure 6: Fatigue cracks appear 10 to 100 times sooner from corroded surfaces (Clark [17]).

Lessening corrosion

The damage tolerance rules let strength fall to *limit* before calling it 'dangerous'. But, for corrosion, operators willingly aim for something more 'desirable' for business. They aim for *ultimate* strength (150% stronger than *limit*), by aiming for 'Level 1' ('corrosion damage that does not require structural reinforcement or replacement') in MSG-3 (the Air Transport Association's standard).

On the same damage tolerance graph as Figure 5, if we lower the upper 'sill' of the 'inspection window' from 'dangerous' to 'desirable', we shorten the 'duration' (so we shorten the inspection interval):

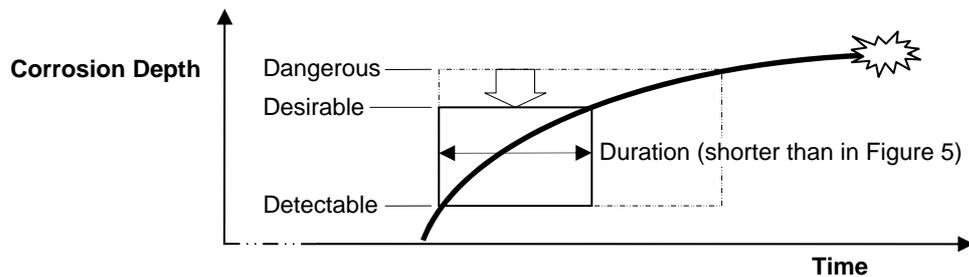


Figure 7: Damage tolerance if we want to *lessen* corrosion

As well as reparability, we improve safety by:

- Lessening the chance corrosion will affect fatigue; and
- Allowing more for the uncertainty and variability we find so hard to estimate.

Preventing corrosion (by inspection)

Surely, prevention is our ultimate goal. We avoid downtime, repair, and the need to consider the interaction with fatigue. This time, our damage tolerance graph is for the coating, not the metal, and for *properties*, not a dimension:

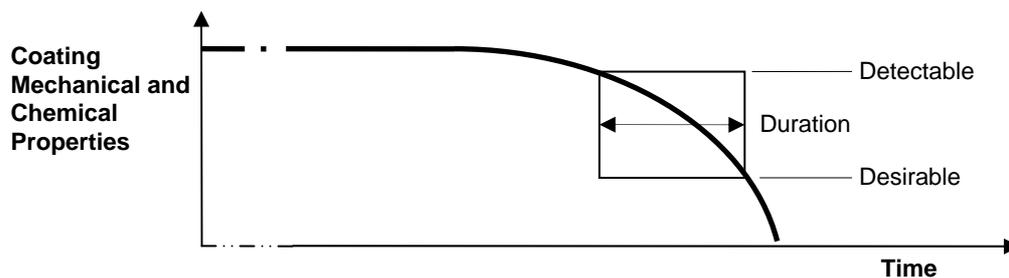


Figure 8: To prevent corrosion by *inspection*, we must show damage tolerance for the *coating*

The above 'scenario' is arbitrary, just to show the idea. There are really two scenarios (one for each property). It doesn't apply if sudden accidental damage is likely. And, it will change when environmental laws ban chromates. Our limit for what is 'desirable' is when the coating has deteriorated so far, corrosion is imminent. For deterioration to be 'detectable' before then, we probably need better than the usual 'visual' inspections. Komorowski lists some NDI in [18]. Others are thinking of hardness tests. Even better may be permanent sensors, which allow 'structural health monitoring' (SHM). An Aerospace Industry Steering Committee for SHM is now guiding research and standards development. Corrosion is on their agenda.

Preventing corrosion (by restoration)

Another way to *prevent* corrosion is to regularly *restore* the coating with inhibitor. Figure 9 is like Figure 8, except:

- The 'scenario' is the deterioration of *inhibited* coating;
- There is no 'detectable' zone because there is no inspection; and
- Our limit for what is 'desirable' is when corrosion is imminent, or when the inhibitor can no longer restore the coating, whichever occurs first.

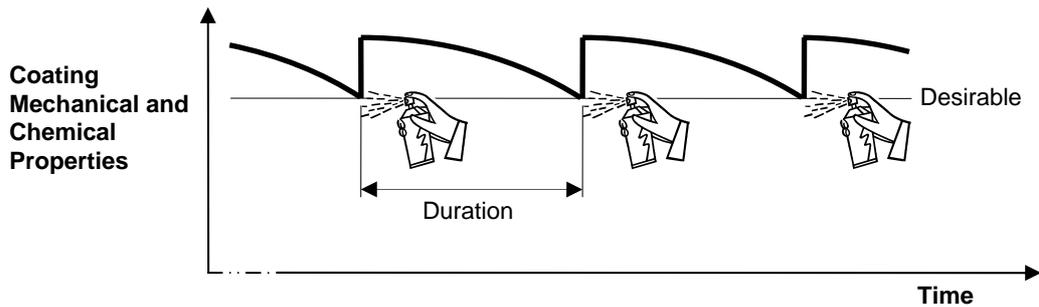


Figure 9: To prevent corrosion by *restoration*, damage tolerance for the *inhibited* coating,

Exposing uninspectability

By forcing us to determine what is 'detectable' and what is 'dangerous', and to compare them, damage tolerance is an important check against uninspectability, which is common, especially in small aircraft. CASA's web site describes a potentially dangerous uninspectability in the wings of single-engined Cessnas [19]. For uninspectability, we must *revise* the inspection method or the design, regularly *restore* the coating or regularly *replace* the part.

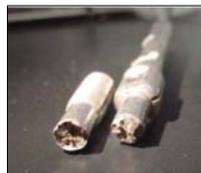


Figure 10: Damage tolerance helped CASA see that regularly replacing stainless steel control cable terminals may be the *only* way to manage uninspectable stress corrosion [20].

Investigating service experience

In *Rough Diamond*, we saw how the diamond's facets form a simple checklist to help manufacturers compare prediction with practice, to improve their programs:

	Prediction	Practice
Site		
Scenario		
Dangerous		
Detectable		
Duration		
	What did the designers assume?	What did the defect or crash investigator find?

Figure 11: Damage tolerance's five-faceted checklist for investigating service experience

Air Safety Week liked this idea for fatigue [2]. It is even more important for corrosion, because, for most small civil aircraft flying today (even small airliners), the left column is blank – there was no prediction! So, investigating maintenance findings may be our last chance to fill in the right side before the crash investigator does. Some manufacturers don't do this well. They put their best people where the money is: designing and certifying new aircraft. I say more on 'continuing airworthiness' in [10], [21] and [22].

Extending an inspection interval

A common argument to extend an inspection interval is repeatedly *not* finding corrosion. But:

- A *slow* start doesn't always mean it *won't* start. Corrosion gets *more* likely with age – unless we regularly restore the coating.
- A *slow start* doesn't always mean *slow growth*. The connection is too tenuous. It could be just a better than average coating, which will make no difference when it's gone.

So, be wary of the 'nil findings' argument, especially as pressures increase to cut maintenance. It can be just as specious for corrosion as *Rough Diamond* warned, by example, for fatigue.

But, MSG-3-based corrosion programs may let us experiment, by leaving room for error, if we extend an interval hoping our aircraft will corrode more slowly than the manufacturer assumed, but it doesn't. If we graph damage tolerance for *strength* instead of corrosion depth:

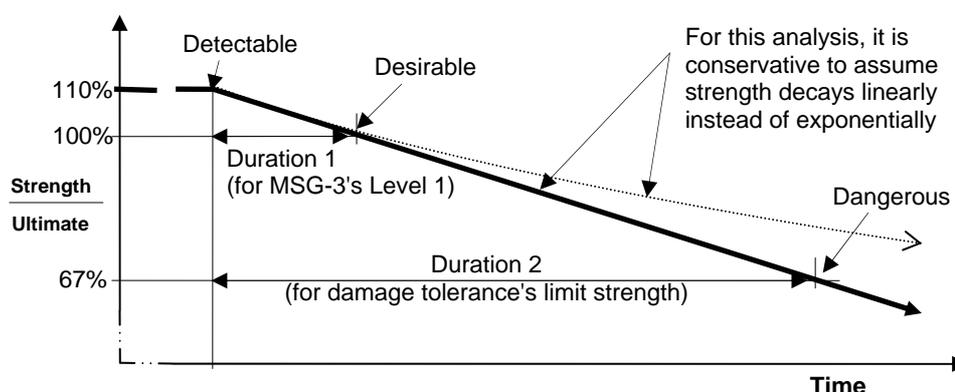


Figure 12: Damage tolerance helps estimate the safety margin for extensions. This assumes we start with a 10% (a common blend limit) margin of safety and we can detect corrosion before we lose any of that.

By similar triangles:

$$\frac{\text{Duration 2}}{\text{Duration 1}} = \frac{(110 - 67)}{(110 - 100)} = 4.3 \quad \text{(Higher if strength decays exponentially, as it often does, instead of linearly)}$$

This is a crude analysis, with crude assumptions. And, we don't want too much corrosion, for too long, in case it promotes fatigue. But, it suggests the arbitrary extensions regulators now allow (to about 1.2 times, or a 20% increase) are conservative. It seems we could allow operators more freedom, if they have the right people, procedures and tools.

Reversing this damage tolerance analysis, but assuming strength decays exponentially instead of linearly, could also help operators quantify how much to *shorten* an inspection interval if they find *more* corrosion than they expected.

Flying with corrosion

Sometimes, we don't want to repair corrosion immediately. We want to wait for a more convenient maintenance opportunity. We will want to do that more often as we get better at finding corrosion. Sometimes, we don't want to repair corrosion at all. We fear the cure could be worse than the complaint [18]. Aggressive grinding and sloppy reprotection recently returned corrosion so severe, so soon, it scrapped a small turboprop airliner in Australia. Sometimes, it is better just to treat light corrosion with inhibitor, so it won't grow.

If we want to know if we *can* keep flying, damage tolerance's 'diamond' (especially the first two facets) helps us start a checklist:

- Site
 - The full extent, not just what we found first
- Scenario
 - If we inhibit, how long will it arrest growth?
 - If we *can't* inhibit, how will it grow?
 - Could pits cause cracks?

Unifying structural maintenance development

If damage tolerance is applicable to corrosion, we could end the division, duplication and danger an earlier section mentions. We could:

- Reunite corrosion with the damage tolerance *rules* (like FAR 25.571)
 - We would *not* need MSG-3 for structure
 - We *would* need damage tolerance-based guidance
- Unite corrosion with the damage tolerance *experts*
 - We would *not* need MRB Structures Working Groups
 - We *would* need to bring their experienced airline mechanics to Certification
- Unite corrosion management with the damage tolerant *maintenance*
 - We would *not* need separate CPCPs
 - We *would* need to blend corrosion into the Airworthiness Limitations

Balancing structural maintenance development

When I get damage tolerance evaluations from manufacturers, modifiers and repairers, I look first for completeness and balance. For example, for fatigue, the best fracture mechanics-based crack growth and residual strength analyses won't help those who skimp on scouring for sites (so miss some) and ignore inspectability (so don't know if there is any safe 'duration'). I talk more about balance in *Gnats and Camels* [21]. Corrosion is the same.

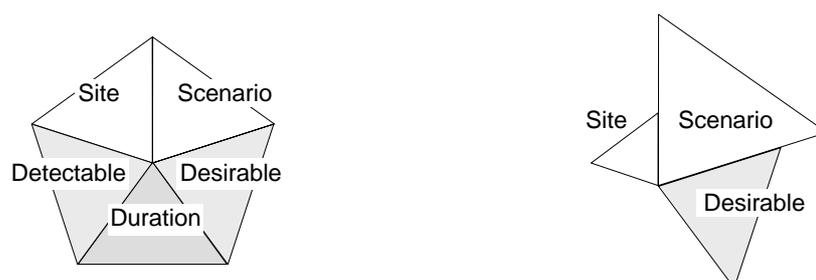


Figure 13: Damage tolerance helps us balance the program - *not* like on the right.

Consolidating the research

Many are researching and proposing new-sounding concepts. But, can we also think of them as improving an old one? For example:

- Corrosion Reliability Centred Maintenance (CRCM) [23]
 - Isn't it using *damage tolerance* to better prevent corrosion (as before, this section)?
- The 'science based probability approach' [24]
 - Isn't it using science and statistics to better predict 'scenarios' and their variability?
- Holistic Structural Integrity Programs (HOLSIP) [25]
 - Isn't it using materials science to better predict 'sites' and 'scenarios'?

Wouldn't it help to consolidate the research in terms of damage tolerance? I like the Canadian National Research Council calling their development of HOLSIP, Probabilistic *Damage Tolerance* Analysis [26]. I like Ockham's Razor:

Entia non sunt multiplicanda praeter necessitatem.

– William of Ockham, 14th Century

William, a wise monk, was saying we should try to explain things simply, using the minimum number of concepts.

CONCLUSION

I have made this letter longer, because I have not had the time to make it shorter.

– Blaise Pascal, 17th Century

I tried to take the time to keep this paper short. I tried not to write 'all you need to know about corrosion'. Others are far more qualified to explain the metallurgical and mathematical detail. I tried only to show that damage tolerance is not only applicable to corrosion, it is useful – as it is for fatigue.

Jerzy Komorowsky, of the National Research Council of Canada, once said this about technologies like the 'technology' of damage tolerance for corrosion [18]:

Transferring these technologies into the hands of the maintenance, repair and overhaul industry will no doubt be a significant challenge.

The point is, researchers, like Komorowsky, and regulators, like me, aren't finished until we've persuaded the practitioners. We must simplify and standardise our messages if we want to 'sell' them to a complacent and cost-cutting civil world. After nearly thirty years, it is slowly accepting damage tolerance for fatigue. Let's try to build on that foundation for corrosion.

If we do, I hope to see fewer civil aircraft *without* a corrosion program. I hope to see fewer programs without enough guidance and tools. I hope to see us *prevent* corrosion, not just lessen it. I hope to see less division, duplication and danger. I hope to see damage tolerance and its diamond helping operators, manufacturers and regulators save time, money and lives.

RECOMMENDATIONS

My main recommendation is simple:

1. We should use the damage tolerance rules for corrosion, not just fatigue.

In support, we should:

2. Write damage tolerance-based regulatory guidance (simple, conceptual, like this paper).
3. Give more freedom to operators with the right people, procedures and tools (Annex 2).
4. Bring corrosion and the experience of MRB Structures Working Groups to Certification.
5. Encourage damage tolerance experts to show more interest in corrosion.
6. Teach corrosion and fatigue management together.
7. Research the deterioration, inspection and restoration of *coatings*.
8. Develop the analysis to support inhibiting instead of repairing light corrosion.

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POSTSCRIPTS

1. This paper covers *intervals* (the times *between* inspections) but not *thresholds* (the times to the *first* inspections). I apologise, but in the space and time available, I will have to leave that thorny issue for another paper, at another time. I hope to show how we could use damage tolerance more consistently and less prescriptively for thresholds, for both fatigue and corrosion, as Airbus longed for in their thoughtful ICAF 2005 paper [27].
2. If I err, please tell me. That's what's great about ICAF. It's not just a conference; it's a caring community always willing to help one another improve aviation safety.

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ANNEX 1

CORROSIVE STRUCTURAL FAILURES

Is corrosion dangerous? The table below lists six fatal crashes from the Aviation Safety Network's database. Hoepfner lists and mentions more in [28], a telling paper for anyone who doubts corrosion affects safety. Often, crash reports blame fatigue, when corrosion started it. In Australia, for airframes, corrosion causes 7% of Airworthiness Directives and 20% of defect reports. This is similar to what Hoepfner reports. The FAA is not alone predicting an increase as our aircraft age [6], like in Australia [29].

Year	Aircraft	Country	Description	Dead
1953		Tanzania	Vickers Viking Central African Airways VP-YEY 'The... booms (of the wing) had...corrosion'.	13
1965		Canada	Handley Page Herald Eastern Provincial Airways CF-NAF 'Failure of corroded skin area along the bottom centre line of the aircraft...resulted in structural failure of the fuselage and aerial disintegration.'	8
1971		Belgium	Vickers Vanguard British European Airways G-APEC 'An explosive decompression of the fuselage occurred...the tail surfaces subsequently failed...corrosion was found in the lower part of the rear pressure bulkhead.'	63
1981		Taiwan	Boeing 737 Far Eastern Air Transport B-2603 'Severe corrosion, which led to pressure hull rupture and the subsequent disintegration of the airplane.'	110
1988		USA	Boeing 737 Aloha Airlines N73711 'Contributing to the accident were...early production difficulties in the 737 cold bond lap joint, which resulted in low bond durability, corrosion and premature fatigue cracking.'	1
1997		Russia	Antonov 24 Stavropolskaya Aktsionernaya Avia RA-46516 'Massive corrosion of the fuselage...caused the tail section to separate.'	50

Source: Aviation Safety Network [30]. Their database covers 'civil multi-engine airliners of which the basic model has been certified for carrying 13 or more passengers'. The photos of the Vickers Viking, Handley Page Herald and Antonov 24 are of the same type, but not the same aircraft or airline. The photo of Vickers Vanguard G-APEC is from the Air Britain Photographic Images Collection (photographed by Stephen John Rendle).

ANNEX 2

DRAFT ADVISORY CIRCULAR¹

Airworthiness Limitations for Aircraft

1 Introduction

1.1 Who should read this Advisory Circular (AC)?

Anyone who wants an Australian:

- Type certificate (TC); or
- Supplemental type certificate (STC).

You will want a TC or STC if you are *designing*:

- An aircraft (TC); or
- A modification to an aircraft (STC).

This AC is *not* for those designing engines or propellers (even if the principles are the same).

1.2 Why should you read this AC?

This AC shows you how to develop the Airworthiness Limitations that the Airworthiness Standard in:

- CASR 21.017 requires for a TC; or
- CASR 21.101 requires for an STC.

For example, for small aircraft designed to the United States *Federal Aviation Regulations*, the Airworthiness Standard is FAR 23:

- §23.573 *Damage-tolerance and fatigue evaluation of structure*
- §23.575 *Inspections and other procedures*
- §23.629 *Flutter*
- §23.1529 *Instructions for Continued Airworthiness*
- Appendix G *Instructions for Continued Airworthiness*

There are similar Airworthiness Standards for large aircraft and rotorcraft.

1.3 What is new in this issue of the AC?

This is the first issue of this AC. It includes guidance for Airworthiness Limitations for corrosion and accidental damage, as well as for fatigue.

2 General

2.1 What are Airworthiness Limitations?

Airworthiness Limitations are instructions for maintaining the aircraft safe (to its type-certified Airworthiness Standard) against the threats of fatigue, corrosion and accidental damage.

They specify *what* to do and *when* to do it.

2.2 What about Instructions for Continued Airworthiness?

Airworthiness Limitations are part of the Instructions for Continued Airworthiness.

2.3 What must I show CASA?

As well as the Airworthiness Limitations, you must show us:

- How they comply with the Airworthiness Standards;
- How you will report and investigate anything unexpected found in service (see CASR 21.3); and
- How you will send changes to the Airworthiness Limitations (which we will want to see and approve) to operators (see CASR 21.50).

2.4 What about stiffness?

For fatigue, corrosion and accidental damage, think about their effect on stiffness, as well as strength. Check the flutter rule in the Airworthiness Standard.

¹ For discussion, not an official CASA proposal.

2.5 What about 'grace periods'?

If changing your Airworthiness Limitations could affect aircraft immediately, consider a 'grace period'. As common as they are, we don't know of any rules or guidance. But, internationally, there seems a willingness to accept a bigger than normal risk, for a few aircraft, for a short time, if it will ease big costs and inconveniences. We are happy to discuss.

2.6 Can I add Airworthiness Limitations?

If the Airworthiness Standard for your aircraft type did not require Airworthiness Limitations, you may add them voluntarily. You will improve safety by:

- Raising structural maintenance to a standard; and
- Forcing operators to do it.

We just need to agree the standard and you just need to show us your Airworthiness Limitations comply.

If you have a SID (Supplemental Inspection Document), it probably already complies. If so, we are happy to approve it as Airworthiness Limitations, to increase compliance.

3 Fatigue

3.1 What is fatigue?

Fatigue is progressive weakening by repeated loads.

3.2 What are the rules for fatigue?

The rules are the *Damage tolerance and fatigue evaluation* rules in the Airworthiness Standard for your aircraft. See 1.2.

The FAA and EASA publish helpful *Advisory Circulars* and *Acceptable Means of Compliance* for their Airworthiness Standards.

For example:

- AC 23-13, *Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes*
- AC 25.571, *Damage Tolerance and Fatigue Evaluation of Structure*
- AMC to 23.571 and 23.572, *Fatigue evaluation: metallic pressurised cabin structures, metallic wing, empennage and associated structures*

Also, see *Rough Diamond*, on our web site: www.casa.gov.au → Airworthiness → Technical Papers. It explains 'damage tolerance' as five simple steps - a handy checklist.

3.3 What strength must I assure for fatigue?

The damage tolerance rules say *limit* strength. Other rules say *ultimate*. Here's an explanation:

- Design the Airworthiness Limitations for *limit* strength for *predicted* threats; but
- Redesign them (or the structure) for *ultimate* strength for *confirmed* threats.

The reason is we want:

- The *least* maintenance for threats that may not eventuate, but
- The *best* if they do.

3.4 May I offer operators flexibility?

Yes. For example, you may include choices that allow operators to trade inspection method for frequency.

4 Corrosion

4.1 What is corrosion?

Corrosion is progressive weakening by chemical reaction.

4.2 What are the rules for corrosion?

The rules are the *Damage tolerance and fatigue evaluation* rules in the Airworthiness Standard for your aircraft. See 1.2.

For years, for large airliners, Maintenance Review Boards (MRBs) have used MSG-3 to develop maintenance for corrosion (see FAA AC 121-22A). We would now prefer you to evaluate damage tolerance for corrosion directly to the Airworthiness Standard, and not to MSG-3, which is not explicitly damage tolerant. We hope to write an Advisory Circular soon to help you. Until then, the method is the same, in principle, as fatigue. See *Rusty Diamond*, on our web site: www.casa.gov.au → Airworthiness → Technical Papers.

We encourage you to involve experienced operators, as in MRB, for their practical wisdom.

If you publish the corrosion section of your Airworthiness Limitations separately, and call it a CPCP (Corrosion Prevention and Control Program), clearly also label it 'Airworthiness Limitations'.

4.3 What strength must I assure for corrosion?

The *rules* are the same as for fatigue. But, currently, we predict corrosion less well. So, our predictions must leave more margin for safety.

So, for corrosion, we want you to assure *ultimate* strength, right from the start, unless you can confidently estimate and allow for:

- Uncertainty and variability in your predictions; and
- The effect on fatigue of leaving more corrosion for longer.

An economic advantage of assuring ultimate strength is cheaper repairs.

4.4 May I offer operators flexibility?

Yes, as for fatigue (see 3.4), or even more, if you:

- Tell operators they first need our approval (we will only approve operators who have the right people, procedures and tools);
- Show them *how*;
- Warn about the 'nil findings' argument for extending inspection intervals;
- List the design, operational and maintenance factors to compare before adopting another aircraft's program; and
- Show *how* to correct a program if it finds more corrosion than expected.

5 Accidental Damage

5.1 What are the rules for Airworthiness Limitations for accidental damage?

The rules are the *Damage tolerance and fatigue evaluation* rules in the Airworthiness Standard for your aircraft. See 1.2.

Consider accidental damage during:

- Manufacture;
- Operation; and
- Maintenance.

But, only if it is 'likely' (at least a 50% chance in an aircraft's life).

Consider accidental damage:

- On its own;
- Affecting fatigue; and
- Affecting corrosion.

6 Airworthiness Limitations for STC Holders and others

If you want or hold an STC, the rules for the Airworthiness Limitations for your STC are the same as they are for holders of type certificates.

Anyone may produce Airworthiness Limitations for *any* aircraft (or STC) if they can meet the rules. This is for individuals or groups (like 'type clubs') who can't get them from the holder of the type certificate (or STC).

7 Continuing Responsibilities

7.1 What are my continuing responsibilities?

Every 2 years, send us a report that shows us how you have met your continuing responsibilities (see 2.3) since your last report. We may also audit you and your Airworthiness Limitations at other times.

7.2 May I issue a service bulletin instead of changing the Airworthiness Limitations?

Yes, if a service bulletin will address a service problem more quickly and fully. But, please tell us. We may want to issue an Airworthiness Directive.

Later, you may wish to incorporate service bulletins into the Airworthiness Limitations, so operators have one document for safety-critical structural maintenance.