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A COLLECTIVE APPROACH TO AIRCRAFT STRUCTURAL MAINTENANCE PROGRAMS

For safety and economy

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Abstract: Steve Swift, winner of IASS 2007's Whittle Safety Award, applies IASS 2008's theme, 'A Collective Approach to Aviation Safety', to aircraft structural maintenance programs. He points out three divisions, which, if united, could improve safety and economy. He offers suggestions for airworthiness authorities, aircraft manufacturers and airlines.

INTRODUCTION

IASS 2008's theme is 'A Collective Approach to Aviation Safety'. How 'collective' is our 'approach' to aircraft structural maintenance programs? [2]

This paper looks at three divisions and their affect on safety and economy:

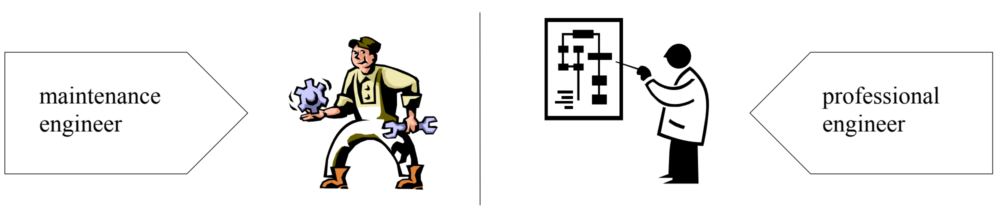
- The division of engineers
- The division of processes
- The division with human factors

Although the focus is *structural* maintenance, other disciplines may see similarities.

THE DIVISION OF ENGINEERS

The first division is the division of *engineers*. It is the old rivalry between the vocational and professional streams. Since Australia and the UK call both 'engineers' (other countries call vocationals 'mechanics' or 'technicians'), this paper differentiates by calling them 'maintenance engineers' and 'professional engineers'. [3]

Figure 1



[1] Disclaimer: This paper presents the author's personal views, which are not necessarily CASA policy.
[2] Fowler [1] and Australia's *Macquarie Dictionary* recommend the spelling 'Program' instead of 'Programme'.
[3] See [2] on international differences in engineering nomenclature.

In the past, they worked apart. Design was for professional engineers; maintenance was for maintenance engineers. Now, designing the aircraft includes designing its maintenance. One affects the other. Maintenance programs are no longer afterthoughts left to intuition and experience. They are now predictive and scientific. So, we now need professional engineers for the science. But, we still need maintenance engineers to keep it practical. Now, the two must work together.

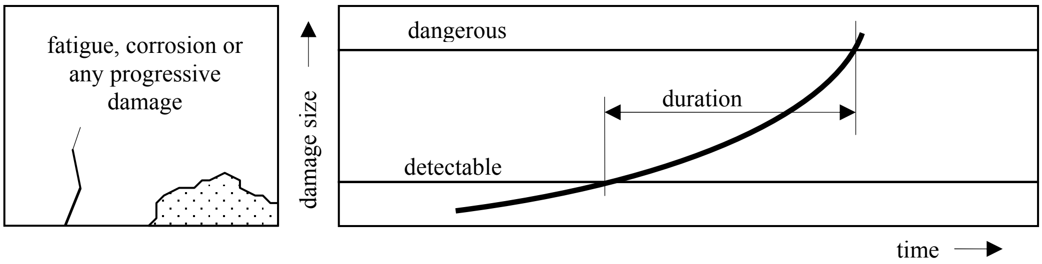
The problem is that the rivalry is old and deep. It will be hard to stop competing and start cooperating. If we don't, we will continue to see inspections that are futile, late and destructive:

Futile inspections

Few, if any, vocational courses teach the maintenance theory in Airworthiness Standards, like *FAR 25 — Airworthiness Standards: Transport Category Airplanes*.[4] For example, as [3] interprets FAR 25.571, inspection *intervals* have three variables:

- The size of damage that is *detectable*
- The size of damage that is *dangerous*
- The *duration* to grow from one size to the other

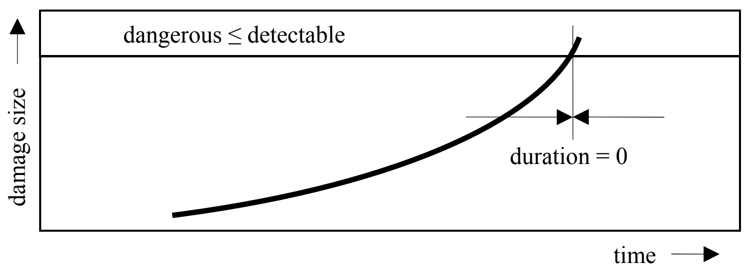
Figure 2



The inspection interval must be less than the *duration*, to allow for uncertainty and variability. A factor of two is common. The shape of the growth curve, and our ability to model it, will vary. But, the same three variables are essential for fatigue, corrosion or any progressive damage [4]. The Airworthiness Standards call this maintenance theory 'damage tolerance'.[5] It is how professional engineers check to ensure that if one inspection misses *damage*, it will stay *tolerable* until the next.

Maintenance engineers, not knowing *damage tolerance*, could miss seeing this situation:

Figure 3



Sometimes, damage is *dangerous* before *detectable*. If so, inspection is futile, no matter how frequent. This is common for high-strength steels in the landing gear of airliners, and for high-strength aluminium alloys in the wing spars of many small aircraft. However, not understanding this, some maintenance engineers vainly trust inspection, even to the point of resisting life limits, which are often the only safe and practical solution.

4 What the US FAA calls 'Airworthiness Standards', Europe's EASA calls 'Certification Specifications'.

5 Those schooled in Reliability Centred Maintenance know the three variables as 'P' (for 'potential failure'), 'F' (for 'functional failure') and the 'P-F interval'. See Chapter 7 of [5].

Late inspections

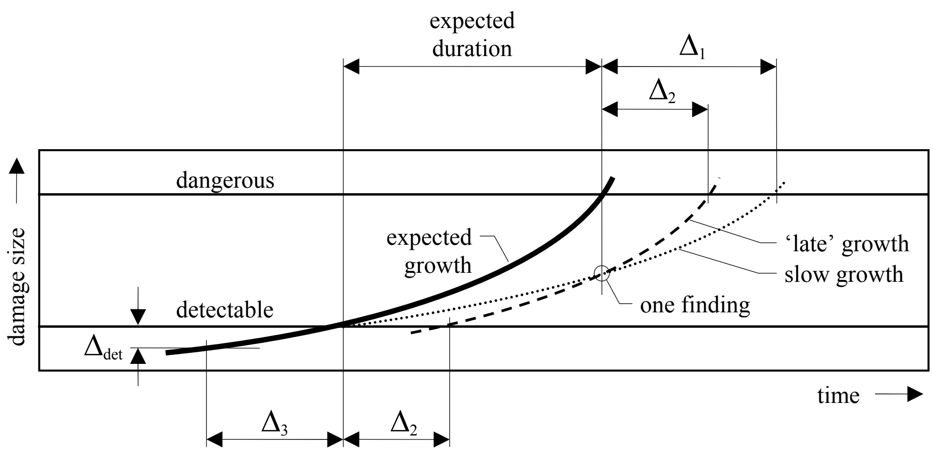
It is common for airlines to use a history of 'nil findings' to escalate inspection intervals. But, is it valid for *structural* inspections? How does it help an airline know, better than the manufacturer:

- The size of damage that is *detectable*?
- The size of damage that is *dangerous*?
- The *duration* to grow from one size to the other?

The answer is that finding *nothing* tells us nothing.

Nor does *one* finding:

Figure 4



That is because, if the finding is small, we cannot tell if the reason is:

- Slow growth
  - dotted curve
  - the potential for escalation is Δ_1
- 'Late' growth[6]
  - dashed curve
  - *no* potential for escalation [7]

We need *many* findings — *all small* — to rule out 'late' growth. And, careful analysis, considering scatter, to confirm slow growth. We may need fractography and other forensics. Then, we need confidence in our growth model's ability to extrapolate, to confirm Δ_1.

Analysis may also suggest our inspection is better. If we can reliably find damage smaller than expected, by Δ_{det}, there is potential for escalation, by Δ_3.

This idea is trickier than it looks. It needs more development, which I hope to do in an Issue Paper for the International MRB Policy Board. Applying *damage tolerance* to escalation may not be easy, but apply it we must. 'Nil findings', while useful for *thresholds*, are not for *intervals*. While the argument seems attractive, it is not valid, at least for progressive damage in structure.[8] We know that for fatigue, for Airworthiness Limitations. It is just as true for corrosion, for CPCPs.

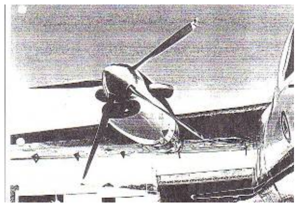
[6] Damage could grow any time relative to inspections. Here, 'late' simply means later in the interval than the solid 'expected growth' curve, which has the most conservative timing.

[7] Although 'dangerous' Δ_2 later, it is also 'detectable' Δ_2 later (so same 'duration')

[8] The 'nil findings' argument is only valid for *intervals* if the time from *detectable* to *dangerous (*the *duration)* is proportional to the time from new to *detectable*. While sometimes true for fatigue, scatter complicates proof. It is less likely for corrosion, which may involve more than one process (penetration of the coating, then corrosion of the metal).

A wrongly escalated interval could mean, eventually, an inspection is dangerously late. It nearly killed all 22 onboard this Nord 298 'Mohawk' (right). The propeller threw a blade, which luckily missed the fuselage, after exceeding the interval that Hartzell, who made the propeller, recommended. Without asking Hartzell, the airline trusted a history of 'nil findings' to escalate the interval. But, fractography showed the fatigue crack, although late arriving, grew exactly as Hartzell predicted.

Figure 5



Published guidance is frustratingly vague on escalation. For example:

- IATA's *Maintenance Programme Optimisation Guidance Material*, Chapter 12 [6]
- IMRBPB's *Evolution/Optimization Guidelines* [7]
- FAA's AC 121-22A, *Maintenance Review Board Procedures*, Chapter 6 [8]

None relates escalation to *damage tolerance*. All they offer is blind experimentation. Gathering and analysing 'nil findings' instead of findings is wasteful as well as risky.

<u>Destructive inspections</u>

Professional engineers can be dangerous too. Lacking practical experience, they sometimes design inspections that do more harm than good. For example, regular removal of tight bolts and bushes.[9] Professional engineers need maintenance engineers to help keep inspections *non*-destructive.

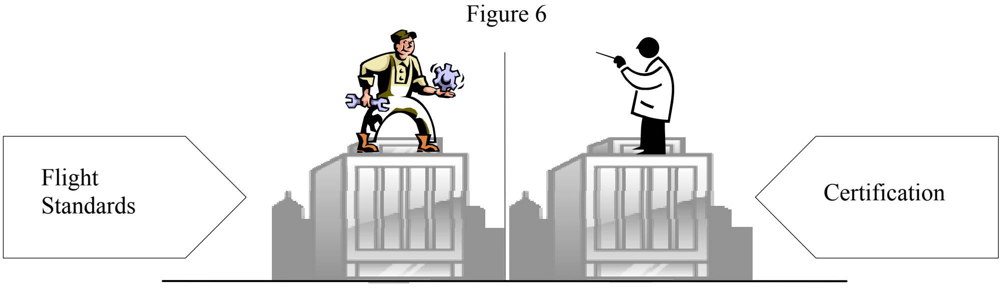
THE DIVISION OF PROCESSES

The division of engineers divides the process for designing maintenance programs. It involves different organisations, standards, participants, damage, emphases, jargon and documents:

<u>Different organisations</u>

As already noted, professional engineers and maintenance engineers prefer to work apart. So, they build different organisations:

Figure 6

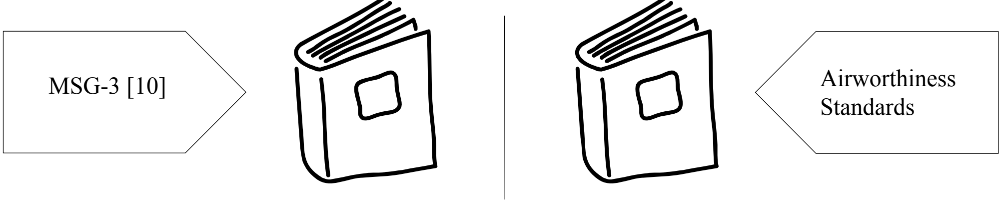


In the FAA, exceptions are Flight Standards' small Aircraft Evaluation Groups (AEGs) inside Certification. In EASA, although Flight Standards is within Certification, the two work largely independently on maintenance programs, even though, now, both have professional engineers.

<u>Different standards</u>

Flight Standards and Certification have different standards for maintenance programs:

Figure 7



[9] In Australia, damage from replacing a bush caused fatigue failure of the wing of a Vickers Viscount. See page 180 of [9].

Yes, Airworthiness Standards are also for maintenance, not just design. For structures, three examples from FAR 25 are:

- 25.571 ‘Damage tolerance and fatigue evaluation of structure’
- 25.1529 ‘Instructions for Continued Airworthiness’
- Appendix H ‘Instructions for Continued Airworthiness’

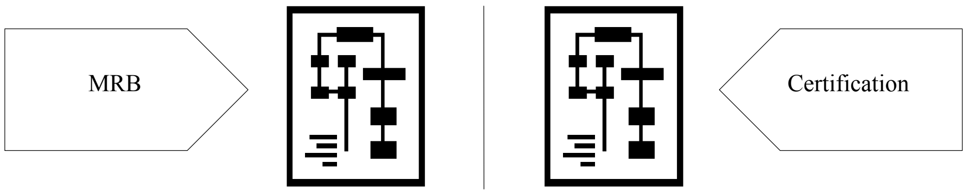
Having different standards for similar things means duplication. For example, the International Maintenance Review Board Policy Board (IMRBPB) discusses some of the same issues as Certification rule-making committees.

And, it means confusion. For example, it is not clear if MSG-3’s ratings methods for corrosion in metals and accidental damage in composites satisfy FAR 25.571, as they should.

<u>Different processes</u>

They have different processes:

Figure 8



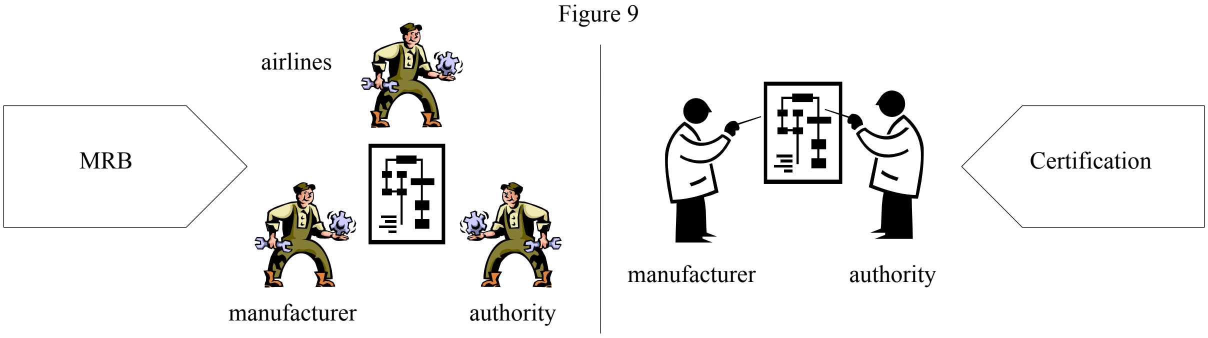
While flow-charts show coordination, is it enough? [10] There is still confusion, at least for structure. Division of responsibility is a recurring issue. It produces some arbitrary and creative boundaries. For example, for accidental damage for composites, one boundary is detectability.

And, again, duplication. The Maintenance Review Board (MRB) assesses similar things for corrosion as Certification does for fatigue. For example, access, criticality, materials and surface treatments.

<u>Different participants</u>

They have different participants:

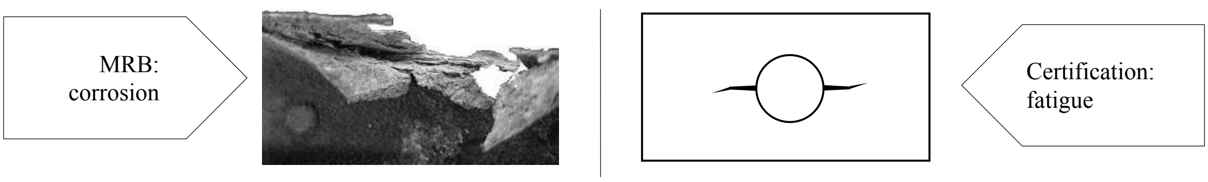
Figure 9



<u>Different damage</u>

They prefer analysing different damage:

Figure 10



[10] See Appendix 3a of [8] and page 2-GEN-34 of [11]

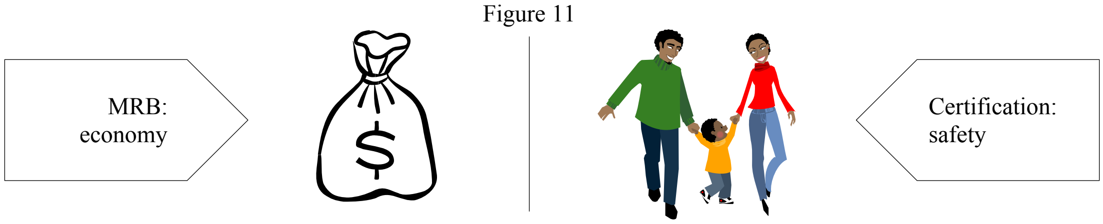
In FAR 25.571, ‘corrosion’ is right next to ‘fatigue’. But, because professional engineers can’t model corrosion as mathematically, they prefer to leave it to maintenance engineers and MSG-3.[11]

The division ignores reality. Fatigue and corrosion aren’t separate. Sometimes they interact: pitting incites fatigue; fatigue cracks coatings. As do their *preventions*: corrosion inhibitors lubricate and change fatigue in joints; fatigue-preventative straps incite galvanic corrosion (see [12]).

<u>Different emphases</u>

They have different emphases:

Figure 11



Although MSG-3 states safety as an aim, its methods emphasise economy. To do otherwise would challenge the safety scope of the Airworthiness Standards. For example, for corrosion, MSG-3 requires reparability, for economy, but the Airworthiness Standards require strength, for safety. While what is good for economy is often even better for safety, there are exceptions. For example, for pitting corrosion, *Level 1* could satisfy MSG-3 but still be dangerous for fatigue.[12]

<u>Different jargon</u>

They have different jargon. For example, try differentiating between a *Structurally Significant Item (SSI)* and a *Principal Structural Element (PSE)*:

Figure 12

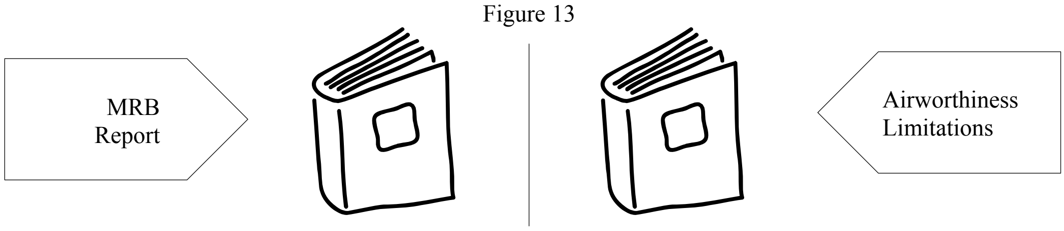
SSI	*Any detail, element or assembly, which contributes significantly to carrying flight, ground, pressure or control loads, and whose failure could affect the structural integrity necessary for the safety of the aircraft (MSG-3)*	*An element that contributes significantly to the carrying of flight, ground, or pressurization loads, and whose integrity is essential in maintaining the overall structural integrity of the airplane (FAR 25)*	PSE

Yet, MSG-3 is adamant that ‘SSIs must not be confused with Principal Structural Elements’. So, MRB working groups waste time arguing obscure differences.

<u>Different documents</u>

They produce different documents:

Figure 13



Integration is a problem. For example, manufacturers don’t always transfer *Corrosion Prevention and Control Programs (CPCPs)* from the *MRB Report* to the *Airworthiness Limitations*, as FAR 25 says.[13]

<u>Different arguments</u>

Despite division causing problems, are there arguments *against* merger? See Annex 1.

[11] This is changing as professional engineers develop mathematical models for corrosion.
[12] *Level 1* is the goal for MSG-3-based corrosion programs.
[13] FARs 25.571, 25.1529 and Appendix H

THE DIVISION WITH HUMAN FACTORS

The third division is engineers ignoring human factors in manufacturers' maintenance documents. It is unsafe and, although improving, is unfinished:

It is unsafe

Maintenance programs must be clear as well as correct. It is not just nicety; it is safety. For example:

- In Australia, ambiguous jargon misled an airline to miss inspections. The incident hurt business as well as safety – it bankrupted the airline. Read the full story in [9], especially page 71.
- Jargon again: why do we call some damage-tolerance-based inspection programs *Airworthiness Limitations* and others *SIDs (Supplemental Inspection Documents)*? *SIDs* are as vital to safety, but airlines — and authorities — misread 'Supplemental' as 'optional'. So, under-maintained aircraft compete unfairly and unsafely in the market. See [13].

Figure 14

It is unfinished

There are now many good guides on human factors in maintenance: from ICAO, FAA, CAA, Flight Safety Foundation, ATA and others. Commendable is the FAA creating a dedicated position — a Chief Scientific and Technical Adviser. Bill Johnson (right) is now a leading champion of the cause.

However, the focus seems more on the doing than the documentation. Three exceptions are:

- ATA Specification 2200 (*i*Spec 2200), *Information Standards for Aviation Maintenance* [14]
- ASD-STE-100, *A Guide for the Preparation of Aircraft Maintenance Documentation in the International Aerospace Maintenance Language* [15]
- ICAO Doc. 9824, *Human Factors Guidelines for Aircraft Maintenance*, esp. 2.8 and 3.10 [16]

But, even they don't yet fully tackle the inconsistency, unfriendliness and fragmentation of manufacturers' documents. For example, for structural maintenance programs, there are ALIs, AMMs, CAPs, CPCPs, FMPs, ICAs, MPDs, MRB Reports, SBs, SIDs, SLs, etc. It is still easy for airlines to miss something. It is still hard to:

- Check for duplication
- Resolve inconsistency
- Sort safety from economy

Human factors are as important for maintenance documents as for instrument panels. For both, misreading is dangerous. For both, engineers need expert help.

CONCLUSION

Our approach to aircraft structural maintenance programs is *not* collective.

It hurts *safety* if division between:

- Professional and maintenance engineers risks wrong *information*
- Engineers and human factors experts risks wrong *interpretation*

It hurts *economy* if there is duplication and confusion for:

- Manufacturers, airlines and authorities designing and approving them
- Airlines interpreting and doing them

RECOMMENDATIONS

"Two are better than one, because they have a good return for their work." – Ecclesiastes 4:9

What could we do to promote a collective approach to aircraft structural maintenance programs?

Airworthiness authorities could:

- Involve professional engineers
  - In rules, policy and training
  - Annex 2 is one simple teaching tool
- Consider merging:
  - MRB with Certification
  - MSG-3 with FAR 25
- Write new rules and guidance for:
  - Human factors for manufacturers' maintenance documents
  - Escalation of inspection intervals

Aircraft manufacturers could:

- Have both types of engineers design the *information*, for:
  - Effectiveness
  - Practicality
- Have human factors experts design the *presentation*, for:
  - Simplicity
  - Clarity
- Analyse together, including interaction:
  - Fatigue
  - Corrosion
  - Accidental damage

Airlines could:

- Have both types of engineers assess manufacturers' maintenance programs
- Respect life limits
  - Sometimes the best inspection is futile
- Use *damage tolerance* theory to escalate inspection intervals
  - Beware the 'nil findings' argument
  - Involve the manufacturer

ACKNOWLEGEMENTS

I thank CASA for supporting my preparation and presentation of this paper. I thank the engineers (of both types) who have helped me with MRB and Certification. Finally, I thank Kathy for 26 years of a collective approach to marriage, including supporting me while writing papers like this one.

AN OPEN INVITATION

I welcome comment. Please email me at steve.swift@casa.gov.au.

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ANNEX 1

ARGUMENTS AGAINST MERGING MRB WITH CERTIFICATION

– with my comments

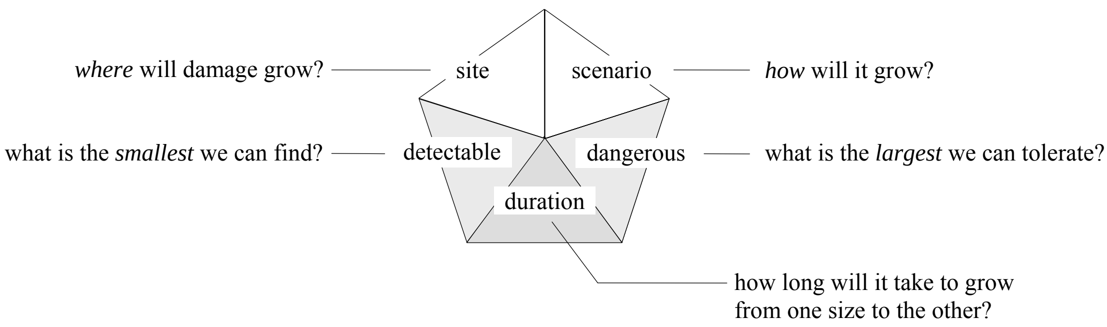
- We would lose the check of an independent *process*
  - But, still have three independent *parties* (authority, manufacturer and airlines)
- The work may be too much for one process
  - But, the new process could combine resources
  - And, no duplication would lessen the work
- The work would take too long done in series instead of in parallel
  - See above
- Manufacturers may not want to share more information with airlines
  - But, airlines could agree to confidentiality, as do authorities
- Airlines may mistake critical sizes for damage tolerance as allowable limits for flight
  - More reason to include professional engineers, who would know better
- There is nothing wrong with MRB
  - It could be better
- The only need is better coordination
  - There are two many divisions to bridge
- Certification and MRB are communities as well as processes:
  - Merger would need sensitive handling to preserve community
- The MRB community would be reluctant to surrender hard-earned control over a well-oiled process
  - Merger would need maturity and humility
- MRB would require rule change
  - But, the FARs do not mention MRB or MSG-3
  - FAR 25.571 already covers corrosion and accidental damage, as well as fatigue
  - So, merging MRB with Certification would only require changing MSG-3 and other guidance
- Merger is less necessary, and would work less well, for systems and other disciplines
  - That may be true, I am not competent to comment
  - The merger could be for structural maintenance programs only
- MRB has advantages over Certification, which merger may lose
  - True, but so is the reverse
  - Merger should try to identify and preserve the strengths of both

ANNEX 2

THE DIAMOND

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

Figure 14



At ICAF 2007, *Rusty Diamond* [4], explained how the same inspection theory applies as much to corrosion as it does to fatigue — or any other progressive deterioration.

Later, at IASS 2007, the 'diamond' helped win the Whittle Safety Award from the International Federation of Airworthiness.

Its beauty is its ability to teach, simply, the basics of *damage tolerance* theory to maintenance engineers. It is proving useful in training courses in Australia, USA and elsewhere.