A Method to Estimate the Cost of Corrosion for Australian Defence Force Aircraft

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Abstract

Corrosion prevention and maintenance has been recognised as a significant contributor to the life cycle cost of Australian defence aircraft, however the scale of the problem is unknown. The goal of this study was to establish a practical method for estimating and validating the annual cost of corrosion for the Australian Defence Force (ADF) aviation fleet. This paper specifies the various corrosion costing methods possible and their key advantages and limitations with regards to the Australian context. Precedent corrosion costing studies from the US are explored. The final costing method comprises of three approaches: a top-level approach using Defence Materials Organisation (DMO) sustainment data; an analogy approach using published costs of corrosion from US defence aircraft; and a detailed bottom-up approach on selected and available aircraft for validation.

Keywords: Corrosion, Costing, Maintenance, Environmental Degradation, Defence

Introduction

Corrosion is the gradual destruction of materials (usually metals) by chemical reaction with its environment [1, 2], and is estimated by the Commonwealth to cost Australia $13 billion annually [3]. The impact of corrosion on the structural integrity of aircraft is becoming increasingly prominent. Corrosion causes 80% of structural issues in ageing commercial aircraft, and is the biggest problem for ageing private Cessna aircraft [4, 5]. In defence, older airframes are reporting that corrosion can be the primary cause of structural non-conformances, and that non-availability due to inspection and correction can be upwards of 10% [6]. For new airframes, improved components incorporating carbon composites are causing significant issues due to galvanic corrosion around metallic fasteners, and OEMs are mandating extensive inspection regimes where 70 to 75% of maintenance actions are for corrosion control [7]. As the extent of corrosion on an airframe is unknown until inspection, little forward planning is possible, and fleet logistics must be flexible. In the US, Ref. 8 estimates an unavailability of 7.3%, 4.8%, and 4.4% for Navy/Marine Corps, Army and Air Force aircraft over their respective service life due to corrosion maintenance.

Corrosion reduces the size and therefore the strength of structure, but also reduces the fatigue life by producing initiation points for crack growth. The consequences of this attack have been significant: from 1975-1995 in the US, corrosion caused 687 incidents, leading to 87 aircraft lost and 81 casualties [9]. In Australia, an RAAF F/A-18 lost a flap in flight due to extensive direct and incidental corrosion damage on the attachment lugs [9]. Extensive corrosion inspections also expose maintenance engineers (often needlessly) to toxins such as chromates, beryllium and cadmium.

Corrosion related maintenance is recognised as a significant contributor to the life cycle cost of Australian defence aircraft [6, 10]. In the US, it has been repeatedly found that approximately 30% of aircraft maintenance costs are due to corrosion [11-13]. DGTA acknowledges that corrosion is the main mechanism of environmental degradation and also the principle cost driver [14]. However, the fiscal burden of corrosion to the ADF has not been accurately determined and the absence of corrosion cost data is identified in the Commonwealth's Environmental Degradation Management System (EDMS) specification [15]. Compared to the US, few studies have been completed on the cost burden of corrosion to Australia. Initial investigations into costing methods and feasibilities have been performed, but not enacted [10, 20].

The goal of this study was to identify a practical method for estimating and validating the annual cost of corrosion of the Australian Defence Force (ADF) aviation fleet. If followed, the method should determine the actual cost to the Commonwealth of managing structural corrosion so that aviation platforms remain airworthy. Such an outcome is intended to give scale to aviation corrosion maintenance, to provide justification for existing and further corrosion prevention and mitigation strategies, and ultimately to reduce the sustainment burden to the ADF.

Previous Studies of Corrosion Costs in Defence

United States

The United States Department of Defence (DoD) has developed a list of strategies for reducing corrosion. One action was to "conduct studies and surveys, collect data, and analyse results to determine the impact of corrosion, pinpoint critical areas for concentration of prevention and mitigation efforts, and develop metrics to measure the effect of corrosion and the results of prevention and mitigation efforts" [11]. To implement this strategy - and address recommendations from the US Government Accountability Office (GAO) - a DoD Corrosion Prevention and Control Integrated Product Team (CPC IPT) was formed from representatives from private industry and all U.S. military services [12, 13]. A method to measure the cost of corrosion in the DoD was developed using both a top-down and bottom-up approach [16, 17], and the Logistics Management Institute (LMI) has subsequently carried out a series of year-long studies assessing the DoD cost of corrosion, as listed below in Table 1. Annual United States Air Force (USAF) fleet costs due to corrosion were estimated at US$5.4 billion dollars in 2008/2009 [12]. These studies represent the most comprehensive study of defence corrosion costings performed on military assets.

Table 1: LMI US DoD Cost of Corrosion Studies and Outcomes

Study year[a]	Study segment	Annual cost of corrosion	Data baseline
2005–2006	Army ground vehicles	$2.0 billion	FY2004
	Navy ships	$2.4 billion	FY2004
2006–2007	DoD facilities and infrastructure	$1.8 billion	FY2005
	Army aviation and missiles	$1.6 billion	FY2005
	Marine Corps ground vehicles	$0.6 billion[b]	FY2005
2007–2008	Navy and Marine Corps aviation	$3.0 billion	FY2005 and FY2006
	Coast Guard aviation and vessels	$0.3 billion	FY2005 and FY2006
2008–2009	Air Force	$5.4 billion	FY2006 and FY2007
	Army ground vehicles	$2.4 billion	FY2006 and FY2007
	Navy ships	$3.2 billion	FY2006 and FY2007
	DoD–Other equipment	$5.1 billion	FY2006
2009–2010	Marine Corps ground vehicles	$0.5 billion	FY2007 and FY2008
	DoD facilities and infrastructure	$1.9 billion	FY2007 and FY2008
	Army aviation and missiles (FY2008)	$1.4 billion	FY2007 and FY2008
2010–2011	Navy and Marine Corps aviation		
	Air Force		
2011–2012	Repeat 2008–2009		

[a] Study period is one calendar year.
[b] Revised because of an improved field-level maintenance calculation method.

Australia

The Defence Science and Technology Organisation (DSTO) has provided scientific and technical support to ADF aviation for many decades, and as part of this periodically undertakes reviews of the engineering problems affecting military aviation in Australia. DSTO staff visited all ADF aviation bases in the early 1990s, and observed a common thread to the discussions with base personnel - their concern about the rising cost of corrosion repairs, and the increasing impact of corrosion-related maintenance on aircraft availability. Estimates of the cost burden of corrosion, for detection, repair and repainting of some aircraft types within the ADF fleet at that time were undertaken. The cost per aircraft per year for the C-130, F-111 and B-707 were established to range from about $250k to $300k, at that time [18].

QinetiQ Aerostructures Pty Ltd has developed a methodology for measuring the cost of corrosion, tailored to ADF platforms that was endorsed as having the capability of demonstrating the entire cost of corrosion for a platform, identifying potential cost avoidance strategies, identifying avoidable costs, and providing data for improved decision making [10]. The method utilised both a top-down method using total maintenance costs and bottom-up evaluation of maintenance records, classification and attribution of costs and a scaling of the bottom-up cost to the top-down costs. Although a pilot study as a means of validating the QinetiQ proposed Cost of Corrosion and Environmental Degradation Measurands was proposed, no field implementation of this methodology appears to have been undertaken [20].

QinetiQ have also performed corrosion costings through the F/A-18 A/B Environmental Degradation Assessments (EDAs). These reports utilise a template model to estimate direct corrosion-related activities. A recent report addressed the period January 2010 through to December 2011 and assessed the cost of corrosion as $2.49 million [6].

Costing Methods

A number of costing methods have been considered for this paper based on corrosion costing studies at a national level (to determine total economic impact) and at the defence sector level.

Input/Output Method

This approach was developed by Wassily Leontief and used by National Bureau of Standards and the Battelle Columbus Laboratories (NBS-BTL) for US national corrosion cost studies [19]. The input/output approach is a general equilibrium model of an economy that considers a real world case, and a world in which corrosion did not exist: the difference is the cost of corrosion.

Each industry sector is assigned coefficients which relate economic inputs to its value of production. For example, the analysis of the steel industry specifies the quantities of each input purchased by the steel industry to make a ton of steel, and might indicate that producing $1 worth of steel requires $0.15 worth of coal, $0.10 of iron ore, etc. These component numbers (0.15, 0.10, etc.) are called coefficients. The coefficients are established with the combination of knowledge from economic and corrosion experts. Elements are identified within the various sectors that represented corrosion expenditures, e.g., coatings for steel pipelines. The coefficient of coatings for steel pipelines was modified so that, for example, pipelines spend nothing on coatings, where the only purpose of coatings is to prevent corrosion. Once particular coefficients for steel pipelines were modified, the sector coefficients were renormalized to add to one. This new matrix represented the world without corrosion, and enabled the full economic impact of 'zero corrosion' to be promulgated through the sectors and the impact subsequently calculated.

While corrosion costs have been derived by this approach, the quality of cost data is dependent on the uncertainty of these coefficients, which require significant effort and cooperation from industry to derive and validate. Indirect costs are also not measured, such as management overhead for command of staff engaged in corrosion preventative and corrective activities, facilities infrastructure costs, and the cost of inventory burden due to an increase in the number of spare parts required in stores.

Net Present Value Method

The Net Present Value (NPV) method is a life cycle costing approach [19]. This method consists of the following three steps:

- determination of cash flow for corrosion related activities;
- calculation of present value of cash flow; and
- calculation of the annualised equivalent rate.

This approach was applied by Corrosion Control Technologies Laboratories Inc in agreement with the Federal Highway Administration and NACE International to assess impact of metallic corrosion to the United States economy [19]. They analysed 26 industry sectors in detail, and the results were extrapolated across the entire United States economy. This method was able to measure the total cost of corrosion and enables lifecycle costs to be calculated, but the method of determining the cash flow for corrosion related activities is not well described, and indirect costs are again not measured. Training, facilities, test equipment and other factors are also excluded from the scope.

Template Method

Via their Environmental Degradation Assessments (EDAs), QinetiQ performed a corrosion costing exercise of the F/A-18 A/B through the use of templates [6]. Data was obtained from the ED Manager on 22 components, and extrapolated across all corrosion occurrences to determine a total annual figure of $2.49 million. Indirect costs were not given a dollar value, but availability impacts were identified.

While successful as a low-cost method, the limitations of the F/A-18 EDA study are that corrosion estimates focused on only direct labour and material costs. Engineering review, administration, deeper maintenance and other critical data common to comprehensive costing analyses were excluded. Further, by extrapolating the cost of the highest occurring defect, any high-cost, low occurrence defects would remain undetected. Prevention and inspection costs were also not included.

Top-Down Method

The top-down method begins with an identification of all the annual costs associated with an enterprise, whether it is a unit, major command, service, or all of US DoD [11-13]. This becomes the upper bound, as corrosion is unlikely to be sole annual cost and cannot be more than the entire enterprise. Equally unlikely, but still conceivable, is a cost of corrosion within an enterprise that is zero. This is the lower bound. The upper bound is brought closer to the lower bound by removing costs within the enterprise that obviously and unambiguously have nothing to do with corrosion. These costs are eliminated from the corrosion “ledger,” producing a new upper bound. Therefore, the top-down estimate is a solution by subtraction.

To illustrate this process, Fig. 1 depicts the US Air-Force cost top-down approach. The process started with identifying the total cost for all of US Department of Defence (DoD), then breaks down the force structure into non-Air Force, non-aviation, and non-maintenance associated costs that do not relate to corrosion. The remaining is all corrosion costs of Deeper Level Maintenance (DLM), Field Level Maintenance (FLM), and outside normal reporting (ONR), if any. These areas (shown yellow in Fig. 1) within each of these three enterprises represent the corrosion cost that remains after all non-corrosion-related costs are eliminated.

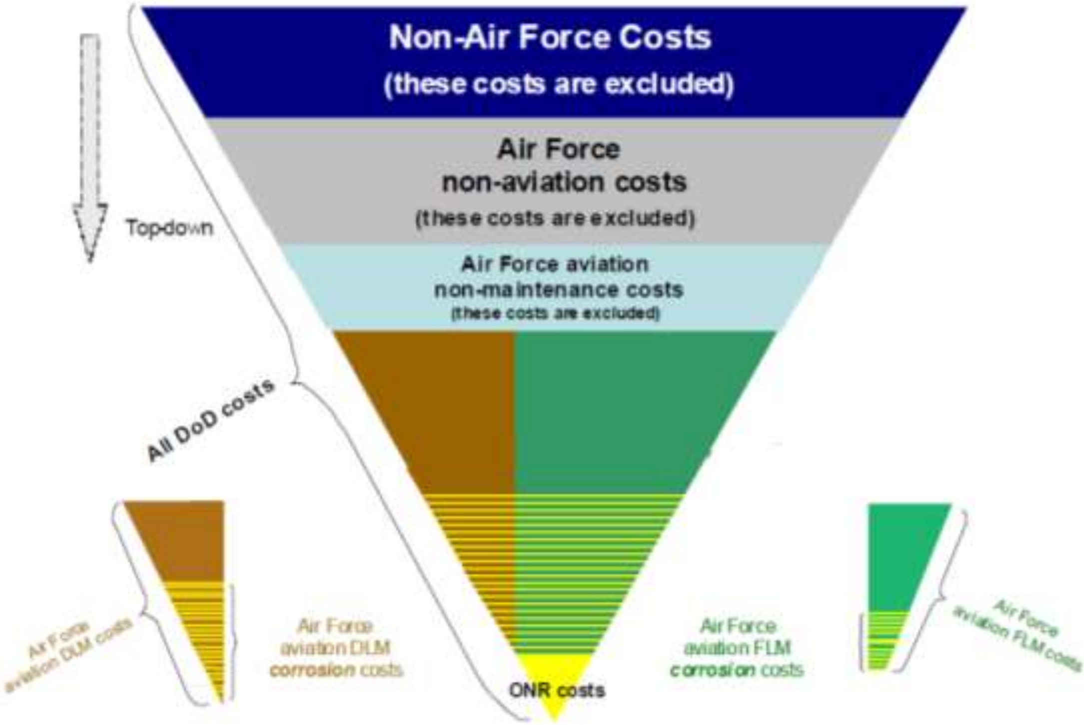

Fig. 1: Top-Down Corrosion Cost Measurement Method [11]

This particular approach offers a very efficient assessment of the potential cost of corrosion, without requiring the significant time or expense to survey, collect and analyse data. The main challenge is the accurate determination of the total cost of an enterprise, and subsequent removal of components such as non-maintenance costs. Starting with an incorrect estimate will almost guarantee an incorrect top-down outcome. The results of a well-implemented top-down analysis can yield a good estimate of overall costs, but that estimate can lack the detail necessary to pinpoint major cost drivers within the enterprise if that is required of the study.

Bottom-Up Method

The alternative to the above method is a bottom-up costing method which aggregates the data associated with individual corrosion events [11-13]. The corrosion-related labour and materials cost components of these individual events are identified separately and must be linked through a unique task identifier, such as job order number, to determine the total cost of the event.

As illustrated in Fig. 2, the starting point for the bottom-up method is an analysis of all maintenance activity, segregating activities that are related to corrosion and accumulating the associated corrosion costs. Other direct costs must also be identified.

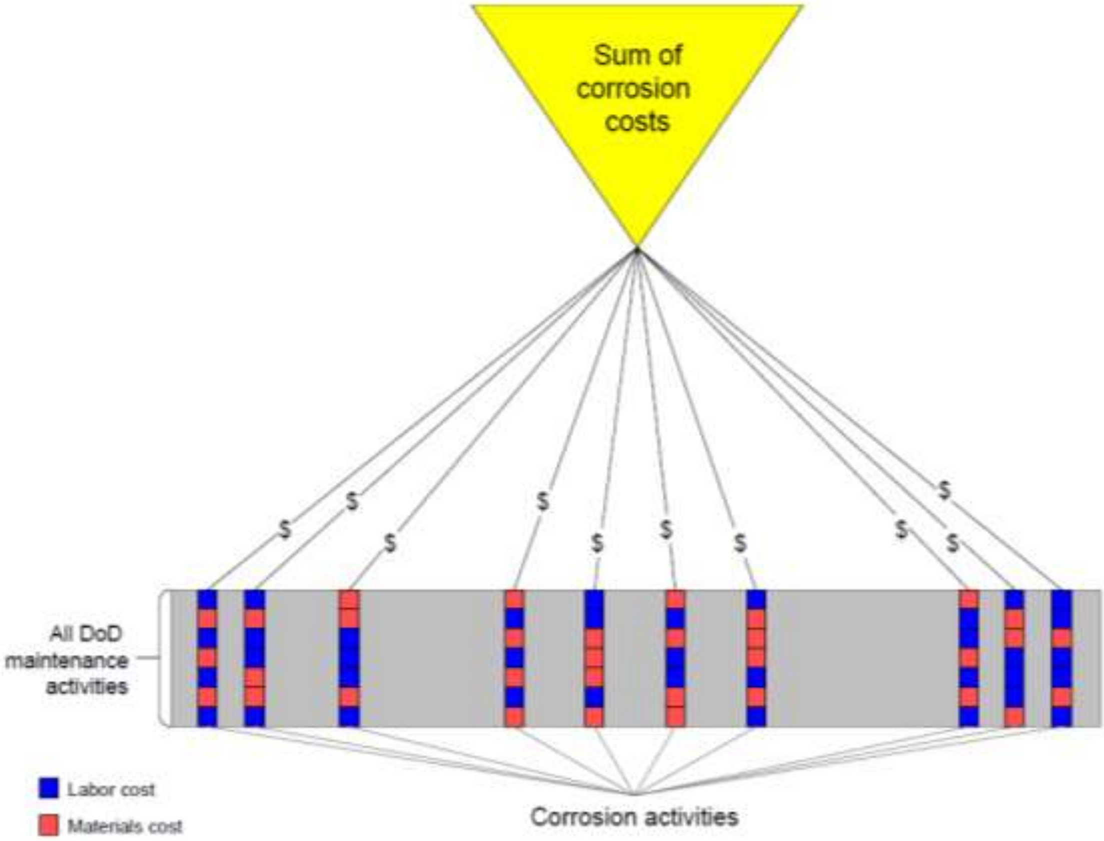

Fig.2: Bottom-Up Corrosion Cost Measurement Method [11]

This approach by addition can produce very accurate, auditable information so long as the maintenance data collection systems accurately capture all relevant labour and materials costs, identify corrosion-related events, and are used with discipline [11]. If any of these three aspects are missing, corrosion costs are likely to be determined incorrectly. In most cases, the costs will be understated.

Evaluation

All studies demonstrated aspects that could be applied to assessing the cost of corrosion within the ADF. The Input/Output methods do not provide data suitable to determine quantifiable cost avoidance strategies. Input/Output methods employ broad based assumptions to calculate the cost of corrosion, while they are only able to make general recommendations for cost avoidance.

The ability to calculate the life cycle cost in the Net Present Value method would be useful for cost benefit analysis; however, this approach did not appear to describe how to obtain corrosion costs. This method could possibly be used in conjunction with another. The EDA template approach is too limited and prescriptive for this study, and the larger methodology developed by QinetiQ requires significant investment in implementation effort, time and costs.

However, both the QinetiQ and US Defence CPC IPT methodologies note that a more rigorous approach of determining the cost of corrosion is to utilise both bottom-up and top-down approaches [10, 11, 20]. If the two values converge, it is confirmation that the corrosion data collection methods and analysis assumptions are acceptable, and the data are adequate and accurate. Further, as the ADF fleet is comprised of many aircraft also serving in the US fleet, the results of the US studies could be used as another top-level estimate if appropriate analogy can be shown.

A significant impact which was not costed in the previous studies is that of aircraft unavailability due to corrosion and corrosion remediation. Unavailability of aircraft can have far reaching operational impacts and place further pressure on already stretched front line operators. An aircraft may become unavailable for operations due to a range of reasons. This potentially includes an increase in the time to make serviceable (TMS) because of a corrosion issue, and the operational aircraft will not be replaced. Rather the loss of availability may result in a loss of pilot training days or increased usage for another aircraft. A reduction in aircraft availability has different implications for different platforms. For example, it may be possible to recover capability of a C-17 or C-130 by hiring a commercial aircraft, to complete a mission, but this may not be possible for an F/A-18.

Stakeholders typically place a very high priority on aircraft availability, which implies a significant cost would be expected if it were unavailable. Furthermore, with contracted maintenance programs in place, aircraft downtime may be the only corrosion related impact that the Commonwealth experience. However, in the ADF organisations evaluated, the various operating units manage to achieve their annual authorised flying programs, using aircraft that are relatively lightly utilised (e.g. typically about 6% of life in the air). As such, availability impacts are not quantified as a cost for this particular study given the difficulty in establishing the associated opportunity costs.

Proposed Method

Three approaches are proposed as practical method for estimating the annual cost of corrosion of the Australian Defence Force (ADF) aviation fleet: Top-down and Analogy to derive platform and overall fleet estimates, and a detailed Bottom-up approach of limited aircraft to provide validation.

1. Top-Down

This approach should efficiently produce a good estimate of platform and fleet corrosion costs, without any detailed maintenance data collection. US studies have determined the fraction of total maintenance costs that are due to corrosion for a variety of different platforms, and these fractions can be taken from published DMO sustainment figures for each ADF aircraft. However, the total maintenance costs of the Commonwealth (including Defence and contractor costs) are different to the published DMO sustainment costs. These Sustainment Product Prices are inclusive of all DMO primary costs for the delivery of supplies and services, such as those provided through external contractors managed by the DMO for engineering, maintenance, supply, training and operating services, inventory purchases (repairable and consumable), and the DMO Sustainment Service Fee. Secondary costs (for services currently provided free of charge by Defence) are not included in the price. The ADF also undertakes maintenance activities that are not directly costed or included in the sustainment figure. Further, DMO publications do not cite costs for all platforms. Significant collaboration with DMO will be required.

2. Analogy

This second approach should also efficiently produce a top-level estimate of platform and fleet costs. The Analogy approach utilizes existing US DoD cost of corrosion data for aviation assets that are deemed analogous to ADF assets. Detailed US DoD data has been collected and analysed by LMI, and presented in a range of published reports [11-13]. This data presents the annual cost per individual aircraft, which is then scaled to the size of the Australian fleet. The costs are converted to Australian dollar values and inflated to current Australian dollar values.

The primary challenge is the correlation between the published US platform data and the ADF fleet. Overall, platform correlation (and hence corrosion costs) is deemed accurate if the platform age, configuration, role and environment are similar. While many Australian aircraft will have high correlation due to their US origins and OEM mandated maintenance regimes, some differences may occur in instances where additional corrosion maintenance activities are performed, major refurbishment is deferred, or periodicities altered due to the Australian operational environment. The US LMI costs are averaged for a large fleet population over a range of operating and environmental conditions which may dampen any extremes in the source data, but may also inherently include economies of scale not enjoyed by the ADF.

3. Bottom-Up

The last approach is a detailed study of maintenance data. An on-site survey is to be conducted with engagement of local Subject Matter Experts (SMEs) to integrate data sources and to assure that estimates developed are comprehensive and sound. The number of aircraft for bottom-up analysis is contingent on the scale and budget of the costing exercise and the availability of detailed data. To assure that a comprehensive survey is conducted, the LMI developed 'corrosion cost tree' is used as a baseline [11-13], but is modified to account for the particular maintenance structures found in the ADF. Fig. 3 shows the adapted bottom-up cost tree used for this approach.

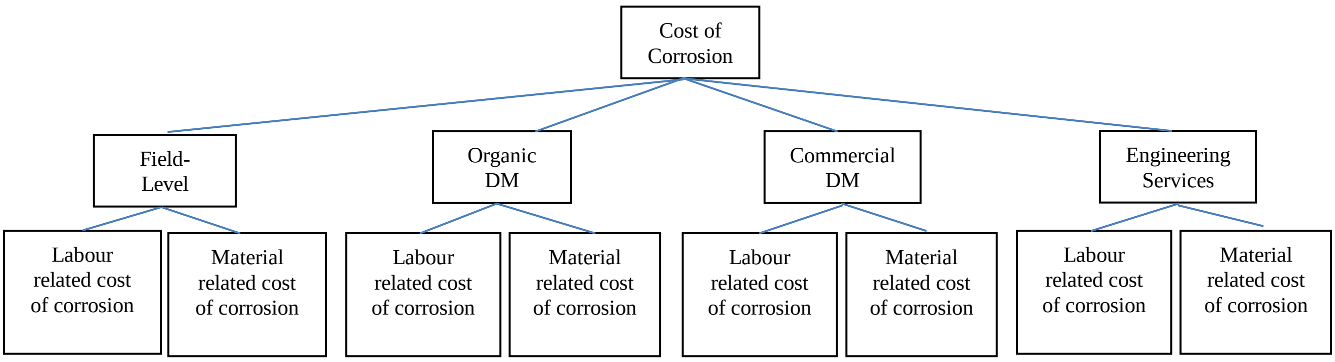

Fig. 3: Adapted Cost Corrosion Tree

Detailed costings are explored in the first instance at four levels of maintenance: Field, Organic DM, Commercial DM and Engineering Services. Field-level labour and material costs cover activities at the Flight Line Maintenance (FLM) level, which is generally the Squadron level. The labour contribution is primarily for the military management and technical personnel engaged on that platform for activities deemed FLM but excludes any staff not applied to cost of corrosion activities, e.g. aircrew and operational training staff. An indirect Labour cost for staff in command organisations above the Squadron that are also responsible for management of the FLM venues is also included. The estimate covers direct and indirect labour costs for Cost of Corrosion activities. FLM activities are typically associated with Before Flight, After Flight, Turnarounds, FLM level Routine Servicing and

Remediation, and any applicable Special Servicing. The material contribution is primarily for corrosion treatment e.g. primer & paint, painter Personnel Protection Equipment (PPE), and Corrosion Inhibiting Compounds (CICs) products. In addition an annual infrastructure rental cost for assets such as flight line carports, squadron FLM maintenance hangars, squadron component paint shop, and aircraft and engine wash bays. Provision for cost of any Base level platform paint facilities for major or complete aircraft painting was included.

Organic DM labour and material costs cover the FLM venue but are deemed Deep Maintenance (DM) work, which is aggregated to reflect a fleet based Organic DM Labour estimate. The labour contribution is primarily for the technical personnel engaged on that platform for activities that are deemed DM. Activities are typically associated with major Routine Servicing and Remediation and are typically the same level of Routine Servicing conducted by external contractors engaged by the DMO for sustainment work. The material contribution is primarily for an annual infrastructure rental cost for squadron DM maintenance hangars.

Commercial DM labour and material costs cover the DM venue of external contractor(s) engaged by the DMO for sustainment work, which is aggregated where there are multiple DM contractors, to reflect an Organic DM Labour estimate. The labour contribution is primarily for the technical personnel engaged on that platform for activities that are deemed DM. Activities are typically associated with major Routine Servicing and Remediation. Labour costs are presented as a factor of the total contract price and addresses all direct and indirect costs. The material contribution is primarily for the Cost of Corrosion element of an Annual Maintenance Program for the platform Repairable Items sent to external venues for DM work. The annual infrastructure rental cost for any DM maintenance hangars is already included within the Commercial DM Labour estimate and is not counted under this category.

Engineering labour and material costs cover activities at Design and Sustainment Engineering organisations, generally DMO System Program Offices and any members of a Technical Support Network, which is aggregated to reflect a platform Engineering Labour Cost of Corrosion estimate. The labour contribution is primarily for any dedicated Corrosion Management staff and the military management and technical personnel engaged on that platform for activities deemed cost of corrosion activities, e.g. analysis and production of corrosion related Repair Scheme Developments, Special Technical Instruction (STIs), Modification Orders, Non-Conformance Reports (NCRs), etc. The material contribution is primarily for any SPO funded external studies or work undertaken by members of their Technical Support Network.

There are also additional non-platform costs that need to be considered at the bottom level. LMI studies [11-13] made allowances for other costs not specifically linked to a platform, or that are performed outside the normal maintenance reporting. For Australia, an obvious cost in this category is the significant research and development on aircraft corrosion funded by the Commonwealth, and performed by Australian entities, such as DSTO and the Defence Material Technology Centre (DMTC).

Conclusion

Three costing approaches have been proposed to estimate and validate the cost of aircraft corrosion to the ADF. A top-down approach using Defence Materials Organisation (DMO) sustainment data and an Analogy approach using published costs of corrosion from similar US defence aircraft will provide platform and fleet cost estimates; a detailed bottom-up analysis should also be carried out on aircraft where maintenance data is available to give confidence and validate the final costs derived by the other approaches.

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