The PBP Bow-Tie Framework for the Systematic Representation and Comparison of Military Aviation Regulatory Frameworks

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Abstract

This paper presents a novel framework, based on traditional system safety modelling approaches, for the representation and comparison of airworthiness aviation frameworks. A disparate array of military airworthiness frameworks have emerged due to a lack of standardisation and the absence of a recognised organisation needed for the harmonisation of military regulatory frameworks. The complexity and subsequent cost in inter-agency recognition of existing certification programs has led to the establishment of a European forum of military airworthiness authorities. The forum is working towards establishing a common regulatory framework across its European member states. The common framework provides the systematic basis for a certification of military aircraft that can be readily recognised by all of the member states. This will have many cost and efficiency benefits for the EU. The framework and recognition process have recently been accepted as a method for establishing recognition outside of Europe, with some identified shortfalls. This paper establishes a method for overcoming these shortfalls for Nations outside of Europe. The Product-Behaviour-Process (PBP) Bow-Tie, which is a novel application of the traditional bowtie risk modelling tool, derives test points that capture the airworthiness attestations for the high-level engineering lifecycle processes of design, production and maintenance. The proposed framework is used to provide a comparison between the Australian Defence Force and United States Army regulatory frameworks. The comparative case-study clearly demonstrates the benefit of the PBP Bow-Tie model in its ability to systematically represent the disparate regulatory frameworks. A novel representation of the output is also described, which facilitates a visual comparison of the results. The application of the PBP Bow-Tie framework to the case-study of regulatory frameworks reveals significant differences that need to be addressed in order for inter-agency recognition.

Keywords: Bow-Tie, Airworthiness, Recognition, Regulatory Framework, Aviation

Introduction

Military aircraft are managed under a framework of safety requirements and processes similar to those applied to civil aircraft. The International Civil Aviation Organisation (ICAO) provides the principles and rules for all civil National Aviation Authorities (NAAs) signatory to the Chicago Convention subscribe. In 1944, at the Chicago Convention, the 52 attending nations signed the International Convention for Civil Aviation(1). The primary role of the convention was empowerment of nations to control the airspace above their countries, but equally important was the motivation to assure consistent safety standard across all signatory states. Throughout the evolution of civilian aviation safety management there has been a constant drive by ICAO to assure all aspects of airworthiness are regulated and safe. The latest evolution focuses on holistic safety oversight through DOC 9734 Safety Oversight Manual(2). This Universal Safety Oversight Audit Program (USOAP) has been implemented to give global oversight of the eight core elements(3) of the program, and the audit results for each member Nation.

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However, there is no international organisation charged with providing harmonised principles and rules for Military Airworthiness Authorities (MAA/MAWA). MAAs are reliant on monitoring to keep up to date with other MAAs, and need to remain cognisant of changes within ICAO (e.g. integration of Safety Management Systems\(^5\)), to identify where improvements to their own regulatory frameworks should be made. One of shortfalls of this approach is that there is no standard for assessment. The European Defence Agency (EDA) have published the European Military Airworthiness Document - Recognition EMAD-R\(^5\), which describes how mutual recognition of other militaries’ airworthiness systems can be made. Mutual recognition is enabled through an assessment of other MAAs’ regulatory frameworks and processes for assuring airworthiness, then leveraging off that assessment to enable mutual benefits, through a judgment of ‘goodness’. However, the EDA recognition process relies on a common implementation of, or at the very least known compliance to, the European Military Airworthiness Requirements (EMARs). This recognition process is appropriate to Europe, which has common motivations for a standard regulatory framework and is progressed through task forces within the MAA forum\(^6\). This mechanism for inter-agency recognition is expected to improve the efficiency and in turn reduce the costs associated with the acceptance of airworthiness certifications made by another European Union (EU) country. This, in turn, is expected to make European defence industries more competitive and reduce the cost of military aviation procurement programs.

Within the MAWA forum, and separate complimentary work within the North Atlantic Treaty Organisation (NATO) and Air and Space Interoperability Council (ASIC) airworthiness working groups, mutual recognition has been given a global priority. For instance, the Unites States Department of Defence (US DOD) issued a directive\(^7\) requiring US airworthiness agencies to ensure that foreign aircraft on which US DOD personnel fly comply with the DOD instruction, this has triggered the US DOD to conduct assessments on their allies. This has expedited the requirement for recognition of other airworthiness authorities. In fact, the US Army Airworthiness Authority (Aviation Engineering Directorate (AED)) has recently recognised the United Kingdom Military Aviation Authority (UK MAA) for safety of personnel\(^8\), while the UK MAA will leverage of US Army aircraft certification. There is similar motivation for US Army AED recognition with the Australian Defence Force (ADF), with both Militaries conducting joint training and operations. The ADF also relies heavily on the US Army for acquisition and sustainment support of some of their military helicopters, currently, the CH-47 Chinook and S-70A Blackhawk helicopters, and tactical unmanned aircraft surveillance platforms (RQ-7 Shadow 200). Currently, there is no framework that can be used to systematically structure, and reconcile the differences between, the disparate military airworthiness frameworks of the two countries. As a consequence, there are substantial management and administrative overheads.

This paper first examines the weaknesses in the application of the existing EDA published recognition procedure to non-EU Nations (Section 0). A new approach for the representation of disparate airworthiness regulatory frameworks is presented. Based on a bow-tie model, the approach facilitates systematic comparisons between frameworks, the identification of points of difference, and subsequently, the basis for the development of a mutual recognition process between MAAs. The paper highlights how the proposed approach can be utilised to overcome the identified weaknesses in the application of the EDA recognition procedure. The case-study analysis and comparison of the US Army and ADF airworthiness frameworks (presented in Sections 0 and 0, respectively) provide a basis for the development of a recognition procedure between the two MAAs (presented in Section 0).

**The work of the European Defence Agency**

The EU was stimulated into action by a ground swell of pressure from the European defence industry. For instance, an individual parts producer can supply every civilian aviation company with the same European Aviation Safety Agency (EASA) certification for product X, who since 2002 has provided harmonised requirements for civil aviation. The same parts producer may then have to certify the same
product in accordance to the standards and procedures of other MAAs in the United Kingdom (UK), Spain, Italy, Greece and Sweden in order to supply product X. The producer would also be subject to audit requirements from all of the MAAs. The process overheads required for the parts producer escalated the costs of supplying the parts, burdening the European defence industry. The additional burden arises from military airworthiness being managed at a national level, with no harmonisation below large multinational aircraft projects\(^9\). Recognising the need to address this situation, the EDA established a project to harmonise the airworthiness requirements and streamline certification processes. The Military Airworthiness Authorities (MAWA) Forum was established by the EDA in 2008 with 26 participating MAAs from the EU. The goal of the MAWA Forum is to harmonise the national military regulations of each participating MAA through the development of a common European Military Airworthiness Requirement (EMAR) set. The EMARs can be implemented and enforced by each of the participating MAAs, harmonising the airworthiness requirements without compromising the sovereign rights of each country.

Further to harmonising the military airworthiness requirements, the EDA has published a process for recognition of airworthiness findings/certifications made by another participating MAA. The purpose of this is to leverage off the common airworthiness requirements and utilise another nation’s oversight to minimise regulatory effort, and minimise the burden on Defence operators and industry. The European Military Airworthiness Document – Recognition (EMAD-R)\(^5\) details the requirements of, and process for, recognition of another MAA. The EMAD-R depends on the EMARs, with one of the first steps of the recognition process requiring establishment of a baseline for compliance to the EMARs. From this platform the countries exchange a Military Airworthiness Requirements Question-set (MARQ) that addresses four components of technical airworthiness:

1) airworthiness authority (always invoked),
2) inspection,
3) production, and
4) aircraft certification (invoked as required)\(^10\).

The MARQ exchange is a three-step process involving; self-disclosure, information exchange, critique, and the gathering of evidence to address issues or differences raised. The MARQ has derived its air safety goals from the requirements of the ICAO airworthiness manual\(^11\) and elements of the ICAO Safety Oversight Manual\(^2\). This foundation gives the MARQ a globally significant identity, although the derivation of the questions based on these documents is disjointed, particularly with the references to the ICAO documents having been removed from the MARQ. This removes the ability to verify that the provided statement fulfils the requirement of the ICAO document from which it was derived. Removing this link, and underpinning requirement, requires the MAA completing the MARQ to determine when they have satisfied the ICAO derived air goal\(^12\). Further, the MARQ is only a subset of the requirements provided in the ICAO manuals. The subset chosen lacks justification. This has created uncertainty in the scope of the MARQ and whether the safety assessment is comprehensive.

The EMAD-R process requires that the two MAAs enter into an agreement for an identified purpose. This may be for any of the technical airworthiness components or sub-components identified within the MARQ. For instance, the UK and French military airworthiness authorities have trailed the EMAD-R process for recognition of A400M\(^a\) maintenance oversight. The EMAD-R process is illustrated in Figure 1. The trial program was a success, with a recognition certificate signed by both parties in May 2013 for recognition of EMAR part 145 organisational approvals and shared audits\(^13\). While the benefits of the trial program have yet to be fully quantified and realised, the process was successful in generating a recognition agreement based on known compliance to EMAR 145 and the MARQ assessment. However, the EMAD-R process cannot be readily applied outside of the EU, due to the absence of a recognised compliance to the EMARs. It was highlighted that its utilisation outside of the EU is possible\(^14\) but that it

\(^a\) A four-engine turboprop transport aircraft designed by Airbus.
has a high dependency on the EMARs, which weren’t developed with input from non-EU MAAs. Despite this deficiency, the EMAD-R process has been adopted by the Air and Space Interoperability Council (ASIC)(8).

ASIC comprises the MAAs of the UK, Canada, Australia, New Zealand and the three arms of the United States Department of Defence (US DOD; Army, Air Force, Navy). Obviously, only one ASIC member is also a member of the EU. Thus, the remaining six MAAs have no known compliance with the EMARs, a necessary component of the EDA recognition process (described in the EMAD-R document and illustrated in Figure 1). In a recent recognition effort between the UK MAA and the US Army, the UK MAA (who had significant input to the development of the EMAD-R and MARQ) chose to skip step five of the EMAD-R process. This stage was skipped due to the UK MAA being unsure of how to satisfy the requirement for a known compliance to the EMARs. The modified EMAD-R process was renamed as the NATO process(8).

A method for assessing the disparate technical airworthiness frameworks and their compliance with the EMARs needs to be defined. No such method exists in literature. A proposed model is presented in the following section.

![Figure 1: The initial steps of the EMAD-R process. The EMAD-R process begins with identifying a need for recognition and then developing an agreement to pursue recognition. Within the agreement legislative considerations, resourcing and times are defined then a baseline is established (normally determination of compliance to the EMARs) and the MARQ assessment is scoped. Then differences, both in resourcing, times and baselines are resolved. The agreement is formalised and then MARQs are completed and exchanged. Unfortunately, the process is weak when used outside of the EU, particularly in the two of the primary steps shown in grey.](image)

**Development of a novel bow-tie for regulatory framework assessments**

The proposed assessment framework is based on a novel adaptation of the Bow-Tie methodology. Whilst a Bow-Tie model typically focuses on a direct safety hazard or “top event” (e.g., a mid-air collision), here the central hazard is described as the system state where there is a loss of technical integrity (Figure 2).

Technical integrity is formally defined as “technical integrity addresses the management of barriers to major accident events that would be harmful to people or environment”(15). Technical integrity of a physical or functional item is reliant on 1) product integrity, 2) behavioural integrity and 3) process integrity (adapted from(16) and developed in(17)). This is the principle for the development of the Product-Behaviour-Process (PBP) Bow-Tie(17). A threat represents the initial state of a scenario potentially leading
to a loss of technical integrity. The threats can be grouped in terms of the three components of technical integrity (i.e., product, behavioural and process integrity, Figure 2).

A “threat line” describes a sequence of events (in this case, a failure path within the airworthiness management process) that originates at a threat and potentially ends with the top-level event. Given the occurrence of the top-event/hazard, a number of consequence paths have the potential to eventuate (illustrated on the right hand side of the bow-tie, Figure 2). A barrier is defined as “any operational, organisational, or technical solution or system that minimises the probability of events to occur, and limit the consequences of such events”\(^{(16)}\). In the PBP Bow-Tie, a barrier represents a regulatory activities put in place to prevent loss of technical integrity (e.g., testing against standards) or mitigate potential consequences (e.g., crashworthiness design). The regulatory activities of Design, Production and Maintenance (or sustainment) can be used to group the regulatory barriers that can exist along the threat and consequence lines. This research currently focuses only on the threat paths and the preventative regulatory barriers that aim to prevent a loss of technical integrity (i.e., the left-hand side of the bow-tie Figure 2).

![Diagram of Bow-Tie Methodology](image)

**Figure 2:** A composition of the bow-tie methodology overlapped with the technical integrity definition and technical item lifecycle, this framework is given the title the Product-Behaviour-Process (PBP) Bow-Tie. Importantly, this research is focused on preventative barriers of the PBP Bow-Tie (the lead up to the top event, shown on the left-hand side of the illustration).

Each barrier can be considered an attestation within the regulatory framework. All attestations of acceptability must be founded on suitably identified standards. This allows for identification of whether the product, behaviour (person) or process being tested is of a suitable standard. There is a process required to be followed when testing against standards. For instance, when designing an item against determined standards, there may be progressive inspections, a test against the standard, identification of any deficiencies and a proposal for rectifications, then finally an attestation that the overall design is acceptable. This is normally a formal attestation that defines the transition to the next phase of within the lifecycle. The design is then forwarded for production (or construction). Standards are set for production and the process repeats. The same process applies for attestations of acceptability of people performing the design, and the processes that the design person is following. By defining the requirements of an attestation, more barriers within the PBP Bow-Tie can be developed. Following the requirements for an attestation, five distinct barriers within each of the technical lifecycle activities for product, behaviour and
process integrity are formed. Further, within a technical domain there is interest in the supply of product. This gives six barriers that are replicated throughout the PBP Bow-Tie; each of these barriers identifies the test points for a technical regulatory framework, in this instance for assessing technical airworthiness. This is shown in Figure 2. However, development of test points is not complete without determining a method of measurement.

![Diagram of PBP Bow-Tie](image)

**Figure 2:** The breakdown of the steps required for attestations of acceptability during the lifecycle of an item. These steps are repeatable through every phase of the lifecycle certification process.

**Independence as an assessment metric**

The location of the regulatory barriers within a technical lifecycle activity, and that the PBP Bow-Tie assessment is aimed at regulatory frameworks, dictates an assessment that identifies regulator interaction. The standards are set and checked by the regulator to remove safety decisions from organisational influence and to maintain a minimum standard\(^{19}\). The decision making, particularly around acceptability, should be made with a primacy on safety. Reason asserts\(^{20-22}\) that there is a significant contribution made by the work environment, management and organisational influences in the decision and actions of personnel. The organisational and environmental influences contribute to latent conditions for failures within the system, or conditions that have the potential to subvert, bypass or weaken the barriers put in place to maintain safety.

Rasmussen’s Dynamic Safety Model\(^{23, 24}\) describes the tendency of organisational drift between three boundaries; Economic, Workload and Safety. An irreversible breach of any of these boundaries is likely to result in an undesirable outcome. It is common for management and personnel to establish gradients away from the cost and resource boundaries. This is illustrated in Figure 4 where the safety barriers are often established internally but reinforced external to the organisation. The tendency is that the organisation will drift towards the safety boundary, as the desire for efficiencies and finite resources push the organisational position closer to the safety barrier. This safety drift\(^{24}\) develops a natural tension between the independent regulators and the regulated organisations. Where the regulated organisations, in an effort to manage resources and remain financially viable, continually strive to identify efficiencies.

An independent regulatory body is typically established so as to ensure important safety barriers are not weakened or breached through these sociological, cultural and organisational behaviours. The regulators are removed from the work environment they aim to control and as such are independent from the organisational influences and aim at maintaining safe operations.
Figure 4: Model of organisational safety drift, where a gradient is established by management and personnel away from economic and resource boundaries, placing pressure on the safety barrier (model developed from\textsuperscript{24}).

Based on the seminal works of Reason and Rasmussen, a measure of independence can be considered as an indicative measure of the degree of freedom from management and organisational influences. In the PBP Bow-Tie framework, we propose that the degree of independence of an attestation made within a regulatory framework. Five levels of independence within a regulatory context can be defined, Table 1. It is important to note that the independence metric facilitates the comparative assessment of attestations; the scale does not provide an indication of the quality or correctness of the attestation made.

<table>
<thead>
<tr>
<th>Attestation Independence Metric</th>
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<tbody>
<tr>
<td>External Regulator / Legislation</td>
<td>5</td>
</tr>
<tr>
<td>Internal Regulator</td>
<td>4</td>
</tr>
<tr>
<td>Manager</td>
<td>3</td>
</tr>
<tr>
<td>Supervisor</td>
<td>2</td>
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<tr>
<td>Practitioner</td>
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Table 1: Scale used to describe the independence of an attestation point

By measuring the degree of independence of an attestation, three important factors can be determined. Firstly, the degree of regulator or legislator interaction with the barriers, where a score greater than three (3) indicates some level of independent regulatory oversight and control over the particular barrier. Secondly, and more importantly, it identifies where decisions are made. Were the decisions are enforced and actions taken. This will identify where the decisions are made without unwarranted organisational interaction with attempts to influence decision making in a way that is detrimental to safety. Lastly, it identifies the areas of focus of a particular regulatory framework. Where, focus can be determined in relation to the phases of the engineering lifecycle (i.e., design, production or maintenance) or in relation to the integrity components of product, behavioural or process. Thus, two potential lenses for analysing a regulatory framework can be applied, which can help to discern the subtleties between frameworks.
Scope of an assessment

When performing an assessment of a technical regulatory framework, it is important to understand the scope of the framework. Within military aviation, there is a requirement for deployment of aircraft to areas of the World in which non-military personnel are not expected to go. These arrangements are expected and understood for military personnel who accept the conditions of service. However, it is now common for home-base operations to be supported by a compliment of defence (uniformed and military employed non-uniform) and civilian (contracted non-uniformed) personnel. That is, design, production and maintenance activities are often shared through contract support arrangements between civilian and military organisations and personnel. Often, airworthiness management agencies have a system for integrating the military and non-military organisations into the technical airworthiness framework. These systems are not always common or consistent between MAAs.

An interesting picture can be developed of the differences between MAA technical regulatory frameworks. For instance, the New Zealand Defence Force (NZDF) does not have organisational approvals for defence maintenance organisations, whilst the ADF has more contracted design and maintenance organisations within their regulatory framework than military ones. Alternatives include requiring compliance with a civilian technical regulatory framework or regulating defence industry under a quality management system approach. All of these approaches have been adopted by various MAA airworthiness systems around the world. For this reason an assessment of the method utilised to manage regulatory activities undertaken by defence industry is required.

The PBP Bow-Tie test points are equally applicable to identifying the independence of the attestations of acceptability for military design, production and maintenance activities and contracted design, production and maintenance activities (i.e., those undertaken by defence industry). The Iris plot, in a symmetrical mirror format, can be used to highlight the areas in which there are differing requirements within the regulatory framework for defence and defence industry.

Visualisation of an assessment

A visualisation of an assessment of a regulatory framework is possible. A Genome mapping tool called CIRCOS(25) was utilised to develop a circular histogram, or Iris plot, as a quick method of comprehending the assessment of a technical regulatory framework. A greater level of explanation and analysis of the Iris plots is given in(17). Importantly, unlike the MARQ, a PBP Bow-Tie assessment is quick to undertake and the results are easy to interpret. For example, a complete assessment of the US Army technical airworthiness framework using the PBP Bow Tie approach took less than two hours. The ease of the assessment is positive for widespread application of the tool. Examples of the visualisation tool are provided in the case-studies in the following section.

Analysing technical airworthiness regulatory frameworks; comparing defence and defence industry

The PBP Bow-Tie assessment is quick to complete. In all assessments so far(17), and those not yet published, the assessment has not taken more than two hours. This is aided by a knowledgeable person from the airworthiness authority. The assessment process follows a sequential interrogation of design, production and maintenance for product, behaviour and process integrity. The independence level for each attestation is captured with supporting references and information regarding the responsible organisation. The supporting information is utilised to determine the motivation and reasons for differences when comparing airworthiness frameworks. The following sections highlight assessments carried out for the ADF and US Army including some qualitative analysis when the frameworks are compared. But first it is important to develop an understanding of how the assessment is conducted; a graphic is shown in Figure 5 detailing the method of assessment and derivation of the Iris Chart.
information. In each assessment a spreadsheet was utilised to capture each of the 57 test point scores (in the example in Figure 5, 114 test points were captured for ADF defence and defence industry) and a short discourse for each test point. The score is represented in the Iris chart, while the short discourse is utilised to explain the differences identified in comparing Iris charts.

**TP4.1 - Behavioural Integrity within Design**

The score is determined by identifying who makes the attestation. The attached discourse is utilised for developing areas for recognition.

![Iris chart example](image)

Figure 5: This graphic illustrates the data capture and its relevance to the Iris chart and comparisons for recognition. In this instance the score for TP4.1 illustrates the internal regulator requirement for standards for design personnel.

This analysis is repeated for each airworthiness system, with the resulting Iris charts and explanatory discourse utilised throughout the comparison. The airworthiness frameworks of the ADF and the US Army will be assessed and then compared in the following sections.

**Qualitative analysis of the Australian Defence Force airworthiness framework**

When a technical airworthiness framework evolves to adapt to changing circumstances, it can occur in a few ways. The ADF made the decision to require contracted organisations to comply with all regulatory requirements of the defence technical regulatory document\(^{(26)}\), and that they are sponsored by an approved defence organisation for the work they carry out. To improve the assessment, a comparison with the approach used in the management of defence industry is required.

As discussed, the ADF require contracted organisations supporting operations to comply with the requirements of the defence regulatory documents. This means that there is little regulatory difference between the defence organisations and contracted defence industry organisations. This is highlighted in the PBP Bow-Tie visualisation for the ADF shown in Figure 6. The Iris plot provides a symmetrical comparison of the independence of attestations for defence and defence industry. This Iris plot is grouped by the components of technical integrity (i.e., product, behaviour and process).
Figure 6: The ADF Iris plot for symmetrical comparison of the attestations for Defence and Defence Industry. This Iris plot is grouped by integrity line. There are little immediately identifiable differences between Defence and Defence Industry attestations for the ADF.

Figure 6 demonstrates that there are only minor differences between how defence and defence industry organisations and personnel are managed within the ADF technical regulatory framework. It is important to note the primary regulatory mechanism (scores greater than four, outside the purple line) is in process oversight. This is enabled through a requirement for design and maintenance expositions, or management plans as they are called within the ADF. These management plans form the basis for the ADF’s regulatory compliance and organisational conformance audits and are common to defence and defence industry. All organisations that perform design or maintenance are issued an approval by the MAA before they are permitted to interact with ADF aviation assets and support systems. Further, it is important to note that the ADF MAA delegates authority to individual platform representatives. This is indicated on the Iris plot by the scores of exactly three on Figure 6.

A different lens for analysis is provided when the Iris plot is grouped by technical lifecycle activity (i.e., design, production and maintenance), as illustrated in Figure 7. Again, only small differences can be identified between the management of defence and defence industry within the ADF regulatory framework. These differences primarily lie within Production (3 and 9 o’clock positions, Figure 7). All local production is performed under the auspices of the design organisations. While larger scale production (including whole of aircraft during acquisition) is normally overseen outside of the ADF regulatory framework by other competent production oversight agencies engaged through contract. Importantly, they are not introduced into the regulatory framework. No such mechanism for approved production organisations exists within the ADF regulatory framework. This is normally carried out by other MAAs, such as the US Air Force (e.g., for the F-35), US Navy (e.g., for the P-8), the US Army (e.g., for the CH-47F) or Spanish Military DGAM (e.g., for the KC-30A). For this reason, among many
others\textsuperscript{(12)}, the ADF is interested in recognising the competence of these MAAs, hoping to provide a more efficient mechanism for attaining airworthiness certification in Australia.

An identifiable positive of the ADF technical regulatory framework is the technical regulatory interaction with design, both for defence and defence industry. These interactions are represented through the number of scores outside the purple line (scores greater than three) within the design segments for defence and defence industry. The ADF MAA’s only other interaction is with maintenance management plans (process integrity). Further, as discussed in Section 4, the PBP Bow-Tie also captures supply. This is represented by the TP8.6 (i.e. TP1.6 is supplied product acceptability during design, TP8.6 is supply processes during production, etc.) in each segment; importantly there is no regulator interaction with supply within the ADF technical regulatory framework.

![Figure 7: The ADF Iris plot symmetrical comparison grouped by technical activity. Compared this way the small sub-regulator differences appear for Production within the ADF.](image)

**Qualitative analysis of the US Army airworthiness framework**

The US Army derive their airworthiness authority through the 10\textsuperscript{th} United States Code\textsuperscript{(27)}. The airworthiness construct of the US Army is complex, with the key appointments of the US Army airworthiness framework assigned through their key airworthiness document\textsuperscript{(28)}, but the organisations enacting that authority delegated through charter. The Aviation Engineering Directorate (AED) is the primary technical airworthiness authority for the US Army and is responsible for the airworthiness qualification of US Army Aviation assets. The AED develop and maintain a series of Aeronautical Design Standards that outline the requirements for aircraft qualification and these, along with procedures, provide the documentation framework for all design work undertaken by the AED. The AED are also included in maintenance and training decisions, which may require determination of impact on
airworthiness. In contrast to the ADF, the US Army does not issue organisational approvals. Therefore it has no repeatable mechanism for including defence industry into the airworthiness management framework. The US Army utilises several other US DOD agencies to manage and provide oversight of certain components of their technical regulatory framework.

A PBP Bow-Tie analysis of the US Army airworthiness was undertaken and the results visualised using the Iris plots presented in Figure 8 and Figure 9. The first Iris plot for the US Army, grouped by integrity line, is shown in Figure 8. It is immediately quantifiable that there are regulatory differences for defence and defence industry within the US Army technical regulatory framework. Some of them are easily explained and subsequently offer little uncertainty. Other areas of difference arise due to the derivation of the airworthiness framework, and warrant further exploration. All framework differences are extracted and acknowledged within the PBP Bow-Tie assessment and subsequent Iris plots, explained below.

![Iris plot](image.png)

Figure 8: The US Army Iris plot grouped by integrity line. It is immediately quantifiable that the US Army does not apply symmetrical oversight of Defence and Defence Industry.

It can be seen in Figure 8, defence tends to focus heavily on product, whilst defence industry tends to focus heavily on process. This interaction occurs in two different organisations and will be examined in detail later. It is immediately reconcilable that there is greater regulator interaction with defence. This appearance is mainly from the lack of scores for design, which is better highlighted in Figure 9, where the Iris plot is presented by technical lifecycle activity. The US Army MAA provides stringent product requirements and maintains a heavy interaction with the design and production activities. This interaction assures product integrity within these technical activities under the US Army technical regulatory framework.
With the Iris plot grouped by lifecycle activity, shown in Figure 9, the fact that there is no defence industry design integrated into the US Army technical regulatory framework is evident. The reason for this is that within the US Army framework there is no defence industry design organisations allowed to approve designs. All designs are approved by the AED before incorporation onto primary US Army Aviation assets. While this lack of scoring appears to indicate a deficiency in the technical regulatory framework, the fact that the AED operates as the final approval authority before the airworthiness or performance qualification of the asset is modified, means that it is not actually a deficiency. It is more of a trait of the US Army technical regulatory framework, something that is common to both the US Army and US Navy within the US DOD.

A key component that is not differentiated pictorially is that there are two primary independent bodies performing the role of the internal regulator (scores of four) for the US Army. The US Army authority has limited interaction with the setting or checking of standards for defence industry, with their only role in providing oversight of maintenance standards. It is the role of the Defence Contract Management Agency (DCMA) to provide oversight of contracted agencies. DCMA oversight powers are enabled through contract law to enforce the quality requirements upon the organisation. Maintenance in defence industry is enabled through contracts to Federal Aviation Administration (FAA, scores of five) approved maintenance organisations. The defence industry maintenance work is mainly on civil-derivative aircraft, and is managed by the DCMA, but regulated and oversighted by the FAA. There is a strong reliance on the US Army Major Command organisations to manage their maintenance functions, an airworthiness disconnection with maintenance.

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b Defence industry may develop designs, particularly the Original Equipment Manufacturer, but the US Army holds the final approval.
The analysis has revealed the complexities of the interaction of the regulatory authority and defence industry. Due to this complexity, there is a strong requirement for effective communication between organisations. The US Army technical regulatory framework may be ineffective in situations where there is insufficient communication of issues and interactions between organisations. Comparison of the ADF and US Army technical airworthiness regulatory frameworks
The ADF and US Army technical airworthiness regulatory frameworks analysis using the PBP Bow-Tie approach and the resulting visualisations were compared to identify differences. Both frameworks have no known compliance to the EMARs but are required to utilise the EMAD-R process. The comparison will detail how the PBP Bow-Tie has helped identify the areas for focus during a MARQ exchange. To facilitate this comparison an Iris plot was generated that symmetrically compared the ADF and US Army for defence and defence industry. These Iris plots are shown in Figure 10 and Figure 11, Figure 11: A symmetrical comparison of the ADF and US Army. (a) Highlights the attestation differences for Defence. (b) The symmetrical comparison for Defence Industry with the comparison for defence (a) shown above and defence industry (b) below is grouped by integrity line. Importantly, there is no new information presented in these Iris plots, for greater clarity on the individual test point scores, refer to the Iris plots shown in Figure 6 to Figure 9. The symmetrical comparison allows for easy quantification of the implementation differences.
Figure 10: A symmetrical comparison of the ADF and US Army. (a) Highlights the attestation differences for Defence. (b) The symmetrical comparison for Defence Industry. This comparison is grouped by integrity line.

The first identified difference between frameworks requiring consideration is the differences in delegation of engineering authority. The ADF utilises organisational approval and personnel authorisations to manage the technical airworthiness of ADF aviation assets. There are formal delegations of the responsibilities down to suitably competent, qualified and experienced personnel within design
organisations. This person is responsible for approving and accepting designs and providing approved maintenance data for the maintenance of each aviation platform. This can be seen for the scores of three throughout the ADF Iris plots were there are scores of three (equal with the purple ring). Conversely, for the US Army, all engineering authority is retained within the AED. This is reflected in the lack of independence for attestations for design behavioural integrity for the US Army (Figure 10 (a)). This difference can also be observed in the high degree of US Army MAA interaction with defence and defence industry for product integrity in design and production (Figure 10 (a) and (b)). The ADF regulator carefully examines the design and maintenance processes in their expositions, or management plans. This provides a mechanism for conformance audits. Within the US Army, the independence of the checks on the design process is diminished due to the designs being produced from within the regulator. This is evident in Figure 12 (a) where the ADF regulator maintains control over process requirements; conversely, the US Army regulator has little interaction for process. The US Army relies on command surveys on maintenance and operations with trend data reported back. There is little direct regulator interaction.

A number of differences and issues can also be identified though examination of the analysis by integrity, Figure 10. Firstly, the US Army regulator, although split between two primary organisations, maintains tight control over product integrity during design and production for defence and defence industry (highlighted by the regulatory scores of four for product integrity for US Army in Figure 12(a)). However, the US Army regulator does not tightly control maintenance beyond engineering related data for defence (most scores of four outside of product integrity are for attestations made by independent training organisations or the DCMA). Instead technical airworthiness within maintenance is the responsibility of the command units. But, in Figure 12(b) it is shown that the FAA (scores of five) and DCMA (scores of four) interact with defence industry maintenance. The US Army does not have symmetrical interaction with defence and defence industry, and there are a series of organisations that perform regulatory roles within the US Army technical regulatory framework.

Conversely, comparing this to the Iris plot for the ADF regulatory framework, it can be observed that the ADF MAA relies on organisational approvals as an entry control, and subsequent conformance audits of their management plans to assure the design and maintenance integrity (indicated by regulator interaction within process integrity for design and maintenance). This is evident in the process integrity grouping of Figure 10 (a) and (b). In contrast to the US Army (Figure 10), the ADF does have a largely symmetrical and consistent interaction with defence and defence industry. Figure 11 illustrates a comparison when grouped by technical activity.
When examining by technical activity, it can be seen that the ADF regulator has the strongest interaction with activities in design. The ADF regulatory framework has evolved this way, with regulations on design preceding those for maintenance by some time. It is also clear that production is not within the regulator’s oversight. Again, the regulator interaction does not discern between defence and defence industry for organisations performing design and maintenance within the ADF technical regulatory framework. The
US Army relies on a series of regulatory organisations to provide regulator interaction throughout the technical item lifecycle, with the US Army technical authority and training organisations proving the regulatory interaction for defence, and DCMA and the FAA providing it for defence industry. Despite the absence of scores for design for defence industry, the US Army has more regulator interaction throughout the technical item lifecycle.

Conclusions drawn from the analysis of the technical item lifecycle shows that the Australian Defence Force does not need to interrogate US Army certification in relation to design attestations for defence industry, as the US Army technical authority (the AED) provide all design approvals. Similarly, it is now immediately apparent which of the regulatory organisations (e.g., the AED or DCMA or the independent training organisations) provide the interaction during each lifecycle activity for defence and defence industry. However, the ADF may need to communicate with the command units to gain confidence with the system of maintenance for defence, understanding that the US Army technical authority does not interact heavily with that activity.

The US Army should interrogate the ADF regulator for information pertaining to design standards, but not request production oversight. The significant difference for the US Army to comprehend is in relation to the concept of organisational approvals. Once the organisational approval is understood, the US Army can have confidence in the setting of standards for maintenance and that the regulator is continually checking for deficiencies. It is also important to note that the ADF regulator performs compliance audits against the regulatory framework and assurances that an approved organisation is conforming to defined expositions/management plans. This concept is different to the US Army approach and will require examination by the US Army. Further, it was highlighted that the Iris plot scores of three for the ADF were derived from delegated authority. Thus, if the US Army requires platform specific information, they will need to open dialogue with the delegated authority for that platform.

**Areas of Focus for Recognition**

The application of the PBP Bow-Tie approach and its visualisation through the use of Iris plots provide a simple mechanism for representing, comprehending and comparing disparate regulatory frameworks for the purpose of inter-agency recognition.

The Bow-Tie has established a baseline for each framework, not based on the compliance to the EMARs, but on the regulatory organisations interaction with the technical regulatory framework. The analysis and comparisons have highlighted that during recognition the Australian Defence Force needs to examine the US Army’s assurance of maintenance, particularly conformance auditing, and interrogate the mechanisms for assuring the design process due to a lack of independence. Further, the Australian Defence Force needs to understand the complex interaction of the multiple US DOD organisations employed in oversight of the US Army technical regulatory framework. This would mean that the Australian Defence Force would primarily focus on the US Army MARQ for the airworthiness authority and for aircraft inspection, while still assessing US Army aircraft certification and production oversight.

The US should thoroughly critique Australia’s production requirements if production oversight is sought. The US Army can gain an understanding of interactions with design and maintenance based on comprehension of the organisational approval process. Greater insight can be gained through a comparison of individual test points, particularly for those regulatory activities where there is a difference in the test point independence scores of greater than two or where only one test point indicates regulator interaction. This would mean the US Army should focus on the Australian Defence Force MARQ for airworthiness authority and inspection with some interrogation of aircraft certification and an intensive examination on production, but only if it is deemed necessary and within the required scope of recognition.
Through the utilisation of the PBP Bow-Tie the differences and motivations, or reasons, for those differences have been identified and characterised. The outcome provides a platform for recognition that will enable the Australian Defence Force and US Army to overcome the regulatory framework uncertainty established through utilisation of the EMAD-R process. Now, during the next joint operation or training exercise, the US Army can assure the US Senate that US DOD personnel flying on Australian military aircraft are doing so at an equivalent level of safety to that of a flight on a comparable US military aircraft. While the Australian Defence Force can identify mechanisms for leveraging off US Army technical authority design attestations, and DCMA oversight of production for the S-70A Blackhawk and CH-47 Chinook platforms while gaining a similar appreciation of the level of safety. These are some examples of potential benefits that the two militaries can expect after successful recognition built on the platform established by the PBP Bow-Tie.

**Conclusion**

It has been stated that the MARQ exchange does not provide a pass/fail test rather it is used to paint a picture of an Authorities organisation, policy and regulation\(^{(13)}\). For MAAs without a known compliance to the EMARs, and who are required to use the EMAD-R process (e.g., ADF, NZDF, US DOD, Canadian DND), the MARQ is the only platform available to make an assessment of the competence of another MAA and the strength of its safety oversight. This is the situation for ASIC Nations. The UK has proposed a process for External Recognition (as it is labelled within the EMAD-R) in their recognition of the US Army. They have named it the NATO method and, in short, it excludes the critical step of establishing a common baseline\(^{(8)}\). This means that the only formal information exchange is the MARQ, which does not provide an understanding of the regulatory structure or regulator interaction with the design production or maintenance. While the UK MAA and US Army have experienced success with this method, the process required greater reliance on gathered evidence to support the MARQ. An alternative is the PBP Bow-Tie approach developed in this paper. The approach is quick and easy to complete and provides a comprehensive and systematic means of representing the subtle differences between airworthiness regulatory frameworks. The visualisation of the results, through the novel use of Iris plots, provides a powerful method of displaying and comparing regulator interaction\(^{(17)}\). If used to complement the EMAD-R process, the amount of uncertainty in the judgment required by the recognising MAA is reduced. It does not replace the MARQ assessment process but serves to complement it.

The application of the PBP Bow-Tie approach to the case-study comparison of the ADF and US Army regulatory frameworks highlights these advantages. The recognition effort between the Australian Defence Force and the US Army has been scoped and justified utilising the PBP Bow-Tie. Important technical regulatory framework implementation differences were highlighted and categorised. The interaction of the regulatory organisations with design production and maintenance provided by the PBP Bow-Tie serves to complement the MARQ. The MARQ provides evidence towards an assessment of the competence of a MAA. The MARQ question set also identifies the airworthiness instruments, inspection and certification intricacies not fully extracted from the PBP Bow-Tie.

The information presented in this paper will be tested for recognition between the two countries in the near future, and some improvements or modifications may be required. However, the platform for recognition established by the PBP Bow-Tie establishes a regulatory baseline for recognition. This is required by the EMAD-R process and is absent for uncommon regulatory implementations. Future research will establish an assessment of the EMARs (once they are fully developed, noting that each country may implement them in different ways). This assessment will provide a comparison tool for identification of areas offering challenges for militaries considering adoption of the EMARs.

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References
12. L. Purton and K. Kouroussis, "Military airworthiness management frameworks: a critical review," Procedia Engineering, Accepted manuscript - article in press.
15. Woodside, "Technical Integrity / Process Safety; what is it?" Presentation to NOPSEMA forum by Woodside (Mary Hackett), February, 2008.