APPLICATION OF MILITARY AIRCRAFT STORES COMPATIBILITY IN THE CIVILIAN AIRWORTHINESS REGULATORY ENVIRONMENT

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ABSTRACT

The paper discusses the application of the military aircraft stores compatibility modelling and simulation, experimentation, test & evaluation (ET&E) and certification methodology in the Australian civilian airworthiness regulatory environment with Search and Rescue stores from the Challenger 604 aircraft for the Australian Maritime Safety Authority.

INTRODUCTION

Over the past quarter of a century, the US Air Force, Army and Navy, Royal Australian Air Force (RAAF), and Royal Canadian Air Force, amongst others primarily in Europe, have made concerted efforts to accelerate the validation and verification necessary to enable the insertion of the latest scientific and engineering approaches into the aircraft stores compatibility modelling and simulation, experimentation, test & evaluation (T&E) and certification methods. There have been numerous organised international fora and conferences for this purpose using the American Institute of Aeronautics and Astronautics (AIAA), International Test & Evaluation (T&E) Association (ITEA), the US Joint Ordnance Commander Group (JOCG), the Five Eyes (Australia, Canada, New Zealand, UK and US) Air Standardization Coordinating Committee (ASCC) for Air Armament, The Technical Cooperation Program (TTCP) and the NATO Science and Technology Organisation (STO).

The Australian Maritime Safety Authority (AMSA) plans to replace Dornier 328 turboprops with Bombardier Challenger 604 special mission jets modified for Search and Rescue (SAR). Similarly, configured CL-604 Multi-Mission Aircraft are in service with the Royal Danish Air Force.
There are several aircraft stores compatibility challenges posed by replacing a turboprop aircraft with a turbojet covering spectrum of carriage and especially employment of the SAR stores. For the Dornier 328 the rear cargo door used for store separation is well clear of the engine, Figure 1a. For the Challenger 604 its just underneath the nacelle, Figure 1b. In addition, the minimal airspeed at which the 604 can release stores is higher.

Figure 1a: AMSA Dornier 328 Turboprop.

Figure 1b: AMSA Challenger 604.

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Unlike military aircraft, the company undertaking the testing and certification of the Challenger 604 SAR aircraft for AMSA did not plan to use wind tunnel testing, Computational Fluid Dynamics (CFD) nor Six Degree-of-Freedom (SDOF) trajectory simulations for assessing the stores separation prior to design of the delivery chute and flight testing. This might have been since the released stores were relatively light weight, the airspeeds low, and incidental contact with the aircraft unlikely to cause significant damage at low airspeeds. Furthermore, the company consciously decided not to procure previous certification artefacts and aerodynamic data to establish provenance.

The Civil Aviation Safety Authority (CASA) is responsible for civilian airworthiness standards and type certification for all Australian civil registered aircraft. CASA confirmed that the certification basis of the Challenger 604 under US FAR 25 was suitable but requested that the company undertaking the type certification for AMSA and CASA receive technical advice by several of the authors on the proposed test planning and execution for the SAR stores carriage and employment.

AIM

The aim of this paper is to discuss the application of the military aircraft stores compatibility modelling and simulation, experimentation, test & evaluation (T&E) and certification methodology in the Australian civil airworthiness regulatory environment using the Bombardier Challenger 604 special mission jets modified for SAR as a case study.

BACKGROUND

Traditionally the Five Eyes and many NATO nations have used [MIL-STD-1763 1984] and [MIL-HDBK-1763, 1998] / [MIL-HDBK-244A, 1990], NATO [STANAG 7068, 2001] and Science and Technology Organisation (STO) [AGARDOgraph 300 Vol 29, 2014] as the basis for conducting modelling and simulation (M&S), laboratory qualification wind tunnel tests prior to ground and flight experimentation, and T&E to establish the certification basis for the military aircraft stores configuration[i] to be operationally suitable and effective to perform testing, training and conduct operations.

The assessment of aircraft stores compatibility[ii] includes an engineering review of the following disciplines for each aircraft stores combination required to determine if a ‘significant change’ (as defined in MIL-HDBK-1763)[iii] is made to an aircraft stores configuration in the areas of the physical (Land (including sub-surface), air, space, sea (including sub-surface) and information domains of war[iv] where the military effects are to be achieve and their safety, operational suitability cognitive and social, and effectiveness, [Tutty etal, 2015]:

I. Function;
II. Form and Fit;
III. Structural & Environmental;
IV. Aeroelasticity;
V. Captive Carriage, Handling/Flying Qualities & Performance;
VI. Employment & Jettison;
VII. Information Suitability: External Interfaces, Mission Planning, Ballistics and OFP Validation & Verification, Safe Escape & Danger Areas (Safety Templates);
VIII. Cognitive Suitability: Procedures, Tactics, Techniques and Procedures and Human Factors;
IX. Emergent Properties for Critical Operational/Technical Issues / Measures of Suitability/Effectiveness: Experimentation and T&E.

Aircraft Stores Compatibility Engineering Review

The aircraft stores compatibility engineering review is most important for establishing such a degree of interoperability i.e. compatibility and assessing interchangeability should commonality of doctrine, equipment or processes not be agreed. Use of the ‘significant change’ criteria in MIL-HDBK-1763 now gives the design engineers and operational users some tolerances that enable minor changes to be progressed without the huge systemic and organisational overheads of traditional ‘point design’ engineering done without interchangeability and prior thinking in mind. Use of such methodologies clearly shows the maturity of any organisation’s processes and leadership.

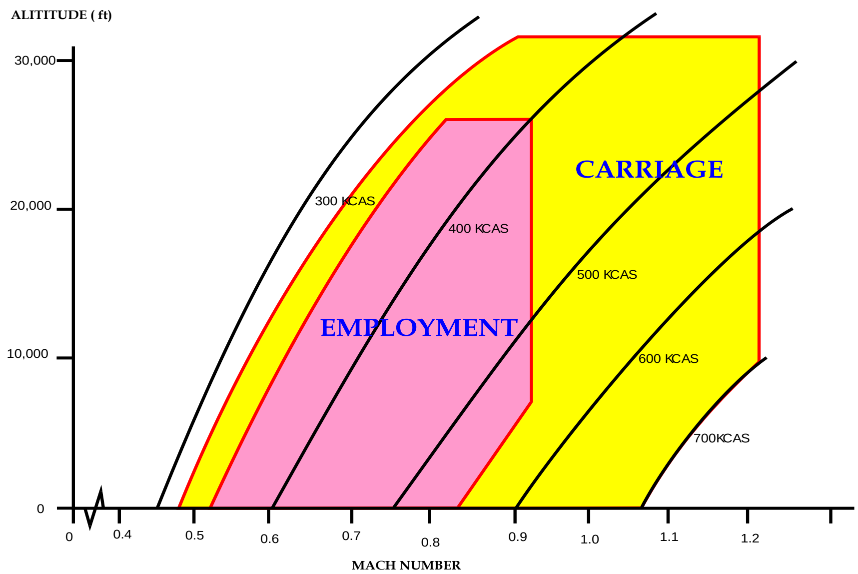


Figure 2: An Aircraft Stores Configuration Operating Limitation for Carriage and Employment (Jettison not shown here).

Depending on the *maturity* of the stores and/or aircraft, there are four separate compatibility situations involved when authorization of a store on an aircraft is required. The four situations, in order of increasing risk, are:

- Adding 'old' in-service stores to the authorised stores list of 'old' aircraft.
- Adding 'old' stores to the authorised stores list of a 'new' aircraft.
- Adding 'new' stores to the authorised stores list of an 'old' aircraft, or adding new aircraft stores configurations and/or expanding the flight operating envelope.[v] [vi]
- Adding 'new' or modified stores to the authorised stores list of 'new' or modified aircraft.

The assessment of aircraft stores compatibility will determine the operating limitations that will then be used by the aircrew in their Flight Manuals, as shown at Figure 2. The aircraft stores configurations and expected operating limitations are always included in a good Concept of Operations (Conops) as they may not need to be the maximum that the aircraft and stores can achieve (i.e., Parent pylon versus multiple ejector rack configurations typically will have different limits). For more mature aircraft and/or stores, and consequently those with less risk, the process is specifically tailored against the Conops such that only those phases required to be conducted to introduce the store into service need to be undertaken. For example, if all the aircraft stores configurations have been successfully demonstrated or certified by known Experimentation, T&E and (airworthiness) certification agencies to operating limits that satisfy the User' s Operational Requirement, an aircraft stores combination could be introduced directly into service with minimal risk. While this strategy has been extremely successful in minimising the work with specific aircraft stores configuration in an acquisition process that is platform-centric, it is often thought less successful when viewed in the context of designing interchangeable stores on fewer platform types. This warrants investment in trade-off studies to determine future Armament Integration Mission Environment needs and often a capability realisation plan/strategy with specific interoperability (covering the systems / System of Systems / Families of SoS, their operating limits **and** the levels i.e., compatible versus interchangeable or common) requirements in mind that meets both national and NATO/Five Eyes needs, [Tutty, 2016].

Military Type Certification approval. The agency requesting aircraft stores certification is always as specific as possible as to their requirements in each of the areas above to assist the certification agencies in establishing the criteria to be used in the clearance[vii] and certification effort. Through the initial certification request and, if necessary, subsequent follow-ups, the certification agencies will determine the appropriate criteria to be applied to the specific store certification program. These criteria will include (but not be limited to) essential and desired aircraft stores configurations (including any mixed load configurations) and the essential and desired operating limitations such as: carriage speeds and accelerations, dive (or climb) release angle, release modes, speeds, intervals and accelerations, selective and emergency jettison speeds, accelerations, flight path angles, and required levels of accuracy, etc., as required for the aircraft stores combination to be operationally effective. Formal approval for certification of an aircraft-store/suspension equipment configuration is accomplished through publication of operational data in appropriate technical manuals. These are:

-1 Operators/Flight Manual (NATOPS/NATIPS)
-2 System Preparation / Maintenance Manual (-2 and -32 Technical Manual/Orders)
-3 Systems Loading Manual (-33 Technical Manual/Orders)
-4 Tactics Manual (TTPs) (-34 Technical Manual/Orders)
-5 Mission Planning Tools (at Domain or Enterprise LISI level)
- Other Joint-Service Technical Data publications (EOD etc)

Predicting safe and acceptable aircraft stores separation trajectories. As noted by [Tutty etal, 2015] and [Tutty, 2016], MIL-HDBK-1763, STANAG 7068 etal, predicting accurate store separation trajectories on today's high speed aircraft under the varying conditions of altitude, Mach number, flight path angle, load factor, and other factors related to delivery techniques (particularly where multiple carriage of stores is involved), is an extremely difficult task, requiring a skilled and experienced analyst. Several techniques are available for store separation analysis, and these are documented throughout the scientific literature. There are well proven wind tunnel and Computational Fluid Dynamic (CFD) M&S experiences that have supported advanced weapon development and integration. Most Five Eyes and NATO nations use a variety of unique CFD codes to augment wind tunnel testing. These techniques have been extensively validated for external store separation. During the past decade, various AIAA Challenges have seen great progress and the US, under the auspices of the DoD High Performance Computing (HPC) Modernization Program Office have combined each of the Services' initiatives to establish an Institute for HPC Applications to Air Armament which has included key NATO and Five Eyes nations. Some are purely analytical in nature, utilising theoretical aerodynamics and complex mathematical manipulation and analyst interpretation. Others utilise wind tunnel testing of small scale models of the store and aircraft, while still others involve a combination of theoretical and wind tunnel data, utilising a high speed digital computer for data reduction. Wind tunnel test data for store separation may be obtained from one, or a combination of, the following:

a. **Captive trajectory.** This test uses a strain gauge balance within the separating store to continually measure the forces and moments acting on the store. An on-line computer simulation determines successive positions of the store through its trajectory.

b. **Grid data.** An instrumented store or pressure probe is used to measure the forces and moments acting on the store in the flowfield through which the store must separate. Trajectories are calculated off-line using this information as inputs to a trajectory program.

c. **Dynamic drop.** The dynamic drop tests use dynamically scaled models that are physically separated in the wind tunnel. Data can either be photographical or telemetry. (This method is generally limited to simulated level flight releases only.)

d. **Carriage loads.** In this test forces and moments are measured on the store, with the store or weapon attached to the aircraft in its correct carriage position. These data are used as inputs to trajectory computation programs.

No single technique will suffice for all cases. Rather, the analyst must examine the particular case to be analysed and select the technique that, in his opinion, offers the most advantages for his particular situation. Most purely theoretical techniques available today suffer severe degradation when applied to transonic store separation, or where multiple stores carriage is involved.

[Tutty, 2016] and [STANAG 7068, 2014] goes into more detail.

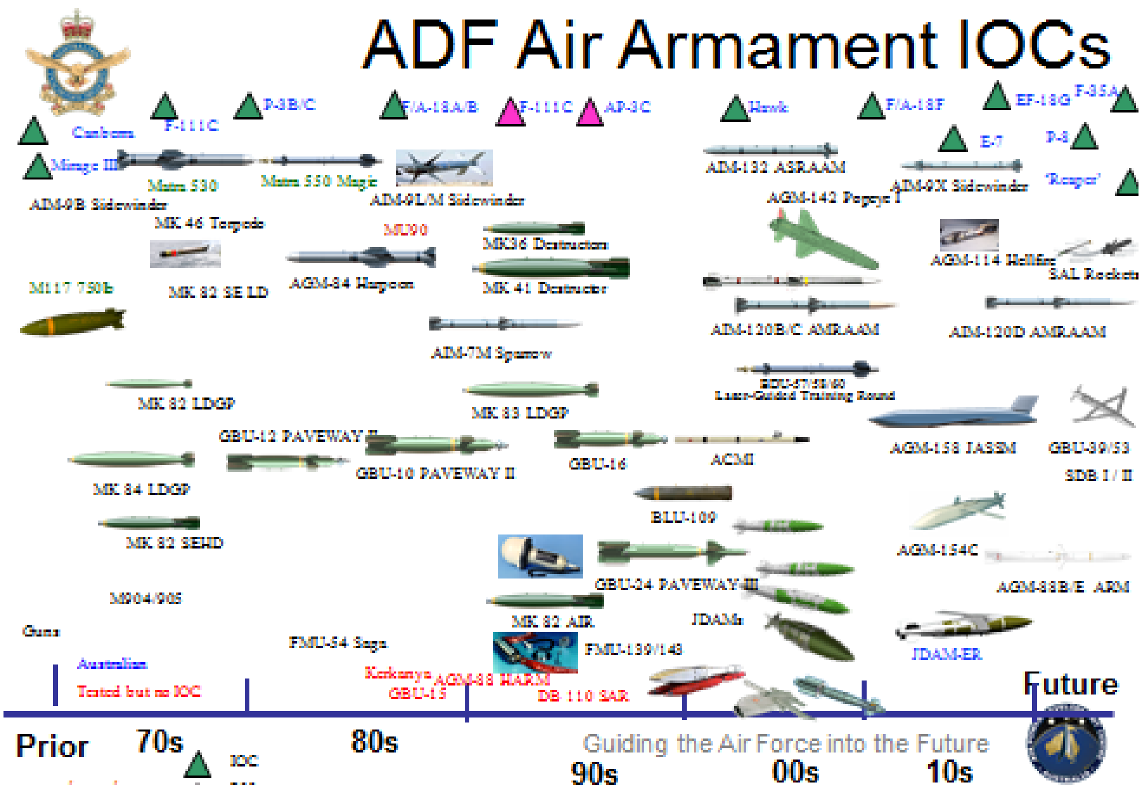


Figure 3. Australian Defence Force Air Armament Initial Operational Capabilities

MILITARY CASE STUDIES

Air Forces have come a long way from the traditional 'dumb weapons' that saw Australia primarily employing unguided weapons in Vietnam from the Canberra and UH-1 Iroquois for example. Furthermore, unguided weapons and dated air-to-air guided weapons were also used by the RAAF on the Mirage III and the analogue F-111C well into the 1980s. Since then there has been a significant transformation in air armament capabilities as shown in Figure 3.

The introduction of a range of semi-active guided weapons on the F/A-18 Hornet enabled the weapons on the digitised F-111C to be made more interoperable. This significantly enhanced level of interoperability was a major step forward in Air Force's options for successfully executing the 'kill chain': the Find, Fix, Track, Target, Engage, Assess (F2T2EA) process used in the munitions effectiveness targeteering and weaponeering. Weapons interoperability was made possible through the long-term engagement with the US, Mutual Weapons Development and Air Standardisation Agreements, and advances with aircraft stores compatibility amongst allied nations.

Over this period, the mission reliability of air armament was also universally improved from under 50 percent to over 95 percent across the diverse aircraft platforms using breakthroughs in our understanding and the modelling and simulation of a range of factors: aerodynamics, structures, the thermal, vibration and aeroacoustic environments, electrical/electromagnetics, computational fluid dynamics with carriage and separations, functional digital systems use of ballistics/safe escape/weapons danger areas, and electronic fuzes with munitions effectiveness at the systems level. Figure 3 shows this fundamental transformation in air powers ability in Australia to achieve the required effects in the joint space. One of the most significant joint trials involved improving internal weapons bays carriage environment and seeking better ways to secure safe separation (employment and jettison).

Analysis of the acoustic suppression, active separation control and release of miniature munitions from RAAF F-111 aircraft. With the advent of the F-35 Lightning II JSF, P-8 Poseidon, and concepts for future Remote Piloted Aircraft / UCAVs, all designed with internal weapons carriage, forward-looking US and Five Eyes research programs focused on the understanding of the complex aerodynamics and aeroacoustics of weapons bays. The RAAF was still operating the F-111, and the Australian – US collaborators saw opportunities to use a flight-test F-111 to investigate the phenomenology of cavity flows with the Small Smart Bomb (the precursor to the GBU-39/53 Small Diameter Bombs (SDB)) in 2001 as reported in [Tutty etal, 2015]. In 2005 such work was further extended significantly with the more complex Powered Low Cost Autonomous Attack System (PLOCAAS) shapes being ejected from a Boeing pneumatic ejector rack using active separations control at [Tutty etal, 2016] as shown at Figure 4. See [Tutty etal 2015] for further details.

Figure 4: F-111 Weapon bay with miniature munitions (PLOCAAS) and ASRAAM in-flight. © AOSG-RAAF

Acquisition of the AIM-120 AMRAAM and AIM-132 ASRAAM brought in a new era of air-to-air capabilities that were complimented with GPS-aided JDAMs and greater air-to-surface stand-off with AGM-142 Popeye I, AGM-154 JSOW and AGM-158 JASSM in the 1990/2000s. More recently the AGM-88B/E HARM and AARGM acquisitions have finally brought an anti-radiation capability first sought for the ADF in the 1980s and both variants of the GBU-39/53 SDB will also be acquired for the F-35 JSF and F/A-18F Superhornet / EA-18G Growler aircrafts.

RAAF changes to ASC clearance methods and certification. Prior to the ACFD II challenge there had been some skepticism as to the ability of CFD to contribute meaningfully to the store separation clearance process at meaningful airspeeds. In Australia CFD had been successfully used in the late 1990s to clear the current Mk65 mine from AP-3C aircraft for mine trials as shown at Figure 5. This was more to validate the USN flight clearance against the current aircraft and weapon types rather than ab initio effort. The fact that ACFD II was a blind test and still gave good results established confidence in the CFD methods within the Australian stores clearance community. This led to greater acceptance and use of CFD for RAAF stores integration projects including the F-111C integration of GBU-24 and AGM-142 missile, also shown at Figure 5. Another example of which is the integration of the AGM-158 JASSM on the RAAF F/A-18A/B, [Akroyd, 2010].

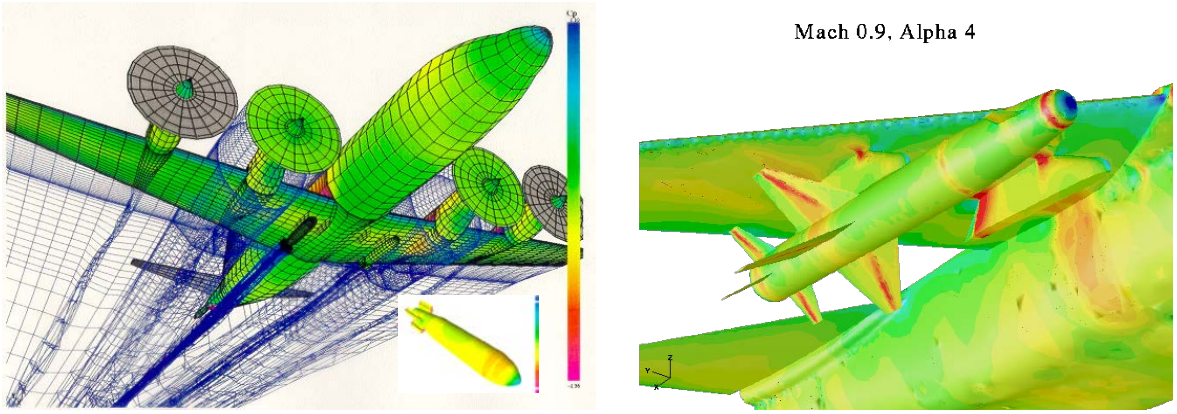


Figure 5: DSTO - RAAF AP-3C / Mk 65 mine and F-111C AGM-142 missile carriage and separation using DSTO CFD

The small size of the Australian transonic wind tunnel at DSTO Melbourne drives the use of half aircraft models for stores integration testing. Data from this arrangement has been consistently proven to be of high quality but obviously suffers from an inability to measure the effects of sideslip and effects on whole aircraft configurations. Furthermore, the maximum Mach that can be achieved in the tunnel is limited to just over Mach 1.1 for practical aircraft stores configurations. CFD has been used to augment the wind tunnel data by filling in the 'gaps' in wind tunnel data.

Figure 6: F/A-18 A/D AGM-158 JASSM CFD.

The AGM-158 presented a significant integration challenge. This is a large missile of non-circular cross section with highly non linear aerodynamic characteristics and is asymmetric due to the upper fin folded to one side for carriage. It is also initially very unstable and requires the upper fin to deploy and wings to be partially deployed very early to achieve a level of stability during separation. On the RAAF F/A-18 the primary carriage configuration is on the outboard wing pylons with External Fuel Tanks on inboard wing stations. The proximity of the EFTs causes significant aerodynamic interference effects and represents a collision risk for deploying fin and wings as shown at Figure 6 and 7.

Figure 7: RAAF flight test F/A-18 Hornet with AGM-158 JASSM. © AOSG- RAAF

Grid loads were generated for the missile in several stages of wing and fin deployment using the half aircraft model in the DSTO Transonic wind tunnel. By testing the store model configured with the upper fin folded to left and also to the right side the effect of the store asymmetry could be accommodated in the tunnel data. However the effect of sideslip for the potentially sensitive and risky separation next to the EFT could not be determined in the wind tunnel with a half aircraft model. To overcome this deficiency, CFD was used to provide the incremental effects of sideslip on the carriage and grid loads at Figure 7.

The hybrid use of wind tunnel data supplemented by CFD proved to be very effective and culminated in a series of successful flight tests, [Drobik and Tutty, 2012] and [Tutty etal, 2015].

FUTURE ARMAMENT SYSTEMS COMPATIBILITY APPROACHES

The previous sections have used a number of examples to illustrate many Australian, UK, Canadian and US collaborative programs that have helped all partners build techniques and tools and issue clearances. Progress with digital communication protocols and data-links now provides the opportunity to network-enable many of our newest weapons at the cross-system or system-of-system level: that is the platform aircraft stores configurations are now no longer isolated from the rest of the (increasingly) ‘small-world’. Future weapons clearances will take place in a more complex, network-centric-warfare space will add complexity to the currently stove-piped process; hence, a framework will be required. This will address in particular the network-enabled operations between systems that at the time of the release of [MIL-HDBK-1763 1998] was not required. The NATO Air Launched Weapons Integration study at [NAFAG ALWI II, 2004] recommended that a NATO STANAG be developed over the next 10–20 years to improve the reusability of aircraft-stores-certification criteria and to streamline the approaches used. [Tutty, 2016] proposes that such a STANAG be based on V&V of a NATO ‘CODe of practice for Experimentation’ (CODEx) for the testing of joint fires operational capabilities[viii] in a new Joint fires Armament Integrated Mission Environment’ with ‘network-centric complex, adaptive mission capabilities’ employing both kinetic (weapons), non-kinetic (electromagnetic) directed energy and cyber effects could assist in this, based on the successes with the use of [MIL-HDBK-1763, 1998] for what are considered simple and complicated[ix] ASC Flight Clearance and certifications in today’s language.

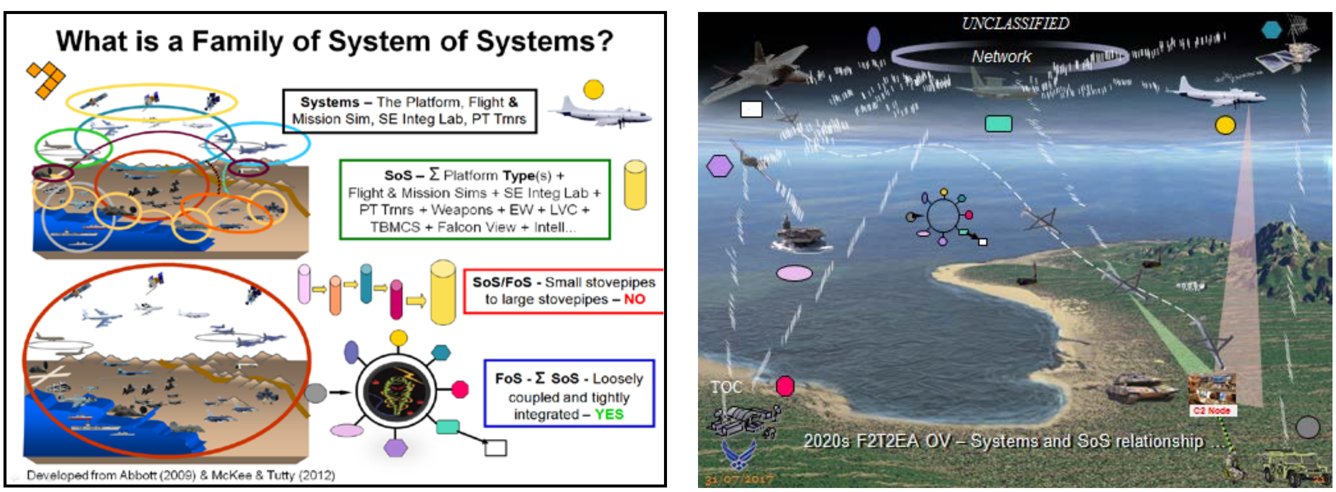


Figure 8: Systems, systems of systems (SoS), and family of SoS (FoS) Operational Views

Research using grounded theory and case studies investigated use of MIL-HDBK-1763, the TTCP GUIDE to Experimentation at [GUIDEx, 2006] and as a result the [STANAG 7068 2014] has been proposed by [McKee and Tutty, 2012] and [Tutty, 2016] as a disclosure draft for further development by NATO STO. The research was conducted in collaboration with over 300 Five Eyes and NATO STO members and other subject-matters experts. As part of that effort, [McKee and Tutty, 2012] reported on the current methods used nationally and internationally for capability preparedness/management, systems-engineering, T&E and project-management practices. They identified the key elements that will increase the confidence in future military capabilities being operationally suitable and effective that are evidence-based and scientifically defensible.

	Capability Preparedness Levels: Operations & Safety Criticality with Mission Confidence γ for Operational Commanders	A	B	C	γ
0	No identified capability, basic principles conceptualised and studies initiated. Capability development being proposed.	1σ	50	20	50
1	Basic principle observed and reported. Studies or initial investigations undertaken. Capability development initiated.				
2	Technology concept and/or application formulated. Potential applications have been identified.	2σ	1σ	50	70
3	Analytical and experimental critical function and/or characteristic proof of concept. R&D has been initiated, work towards validating the concept done. Capability is Managed.				
4	Component and/or breadboard validation in lab environment. The basic elements of the Capability (SoS/Major system/product) have been integrated to show they will work.	3σ	2σ	1σ	90
5	Capability SoS/Major systems and/or components/breadboard validation in relevant environment. A higher fidelity validation of the Capability in a realistic environment. Capability is Defined.				
6	Capability SoS model or prototype demonstration in a relevant / realistic environment.	4σ	3σ	2σ	95
7	Capability SoS prototype demonstration in operational environment with representative personnel and C2 iaw Conops. 'Production' can now commence. Capability is being Quantifiably Managed.				
8	Actual Capability SoS completed and mission qualified through test and demonstration with operational personnel and C2. Actual Capability SoS has been successfully tested, qualified and certified iaw Conops.	5σ	4σ	3σ	99
9	Actual Capability SoS proven through successful mission operations with operational personnel and logistics support. Actual Capability SoS has been successfully fielded.	6σ	$> 4\sigma$	$> 3\sigma$	
10	Actual Capability SoS has been found to be operationally effective, suitable and sustainable in successful real-world network- enabled operations with other identified SoS as a FoS. Capability is being Optimised.				

Figure 9: Capability Preparedness Levels and OPCF P6 Framework [12] x

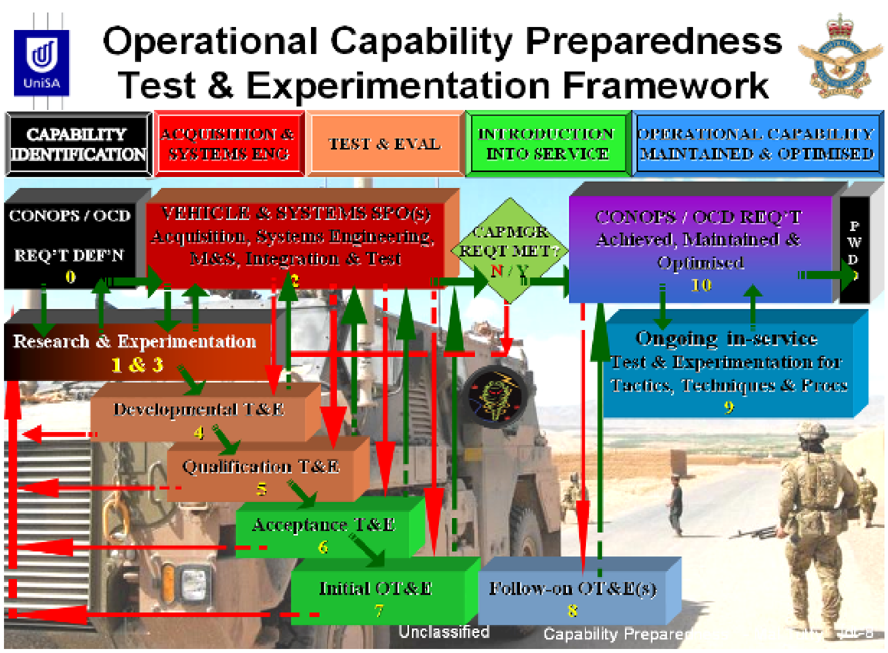


Figure 10: Operational Capability and Preparedness ET&E Framework

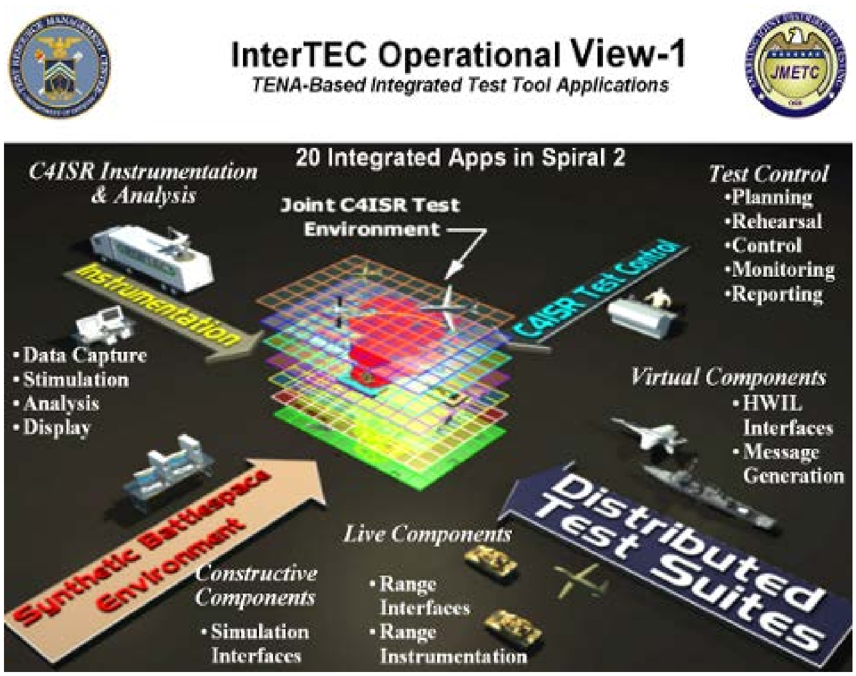


Figure 11: US Distributed M&S LVC operational view via InterTEC, [McKee and Tutty 2012]

A conceptual framework for network-enabled, force-level armament systems compatibility has been proposed by [Tutty 2016] at [STANAG 7068 2014] to achieve balanced capability management that integrates the experimentation, systems engineering, test and evaluation, and system-safety communities, as shown in Figures 9 to 11 throughout the life of the capability and that ET&E and certification is synchronised to ensure operational commanders have confidence in the capability, at least at the JTF level.

To implement this strategy, a change in focus by both the systems engineering and the experimentation and T&E organisations will be needed, so that they are able to also conduct scientifically rigorous testing, training, and experimentation that build confidence and remove risks in capabilities for conducting secure, network-enabled real-time kinetic and non-kinetic effects.

The ability to independently test systems, SoS, and FoS using a scientifically defensible approach using the LVC environment is critical. As predicted by [Cenko, Piranian etal, 1997], in the aircraft-stores-separations arena, scientists and engineers will see a new higher-level systems engineering level approach for wind-tunnel and flight tests with increased use of CFD. [Steinle et al, 2010] for example also propose numerous improvements in wind-tunnel testing and CFD modelling with the Live Virtual Constructive (LVC) ‘simulation’ worlds via use of the joint-T&E methods discussed in [Tutty, 2016], while also performing other, more ‘mundane roles’.

In the race to be last, the platform always wins. We’re going to fix that with your guys and gals help.

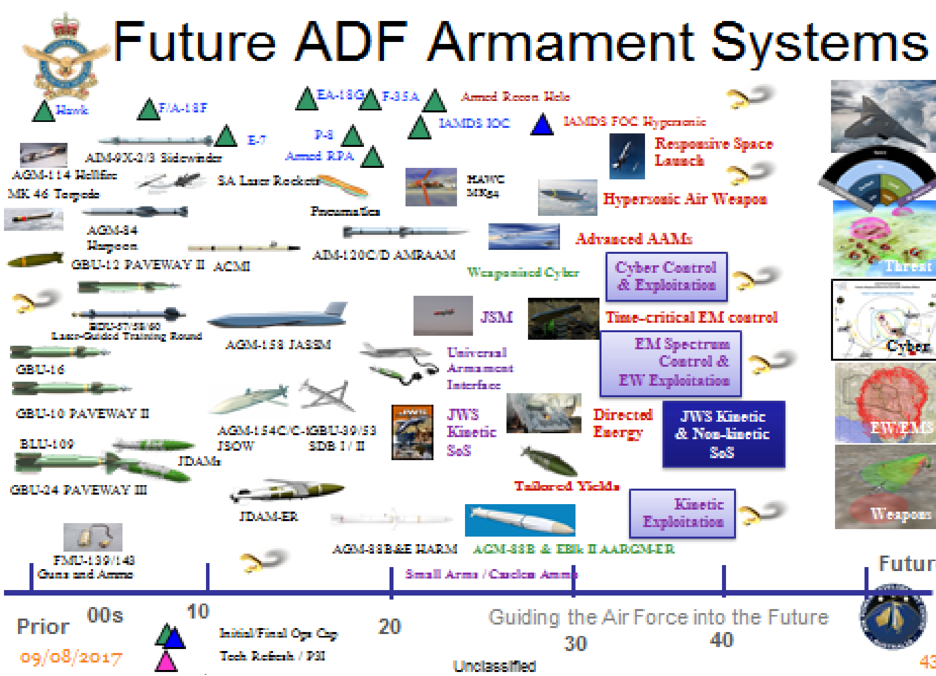
- Tom ‘Slow Ned’ Pfeiffer, USAF fighter pilot and ASC engineer

Today we accept (nay: expect) the paradigm that the reliability and the operational effectiveness of our air armament is over 95 percent in the environment and the missions we have been using it in. This includes a range of missions to achieve effects in both deliberate and dynamic targeting joint fires scenarios. The progress with digital communication protocols/data-links and Artificial Intelligence (AI) now means our newest weapons are network-enabled at the cross-system or system-of-system level. That is the aircraft stores configurations are now no longer isolated from the rest of the (increasingly) ‘small-world’ and their performance can therefore be optimised against the latest intelligence.

Use of Joint Munitions Effectiveness Manual Weapon System (JWS) software-intensive-systems with the aircraft Joint Munition Planning System (JMPS) and Universal Armament Interfaces can now rely on the use of Five Eyes managed tools so that the targeteers and users can capitalise on tailoring effects offered by modular, precision guided, extended range and network-enabled weapons with tailored yields. The Five Eyes have to *take-back* their responsibilities for optimising and tailoring air armament as we have done with countering the Improvised Explosive Device (IED) performance, effectiveness along with danger areas/collateral damage estimates being used by our crews in the joint battle-space of the future to defeat our adversaries' threat(s). This will need to be aggressively extended to all ADF weapons and their delivery platforms so Australia can use the full range of network-enabled armament systems. These improvements provide optimised, tailored and nuanced effects in the land (and sub-surface), air, space, sea (and sub-surface) and information domains as we head back into contested and conjested environments.

The use of the interoperable JWS with all future Five Eyes armament systems will see users better able to understand and optimise in near real-time the options being presented from our network-enabled weapons and electronic/cyber warfare. The information will be fully visible in the platform cockpits and battle-management systems of our joint focused Army, Navy and cyber brethren.

Figure 12: Future ADF armament systems capabilities?



As the RAAF's Plan Jericho[xi] activities to transform the air force into the fifth generation progressively transition into the Air Warfare Centre, Air Force will see greater experimentation with how humans operate the aircraft platforms to control and optimise use of the network-enabled armament systems in-the-loop with the sensors and C2 to attain the effects sought. The distributed Live, Virtual and Constructive (LVC) simulation environment will enable the routine, seamless use of network-enabled armament systems in experimentation, testing, training, exercises and in operations.

We will then realise that the 20th century approach in the defence forces of today is fundamentally flawed as we head into the Information Age. We jointly need to urgently address several key systems and system-of-system vulnerabilities that remain exposed with the poor understanding of Information Technology (IT) use operationally and beyond the cyber scaremongering. In the Information Age, it is no longer acceptable that the disparate tribes within all our defence forces have different, antiquated views and cannot advise Commanders on the operational risks and the confidence levels in our ability to apply the required operational effects against threats in a timely manner. Relying on 'grandfathered' land/air/seaworthiness criteria that is fixated on civilian 20th century civilian systems technology and/or criteria will also need to change so that technical and operational control can be established and evolve to deliver the kinetic, non-kinetic electronic/cyber warfare effects by equally complex, adaptive platforms. The F-35 JSF has been the first (and maybe the last) platform designed:

1) to a volume set for the X-35 prototype using traditional airworthiness approaches with the addition of enhanced low observable characteristics given the change in the threat environment, and
2) absolutely focused on applying disruptive AI via network-enabled access to the information domain.

Future remote-piloted and piloted systems will see non-traditional complex, adaptive approaches of AI with not only electronic functionality and a full LVC environment but also: structures, shapes, flight control, full platform EO life-cycle environmental monitoring (via sensors in platforms/stores/EO/canisters using IT to seamlessly predict service life on a per item basis) and active noise/vibration/aeroacoustic suppression (to extend the service life). Furthermore, future mission systems need to use a 'Doogle Earth' which is a Defence orientated view of the world capable of doing 3D weapon fly-out and electronic/cyber effectiveness and confidence/failure modes and modelling and display in real-time in an LVC environment. 'Crowd' and 'all-sources' validated and verified imagery overlaid along with targeteering/weaponeering target location error and collateral damage grade data need to be available within the region of significant interest of our armament system Users.

To be ready for, and capitalise on, the complex, adaptive systems behind future armament systems, we need a universal, operationally focussed non-linear decision making framework that captures both the yin and the yang to address the safety/operational risks and the confidence our Targeteers, Weaponeers and Users can easily visualise and also selective apply in the LVC simulations before running real-world operations.

Targeteers, Weaponeers, Users and Commanders must have a straight forward decision-making framework about their ability to defeat the evolving threats by dominating the 2030+ battlefield/spaces with kinetic and non-kinetic effects, control of the electromagnetic spectrum and full use of the resources in our own protected information domains.

The future is not so much about the technology necessarily but about using technology to make informed decisions about the safety of our people and being able to intelligently defeat any threat posed and any potential adversary.

Yin - Danger	Risk Level	Yang - Confidence γ
Operations Only iaw SPINS	Extreme	Very, very, very 'Bad'
High Risk Operations (needs Waiver)	High	'Bad'
Test and Operations (needs Test Plan)	Medium	Some 'goodness', there are 'Issues', some potentially 'Bad'.
Mission Essential Personnel Only (needs Test / Exercise Plan)	Low	'All goodness', 'On Target', 'Under control'.
Very Low: Public Risk	As Low As	Robust Solution that meets and exceeds the Need identified that is being IV&Ved & Optimised

Changes in the State Military Airworthiness Regulatory environments.

In Australia the military airworthiness regulatory (MAR) system was formally established in the 1990s to address significant technical and operational airworthiness deficencies found in numerous aircraft accident boards of inquiry. In the UK, the Haddon-Cave (2009) review of an RAF Nimrod explosion in Afghanistan resulted in the outright naming of organisations and individuals in the subsequent inquiry and caused a major change in the UK MAR. The Australian MAR at [DI(G) OPS 2-2 2010] has been further updated to better align with the Australian civil aviation MAR with recognition of any prior certification basis and the new Defence Aviation Safety Regulatory (DASR) now directs use the European MAR environment, [ADF Directive 24 2016], [EASA Aviation Regulations 2014] as shown at Figures 13a and b.

Not surprisingly, the civilian MARs do not recognise the use of aircraft stores/weapons or even Explosive Ordnance (EO) as a 'role'! In the Australian context the DASR has therefore recently determined that:

> **"[Technical Regulation of] Explosive Ordnance (EO).** Joint EO domain Authorised Engineering Organisations (AEOs) and Authorised Maintenance Organisations (AMOs) will not transition to being regulated under DASRs on 30 Sep 16, instead they will move to a new EO Safety Assurance Program under DGEO. The T[echnical] A[irworthiness] Regulator] will no longer be the Lead for Defence EO, with responsibility for safety

assurance of Defence EO transferred to DGEO. The EO safety assurance program will be established by DGEO in satisfaction of Vice Chief Defence Force's obligations as the Single Point of Accountability for Defence EO. To support a phased transition, the Defence EO organisations will continue to be approved as AEOs, AMOs and OTAs under the Defence Aviation Authority with responsibility for ongoing certification, oversight and enforcement vested in DGEO. When these organisations are no longer authorised as AEOs or AMO, further development of an assurance strategy for these EO organisations will be required by each DASR 21, 145 or M (to be documented in the relevant Exposition) before ***product*** can be ***consumed***.'"

"Operational Regulations. Military aviation (MILAVREG), operational airworthiness (OAREG) and technical airworthiness regulations are combining into one regulation suite under DASR. The extant operational airworthiness regulations are contained in AAP 8000.010 and some relevant MILAVREGS."

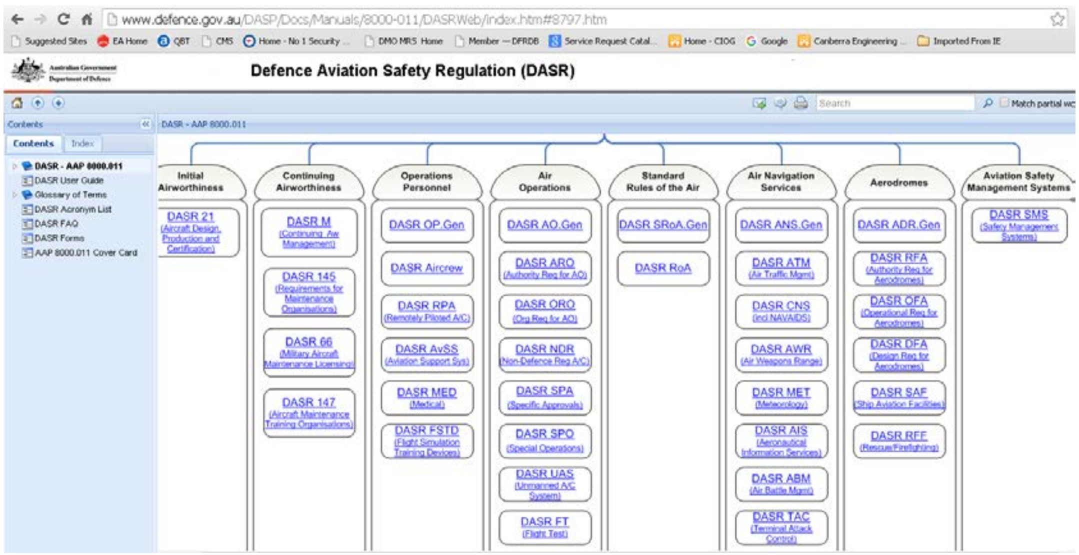


Figure 13a: Australian DASR

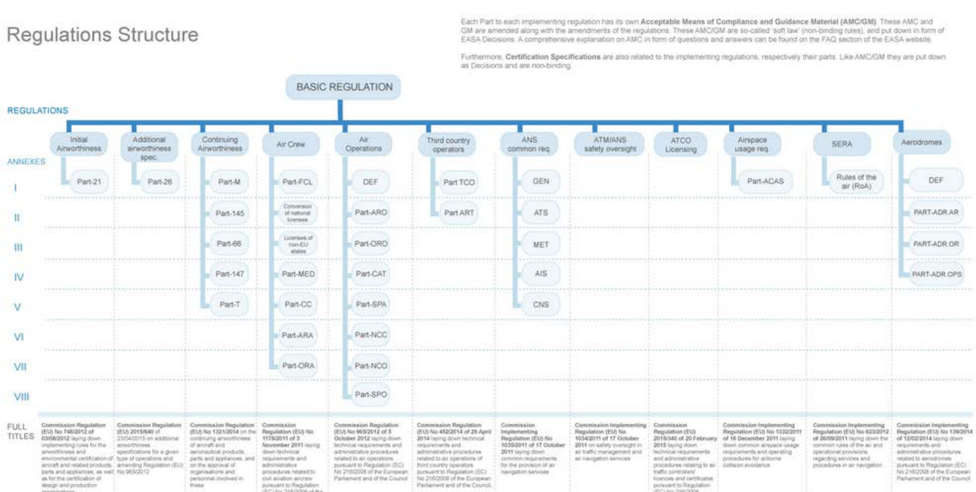


Figure 13b: European Regulatory Structure.

DGEO published implemented the start of the required changes with amendments to the Defence EO Publication DEOP 100 Volume 2, [ADF DEFGRAM 269, 2017]. The guiding principles for the EO materiel safety are not unsurprisingly:

1. Informed decision making based on ‘EO [Safety and Suitability for Service] S3 Advice’

2. Only competent EO Safety Advisors (EOSAs) to provide ‘EO S3 Advice’

3. Evidence proportional to risk

4. Safety Case approach

Whilst these principles are strongly supported for ensuring the safety of EO in Australia during the Manufacture to Target Disposal Sequence (MTDS), the EO Safety Regulator does not explicitly determine how the S3 Advice and Safety Case ensure the operating limitations on the service platforms keep the munition ‘free from hazards’. Consequently, the several Airworthiness Boards and the first S3 Safety Cases[xii] since implementation of the DASR have cited the RAAF and US Navy ASC Flight Clearance for all aircraft stores/weapons including EO as part of the “Exposition” to the Airworthiness Regulator. This will continue to ensure the compatibility of all aircraft stores configuration and be consistent with establishing that the technical integrity and technical control of the air armament systems has been maintained.

However, it is noted that the airworthiness community in Australia and the US continue to think of ***products*** and ***outputs*** as pieces of paper (in the case of weapons this is the traditional EO ‘Design Approval’ and ASC Flight Clearance); the ***product*** should however be the ***safe and effective operation of the system-of-systems***: which the above documents are generated to support or provide evidence towards. The EOSP and joint fires principles in contemporary military organisations don’t therefore align with the airworthiness concept of ***consume***. A technical argument of effectiveness and safety in a systems-of-systems is by nature complex to understand, and even more so to articulate well. As such, the attempted characterisation of a document for ‘consumption’ is a second order effect of engineers not able to articulate these speciality disciplines in terms understandable to decision makers, or even other engineers. It is not being suggested that the concept of articulating a MAR exposition is flawed, rather a hypothesis proposing that advice developed by specialist disciplines (like S3 and ASC, and also other aeronautical and mission systems specialty areas) must be put into terms more understandable to the user (and more importantly: executive/command) communities: so that users don’t try to categorise such technical advice without reading and understanding the emergent properties directly affecting operations. As such, the ‘assurance strategies’ within DASR 21, 145 or M Expositions must be the internal expertise to understand, implement, and question such arguments.

The MTDS is based on a Capability Managers operational requirement and expected rates of effort in the required service environment. Because this must be managed/updated to reflect reality: EO materiel acquirers and sustainers can’t possibly do this in isolation of the aircraft and integration community, which from an ASC perspective, might mean a feedback loop back into the EO management space. The push is for focus on sustainment and CLC management through systems safety; and to break the stovepipe of tossing an assessment certificate over the fence(s) into sustainment. Future space: would it be so strange to have the EO S3, ASC Flight Clearance and the AWB Exposition done near-real time, jointly? Or to have integration hazards and risks (ASC) fed back into the EO management through-life safety case (as either the rate of effort or the service environment experienced has changed) because of the effect on the through-life EO safety argument? It is thus also implied that ongoing ASC program involvement is required not only as user requirements change, but as a community we confirm or reject our initial desktop null hypothesis; through actual environmental exposure, and hopefully through planned test before incident. Indeed, section 17 of MIL-STD-516C requires this and “should be applied at any point throughout the life-cycle of an air system when an airworthiness determination is necessary.”[xiii] The authors suggest there must be better streamlined answers in the Information Age for our operational users to understand the safety/risks while advising Commanders as to the confidence they should have in achieving the required effects against our adversaries, safely. For example there is no reason that since most current guided weapons are delivered in containers that the whole temperature and environment being sensed by the weapon cannot be monitored and the service tailored in real-time!

Such a system is a trivial exercise to implement and just needs to have positive control and management. There will be important lessons to be learnt from the military system-of-systems research with the use of safety critical systems as part of all future potentially complex, adaptive systems for the civilian MAR as commercial aerospace systems also move headlong into use of remote piloted systems and a complex, adaptive air traffic control system.

CIVILIAN CASE STUDY

Search and Rescue (SAR) Store Separation from Turbojet Aircraft.

The AMSA CL-604 aircraft has a large selection of Search and Rescue (SAR) stores that can be released from the Air Operable Door (AOD) as shown at Figure 14. These range from freefall items of less than 1kg all the way up to parachute delivered 74kg fuel containers. It would be expensive and time consuming to flight test every single item that can be released and so a means to reduce testing is required for the stores and possibly eliminate the requirement for separation tests for variations of these stores in future. Using the military approach this is ideally accomplished using modelling and simulation with only limited selective flight tests to validate the models and/or to provide sufficient test evidence for clearance by analogy where possible.

Any separation event is driven by the initial conditions, in this case the velocity and orientation that the store enters the air flow, and the physical properties of the store such as mass properties, and external shape. The latter determines the free stream aerodynamic loading that is applied by the air flow and so subsequent motion. Stores in close proximity to an aircraft experience an aerodynamic interference effect between the store and aircraft flowfields that can dominate the separation trajectory and drive the store into a violent collision with the aircraft, particularly for high speed aircraft at transonic conditions.

Figure 14: A selection of Challenger 604 SAR Stores

However, in the case of door launch from a SAR aircraft it was considered that any interference is likely to be small due to the compactness of the stores, lack of store lifting surfaces, and very low airspeed of the aircraft at release. Any effect is also transitory as the store is launched from within the cabin, rather than starting in a location with such interference. Consideration of the free stream aerodynamics alone was believed to be satisfactory for a useful separation model, with some treatment for the progressive transition from relatively still cabin air to the external flow.

The use of CFD to determine interference effects was also a consideration, but thought too time consuming for even simple Euler methods given the variety of stores and launch conditions. However, the application of older panel methods may have some merit in this scenario, as proposed by [Cenko, 2017]. CFD has been used to produce the store freestream aerodynamics databases. The OpenFoam code has been found to produce good results using the Reynolds-averaged Navier–

Stokes (RANS) solver for bluff body stores at the low speeds representative of SAR. A freestream database for a store can be generated using OpenFoam in a couple of days on a desktop computer.

For a SAR aircraft, where stores are effectively hand launched or slide down a ramp out of the door or pivot on the door step, the major impediment to the use of the MIL-HDBK-1763 stores clearance process is the large variability in the launch conditions. This lack of repeatability in launch also brings into question the validity of the traditional flight test based approach in this situation, where all possible launch conditions could not have been tested with even the most comprehensive test programme. In contrast, a modern separation simulation tool can be used to assess thousands of launches using Monte Carlo or batch runs. An example of such a separation model has been generated with the ASTERIX (Aircraft Store Trajectory Estimation Realised In Xcos) store separation modeling system, with an indicative output shown in Figure 15.

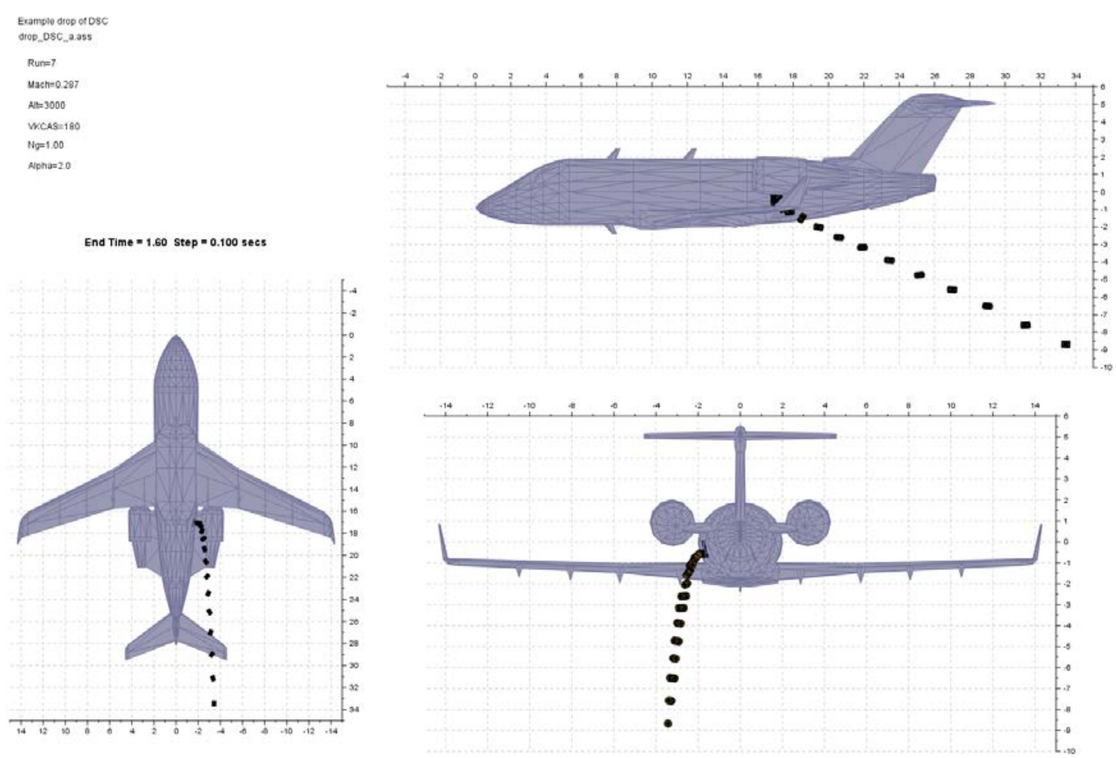


Figure 15: Example Challenger 604 SAR Stores Separation Prediction

Even using modeling and simulation there are still a large number of stores to be accommodated and so analogy should be used where possible. In this situation analogy would rely more on similarity of shape, with mass a secondary consideration. For example, with a range of squat cylinder shaped stores, assessing the lowest mass and highest mass would allow clearance by analogy to the remainder. To facilitate such an approach the SAR stores were grouped as follows.

a. Squat cylinders – e.g. Diesel pump, Droppable Stores Container
b. Slender cylinders – e.g. SLDMB, Marine Supply Container
c. Bagged stores – e.g. Life raft, Sea Anchor kit, Tropical Recue platform
d. Small, hand launched –e.g. EPIRB, Signal kit
e. Large Square stores – e.g. Petrol pump, 40L fuel container

Simulations and flight tests for samples in each group should be sufficient to allow clearance analogy for the rest. Such initial simulations were undertaken and determined that separation at the required SAR flight conditions should be safe, though there were some concerns for the very light hand launched stores due to the large variation in possible launch direction and velocity. The provision of an ASC Flight Clearance during this process served to clarify the project management and test teams approach to reconfiguring the stores operation in preparation for the ground and flight trials. Flight testing was conducted successfully and met the expectations of AMSA and CASA, but unfortunately no test data has been made available by the operators for direct comparison with simulations as yet.

CONCLUSION

Over the past three decades, collaboration between the Five Eyes in the area of aircraft stores compatibility, ET&E certification and separation in particular has considerably improved the capabilities of each nation. These joint efforts have established the credibility of new tools, eliminated duplication, and provided significant cost and time savings.

These collaborative efforts were the result of predominantly Five Eyes and NATO, ASCC and TTCP international agreements and specialist conferences (AIAA, ICAS, ITEA), as well as agreements between individuals to do interesting work that would complement their respective agencies' priorities. Future joint task forces using families of systems of systems will require even more collaborative and cooperative systems for aircraft-stores configurations to be part of a greater framework that has network-enabled armament systems compatibility across the systems of systems and are operationally suitable, effective and prepared.

MIL-HDBK-1763 has been critical to this revolution in air armament affairs until now, to which the Applied CFD has been a common Five Eyes initiative. CFD has become an increasingly accepted tool in the aircraft stores separation and certification process. The tools developed in the use of CFD in the aircraft stores separation and certification area are long overdue for use in other domains such as non-kinetic electromagnetic compatibility, directed energy and cyber operations to achieve this.

To address the network-enabling of joint fires operational capabilities, the Five Eyes and NATO need to urgently develop and implement use of a replacement based on the research underpinning the proposed STANAG 7068 to ensure that armament system compatibility is established and maintained for increasing the confidence of commanders and operational users in what levels of interoperability and capability preparedness are demonstrated and are scientifically based.

The authors found that STANAG 7068 may have greater application in being complementary to the developing EMAR for non-military stores as civilian aviation also heads down the route of greater mission systems connectivity.

Movie 1: Joint fires 'Doogle Earth' LVC animated view, [Tutty, 2016].[xiv]

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Endnotes:

[i] **Aircraft Stores Configuration.** An aircraft stores configuration refers to an aerospace platform, incorporating a stores management system(s), combined with specific suspension equipment and aircraft store(s) loaded on the aircraft in a specific pattern. An aircraft stores configuration also includes any downloads from that specific pattern resulting from the release of the store(s) in an authorised employment or jettison sequence(s) All definitions are from MIL-HDBK-1763, unless noted otherwise.

[ii] **Aircraft Stores Compatibility**. The ability of each element of specified aircraft stores configuration(s) to *coexist without unacceptable effects* on the physical, aerodynamic, structural, electrical, electromagnetic, optical or functional characteristics of each other under specified ground and flight conditions.

[iii] **Significant Change.** A change in the vehicle/aircraft (including mission systems) and/or store configuration which necessitates a formal reassessment of the aircraft stores compatibility. A significant change to either a vehicle/aircraft or store form, fit, function and qualification limits, requiring reassessment of vehicle/aircraft and mission system compatibility with the store is caused by the following criteria:

- **a.** Any change to the external aerodynamic shape of the vehicle/aircraft or store that may affect physical fit, performance, handling/flying qualities and/or separation characteristics.
- **b.** Any change in basic vehicle/aircraft or store structural characteristics, including the addition/deletion of any antennae, vents, drains, probes or ducts that may affect the store in any way.
- **c.** Any change to the flutter/aeroelastic or wing mass distribution characteristics of the vehicle/aircraft.
- **d.** Any change in the vehicle/aircraft Basic Weight Configuration that affects the carriage and employment of a store or stores combination.
- **e.** A 12.7mm (0.5") or greater change in store C of G (excluding any allowable tolerances).
- **f.** A 5% or greater change in store weight.
- **g.** A 10% or greater change in store pitch, roll or yaw moments.
- **h.** Any change in functional concept, including weapon delivery mode changes.
- **i.** Any degradation in the Electromagnetic Radiation environment affecting the electromagnetic compatibility of the aircraft/store configurations.
- **j.** Any degradation in the HERO/HERP/HERF characteristics of the vehicle/aircraft or store.
- **k.** Any change in electrical/electronic connector characteristics or their location.

- **l.** Any change in store suspension lug location.
- **m.** Any change in arming wire or lanyard routing.
- **n.** Any change in vehicle/aircraft or stores fuze safing, arming design or Hazard Classification Code.
- **o.** Any change in vehicle/aircraft or stores environmental qualification or tolerance.
- **p.** Any change in vehicle/aircraft thrust or stores ballistic and/or propulsion characteristics.
- **q.** Any change in stores explosive fill or casing affecting blast performance or store fragmentation patterns.
- **r.** Any change in vehicle/aircraft or store OFP software or SMS changes that affects the operation, employment or accuracy of the store or Operational Category A systems.
- **s.** Any change to the vehicle/aircraft, store or Safe Escape Manoeuvres that causes an increase in the Minimum Safe Release Height or Region of Significant Influence (Weapon Danger Area/Zones/Safety Template) during employment of the store.
- **t.** New nomenclature for either vehicle/aircraft or store.
- **u.** Individual changes that do not necessarily make a significant change which, when considered cumulatively, result in a significant deviation from the design specification of the presently certified aircraft and/or store are considered to constitute a significant change. The term 'aircraft' also includes the aircraft Stores Suspension Equipment.

[iv] The definition used by the authors in recent Australian doctrine discussions agreed that "A (military) domain is '***The distinct environment where a desired effect is achieved by (military) action'"***. ***It is all about where the effect is achieved, not what Service delivers it.***

[v] It can also be argued that depending on the novelty / technology readiness level (TRL) of the 'new' aircraft or 'new' store i.e. the degree of analogy basis - that the second or third situation may actually need to be reversed. Store performance/integrity and unique (but undiscovered) aircraft characteristics/environment can increase/decrease the risks between these two scenarios. This may be the case for any complex adaptive system and aircraft using active separation control techniques.

[vi] **Analogy.** A form of reasoning in which similarities are inferred from a similarity of two or more things in certain particulars. Analogy plays a significant role in problem solving, decision making, perception, memory skills, creativity, explanation, emotion, and communication. [12]

[vii] **Aircraft Stores Clearance.** Primarily a *systems engineering activity* used in most Five Eyes and NATO countries to formally document in a Flight Clearance, or similar document, the extent of aircraft stores compatibility within specified ground and flight operating envelopes.
Aircraft Stores Compatibility Flight Clearance. A *document* issued by the Technical Airworthiness Authority that explicitly defines the extent of aircraft stores compatibility to safely prepare, load, carry, employ and/or jettison specific aircraft stores configurations within specified ground and flight operating envelopes. This document is a mandatory basis required by most NATO nations for release to service of the aircraft stores configurations.

[viii] See [US JP 3-09, 2006, 3.09.32, 2010 and US Range Commander Council 321, 2007].

[ix] 'Complicated systems' (such as aircraft, ships, ground vehicles and their C^2 systems) may be reduced to their parts for both design and analysis purposes so that their behaviour and even any emergent properties can be predicted to a high degree of certainty and confidence during validation, verification and operations.

[x] The following definitions are proposed by [Tutty, 2016] for future SoS & FoS in Joint Fires operations:

- **Ops Category A – <u>mission and safety critical</u> operations.**
- **Ops Category B – <u>mission critical – safety affected</u> operations.**
- **Ops Category C – mission affected/advisory – 'non-safety critical' operations.**

Such a taxonomy closely aligns with the systems, SoS and FoS views and the three V&V implications levels as proposed at [Tutty, 2016 Table 6.1]. This is vital to delineate those SoS and FoS that are OPS CAT A and safety critical, complex and adaptive in nature versus OPS CAT C engineered systems.

[xi] Plan Jericho outlines how the RAAF plans to become an agile, adaptive component of the joint force required in the information age; a Fifth Generation Air Force. To expand the perspective of Air Force from the here and now to look at how we should operate into the future, *Beyond the Planned Air Force: Thoughts on Future Drivers and Disruptors* (BPAF) was initiated. Using the Joint Force Design *Future Operating Environment of 2035*, BPAF prepares to explore the Air Force Strategy beyond 2027.

[xii] That is they must consider the service environment reality of exposure, which is bounded by the ASC Flight Clearance.

[xiii] It should be noted that the modern MIL-STD-516C still commonly references [MIL-HDBK-1763,1998] and (the now dated) MIL-HDBK-244 as a method of test!

[xiv] The image has a hypertext link to http://www.maltutty.com/content/joint%20fires%20LVC%20view.mpg embedded, which will play by 'CNTRL CLICK', iff your computer viewing this document is connected to the Internet.