AUSTRALIAN AND US NAVY COLLABORATION IN STORES SEPARATION DURING THE PAST THREE DECADES

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Abstract

The Royal Australian Air Force and the US Navy have used variants of the F/A-18 Hornet, and now Super Hornet, aircraft as their primary fighter and weapons-delivery platforms. For aircraft stores clearance, these countries use similar approaches to performing aircraft-stores-compatibility assessment, based on the methodology of MIL-HDBK-1763. This methodology has traditionally relied on the use of prior analogous stores results, along with wind-tunnel and flight testing. Over the past three decades, Australia and the US Navy have collaborated on improving computational fluid dynamics, wind-tunnel and flight testing for stores separation. The advances have led to a greater role for modelling and simulation that is leading to more cost-effective clearances.

1 Introduction

For many decades, operators around the world acquired new air platforms and either used the original equipment manufacturer (OEM) or collaborated with the lead customer, e.g., NAVAIR with the F/A-18 Hornet, for certification of aircraft–stores compatibility (ASC) and flight clearances.

As new acquisition and support models are required in an environment of shrinking Defence budgets and the costs of clearing stores has risen, in part due to the increasing numbers of aircraft stores combinations and operating envelope breadth, burden-sharing has become increasingly important. Reducing the cost of flight-test validation is a key driver of the ASC community. This paper focuses on the aerodynamic aspects of the ASC process and in particular on how the gains in computational fluid dynamics (CFD) and modelling and simulation (M&S) have aided in reducing costs.

The Australian—US experience provides a useful narrative on how these gains in improving aircraft stores separation assessment may be made in other areas of aircraft stores compatibility and systems-engineered products. Separations compatibility ultimately determines an aircraft stores configurations' operating envelopes, operational suitability and effectiveness [1].

2 Background

The detailed technical collaboration between Australia and the US had its inception at an ASC meeting more than three decades ago. The initial stages involved a formal Air Standardisation Coordinating Committee (ASCC), Mutual Weapons Development (MWD) agreements, and international engagement through The Technical Cooperation Program (TTCP). Confidence was then built in mutual capabilities through officer exchanges in which each of the nations and Services' processes and procedures were understood and improved. For example, exchange agreements were instituted between Australia and the US Air Force in the area of air armaments at Eglin Air Force Base. A wider community of practitioners at armament fora and ASC conferences also developed.

Following this, the technical specialists began to interact at conferences and then to propose joint work programs, often at a general tool-development or technique level [2]. Collaborative fora included TTCP programs, and additional leverage was achieved through participation in NATO military standardisation panels and meetings of the Research and Technology Organisation (RTO) and of the Institute of High Performance Computing (HPC) Applications to Air Armament (IHAAA). These provided useful multi-lateral paths to share the lessons learned, as well as to develop linkages outside the normal communities of practice. This is particularly important when increasingly complex, costly, multi-disciplinary, systems-engineering approaches are required.

The foundation of the collaboration was built on the use of similar approaches to evaluating ASC based on the methodology of MIL-HDBK-1763 [3], the framework for which is illustrated in Fig. 1. The method has traditionally relied heavily on the use of what is now termed "informed recognition of prior acceptance", i.e., acceptance of *analogous* aircraft-stores-compatibility results and wind-tunnel and flight testing results.

Fig. 1 MIL-HDBK-1763 process

Secondly, the US Navy interactions arose from the sharing of common air platforms from historical connection with the A-4 Skyhawk and S-2E Tracker, through to the current S-70B Seahawk, P-3 Orion and F/A-18 Hornet. This commonality should lead to future opportunities on common platforms such as the P-8 Poseidon and F-35 Joint Strike Fighter (JSF). However, more fundamental changes in the approach to future capability development will be required as the various layers of integrated weapon platforms require a more multi-disciplinary, multi-tiered approach.

3 Historical context

The Second World War was notable in that bomber aircraft with internal weapons bays, such as the B-17, the Avro Lancaster and the Heinkel He-111, predominated. Fighters generally did not carry bombs, as they specialised in close air-to-air combat, where manoeuvrability was supreme.

With the advent of the jet age and the development of longer-range, air-launched missiles, the 'pure' fighter evolved into the fighter-bomber. As Thomson noted some thirty years ago, "combat aircraft have been designed to be efficient flying machines in the clean configuration, and subsequently the external stores have been attached to the airframe, usually on an 'as much as possible' basis" [4]. Load-outs now not uncommon are shown in Fig. 2.

In this century, aircraft are often flown in multiple roles, with additions such as high-resolution infrared targeting pods or electronic warfare self-protection devices further disturbing the aerodynamic flowfields, thus impacting the aircraft store release problem.

The focus of this paper is the F/A-18, and, although the variants of the F/A-18A/B/C/D aircraft have different performance characteristics, for store separation purposes, the variants have the same characteristics. However, basic research looking at weapons-bay cavities will also be undertaken due to the requirements for the P-8 and F-35 platforms.

Fig. 2 RAAF flight test F/A-18 Hornet with JASSM. © AOSG- RAAF.

4 F/A-18C/JDAM applied CFD Challenge II

The first example of this collaboration occurred in 1999, during the F-18/JDAM Applied CFD Challenge II [5, 6]. The CFD challenge concept started in 1996, when the F-16 with a generic finned store was used to exercise the state-of-the art applied CFD tools of the day [7]. The second challenge was based on the existence of large sets of wind-tunnel and flight-test data for the F/A-18C and JDAM configuration. Importantly, the results showed unexpected miss-distance time histories, at particular transonic Mach numbers. A final, but significant, element was that the data was publicly releasable; and it was made available after participants made their 'blind' submissions.

Many of the results showed excellent correlation with both the wind-tunnel and flight-test results for the release conditions selected. The US Navy organised the challenge and presented a paper describing the wind-tunnel and flight-test results [5]; and Australia presented a paper comparing the CFD predictions with the flight-test data [6]. A unique feature of this challenge was that representatives of national agencies in Canada and Australia and the USAF/USN formed a judging panel that reported the results [8]; and, as previously noted, the participants were not given the flight-test results until their predictions were submitted. Fig. 3 shows the computed GBU-31 trajectory from the F-18C/D aircraft.

Various participants used Euler and Navier–Stokes (N–S) codes; and the codes gave similar results. The challenge therefore did not clearly elucidate the efficacy of viscous N–S as compared to the inviscid Euler codes in which numerical dissipation may have had fortuitous cancelling effects. A key finding was that for CFD-diagnostic purposes, gross force and moment measurements made in wind tunnels and trajectories derived from flight tests do not provide sufficient detail to validate the local flow conditions predicted with CFD.

The success of the CFD Challenge led to joint participation in several further Key Technical areas (KTa's) under the auspices of TTCP Panel WPN-2, Launch and Flight Dynamics, as described in the following sections.

5 Accelerated development of store-trajectory-prediction techniques using flight measurements

The previous F/A-18/JDAM CFD Challenge example showed that while gross forces and moments and trajectory traces are useful for establishing global agreement in store-trajectory prediction, they do not provide the insight into the detailed flow physics required when analysing the differences between CFD codes or experimental results.

In KTa 2-18, Accelerated Development of Store Trajectory Prediction Techniques Using Flight Measurements [9], pressure-sensitive paint (PSP) was used at the Canadian National Research Council's (NRC) high-speed wind-tunnel; and flight-test-trajectory data for the release of a single MK-83 low-drag store from a

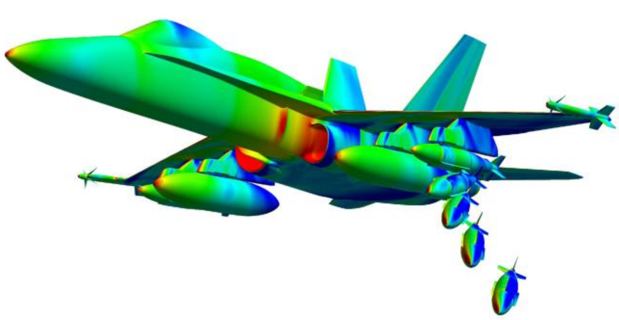

Fig. 3 GBU-31 trajectory from an F-18C/D aircraft at a Mach number of 0.96

vertical ejector on the wing of an F/A-18 was available. The results were compared with CFD predictions using a range of flow solvers.

Pressure-coefficient (C_p) data derived from PSP measurements with enabled better insight into shock locations and highlighted the issues involved in the use of inviscid codes for release predictions with viscous effects. Good agreement was achieved both with the pressure comparisons, as shown in Fig. 4, and with the flight-test trajectories. A major benefit of the collaborative activity was the access to a richer ground-based experimental dataset with flight validation data. The use of PSP, and the availability of comparative CFD data highlighted limitations of the technique, such as surface contamination and deterioration [9].

6 Analysis of the release of the SSB from the F-111 aircraft

With the advent of the JSF, P-8, and future UCAVs, all designed with internal weapons carriage, forward-looking research programs focused on the understanding of the complex aerodynamics and aero-acoustics of weapons bays. The Royal Australian Air Force (RAAF) was still operating the F-111, and the collaborators saw opportunities to use a flight-test F-111 to investigate the flow phenomenology of cavity flows for the Small Smart Bomb in 2001 [10] and, in 2005, dummies of PLOCAAS, shown in Fig. 5.

In KTa 2-22, Analysis of the Release of the SSB from the F-111 Aircraft [11], neither the wind-tunnel, nor CFD results matched the flight-test results. The reason that the wind tunnel did so poorly was due to the aft store trajectories starting some two feet (at full scale) from the carriage position, as shown in Fig. 6.

Fig. 5 F-111 Weapon bay with PLOCAAS in-flight. © AOSG-RAAF

Because a trajectory is largely determined by initial conditions, if these are wrong, the prediction will be in error. The forward store was tested at the end-of-stroke position; and, although those trajectories seemed to compare better, sting interference effects in the cavity might have corrupted the subsonic and transonic results. Although this KTa did not resolve the issue of CFD applicability to internal weapon bays, it helped determine the wind-tunnel-testing methodology for both the JSF and P-8A programs.

Further, the work indicated that the lack of *a priori* information on sting effects could be overcome by characterising the effects using CFD techniques; in this way, stings could be designed for minimal, or at least known, impact.

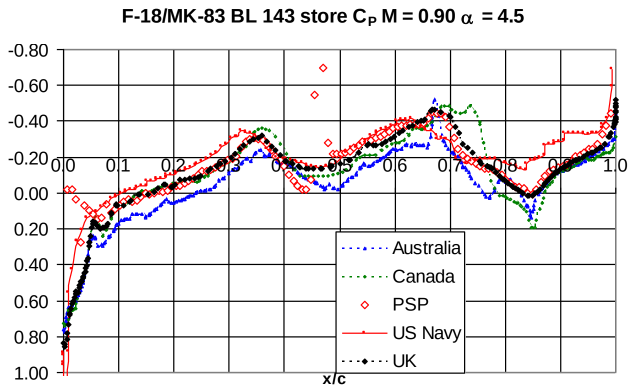

Fig. 4 Comparison of PSP test data with CFD predictions

Fig. 6 Aft sting arrangement for SSB in F-111 bomb bay

For these reasons, KTa 2-26, Weapon and Cavity Aerodynamics and Aeroacoustics [12], was initiated in 2008. The work, in this case was based on the UCAV 1303 geometry [13]. This configuration has been widely studied, and significant experimental testing has occurred [14] for a generic store in a rectangular weapon bay, along with complementary CFD. Recent results from this KTa indicate that CFD can be used to account for sting-interference effects in the cavity, as well as to predict the weapon-bay aerodynamics and aero-acoustics.

6.1 F/A-18 separation effects with targeting pods

As the military and political requirement for precision strike has increased, the requirements for precision targeting pods, such as the AN/AAQ-28 Litening Pod and AN/ASQ-228 Advanced Targeting Forward-Looking Infrared (ATFLIR) Pod, have had significant impacts on ASC programs. The pods modify the aircraft external geometries and, in may cases, decrease the store-to-aircraft distances in critical areas. The following sections illustrate a number of examples of weapon/pod mixes that demonstrate the evolution of the tools and techniques applied to the ASC problem.

In 2005, Northrop Grumman marketed the Litening pod to the Australian and Canadian governments for use on their F/A-18A/B/C/D aircraft. Northrop Grumman contracted NAVAIR, via a commercial-services agreement, to support flight certification of the Litening pod and the associated pylon-mounting system on station 4, illustrated in Fig. 7. The goal was to clear the GBU-12, GBU-38, MK-84, dual AIM-120, and 330-US-gallon FPU-8 fuel tank adjacent to a Litening pod to the present TACMAN limits (with an adjacent ATFLIR).

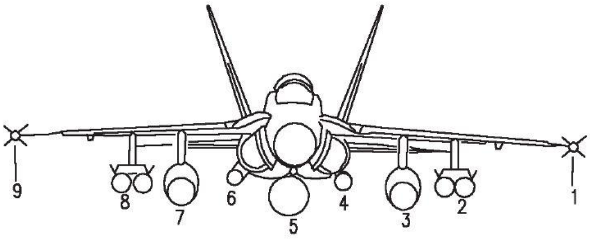

Fig. 7 F/A-18 load positions

6.2 CFD-based clearance of stores on F/A-18

During the first phase of the project, the lessons learned from the F-18/JDAM CFD Challenge, as well as from KTa 2-18, allowed CFD to be used to clear the MK 65 mine from the RAAF AP-3C for a flight test demonstration and GBU-12, GBU-38, MK-82, MK-83, and MK-84 from the F/A-18 parent pylon without the need for wind-tunnel testing [15, 16]. Fig. 8 shows the comparison between the predicted pitch, yaw and roll attitudes and the flight test results for the MK-84 trajectory. This validated the approach used and determined the next steps.

6.3 Wind-tunnel testing in support of clearance of stores on F/A-18

For the clearance of the Litening Pod with these stores, the DSTO Transonic Wind Tunnel (TWT) [17] was used to determine the characteristics of the dual AIM-120, as well as the GBU-32, GBU-38, MK-82 and MK-83 stores on ‘Canted Vertical Ejection Rack’ configurations adjacent to the Litening Pod.

The DSTO TWT has a relatively small test section (0.8 m × 0.8 m); and as a result, half models on the plane of symmetry are used to maximise model size. Significant validation of this type of testing has been performed [18]. For the F/A-18, a 9%-scale half-model can be used, resulting in Reynolds numbers of approximately 0.5×10^6 for a JDAM store-separation test. The

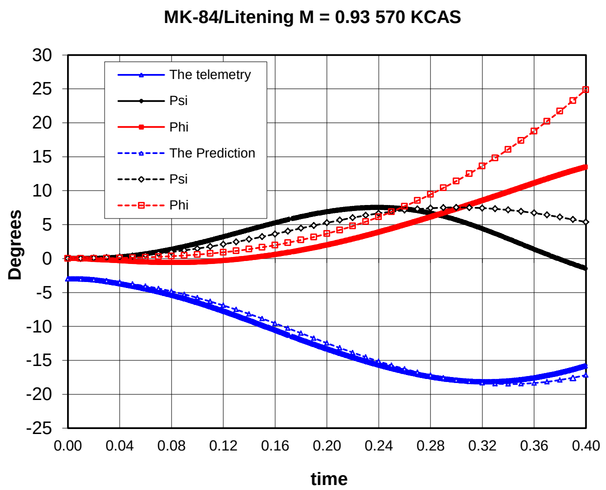

Fig. 8 Comparisons of MK-84 trajectory predictions with flight-test data

use of half-model testing was a first for NAVAIR, and another indicator of the increasing collaborative trust built through common testing programs. This program is still continuing, and the configurations will be tested in late-2012.

In the first part of the program, NAVAIR used the Navy's generalised separation package, NAVSEP, to predict the trajectories of dual AIM-120 and a LAU-127 launcher assembly jettisoned from an F/A-18.

The wind-tunnel data was used in this case because high-angle-of-attack freestream data of the AIM-120/LAU-127 combination was required for jettison. Additionally, the wind tunnel was used to efficiently generate grid-survey data for the store/launcher combination in the near flowfield.

Due to the impracticality of manufacturing an internal strain-gauge balance for the launcher, a specially designed rig was built to hold the assembly, with the force balance housed on the support arm, aft of the launcher (Fig. 10). Freestream and grid data were obtained with and without the dual AIM-120 and launcher assembly so that the interference effects of the balance housing and aft support can be deduced.

Fig. 9 shows a comparison of the predicted jettison trajectory with the flight data. The graphs show excellent agreement between all three displacement components and the pitch attitude, whereas the yaw attitude is slightly under-predicted and the roll is over-predicted. The

Fig. 10 Dual AIM-120 and LAU-127 launcher mounting system in the DSTO Transonic Wind Tunnel

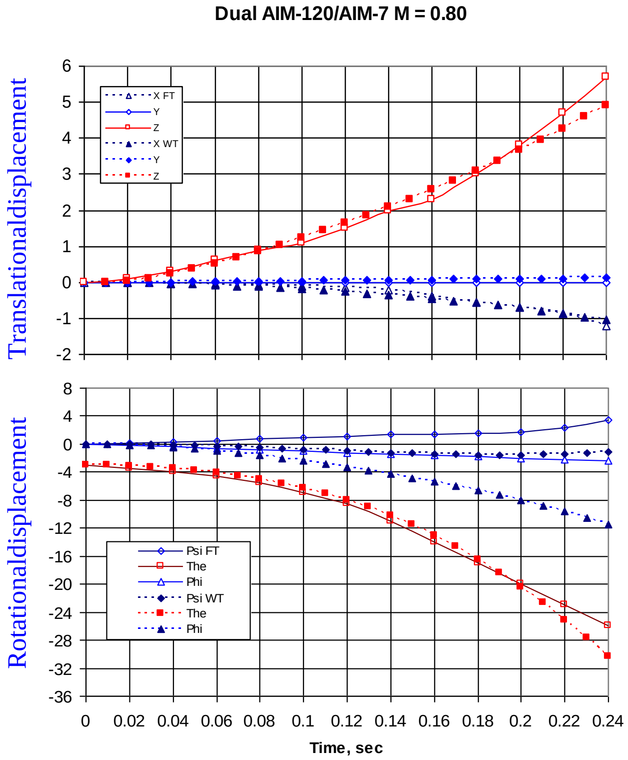

Fig. 9 Comparisons of flight-telemetry data with the predicted trajectory of a dual AIM-120 – Translational- and rotational-displacement time histories

dissimilarities in the predicted yaw and roll with the flight-test results were attributed to higher uncertainties in the test data caused by the unusual mounting system.

6.4 Further store combinations with F/A-18 Litening Pod

In another program, freestream and grid data were obtained in DSTO TWT for GBU-32, GBU-38, MK-82 and MK-83 to evaluate the separation of each of these stores from an F/A-18 with a Litening Pod mounted at station 4 [19-22]. Flight trajectories were then predicted by NAVAIR using the NAVSEP package. Flight-test results have been previously conducted for the MK-83 store and these are compared with the predicted trajectory in Fig. 11. The comparison shows that the predicted displacements and attitudes are in very good agreement with the flight-telemetry data.

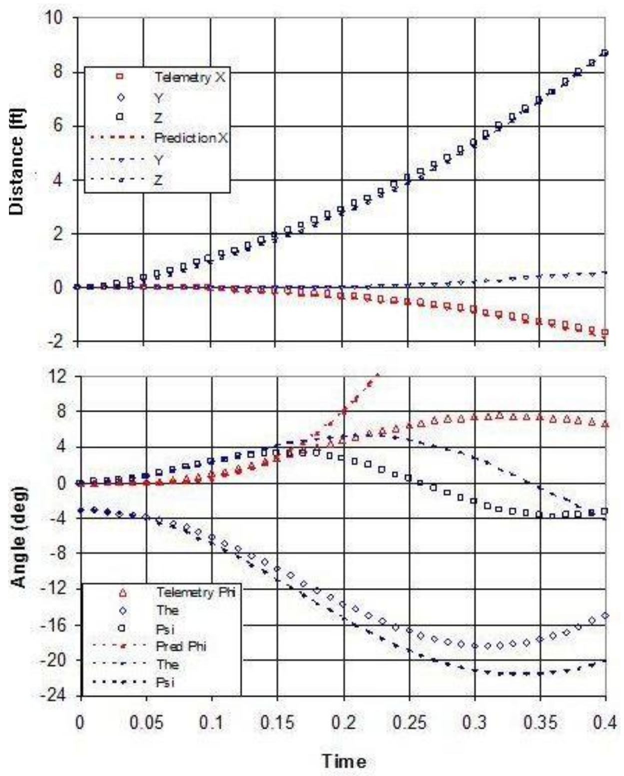

Fig. 11 Comparisons of Flight-Telemetry Data with the Predicted Trajectory of an Mk83

7 Future multi-disciplinary systems approach

The previous sections have used a number of examples to illustrate the RAAF/NAVAIR collaborative programs that have helped both partners build techniques and tools and issue clearances. However, future weapons clearances in a more complex, network-centric-warfare space will add complexity to the currently stove-piped process; hence a new model and framework will be required.

As an example, the NATO Air Launched Weapons Integration study [23] recommended that a NATO STANAG be developed over the next 10–20 years to improve the reusability and streamline aircraft stores certification criteria and approaches. The supposition that a NATO 'CODe of best practice for Experimentation' (CODEx) for the experimentation and testing of 'Joint Fires applications of Armament in an Integrated Mission Environment (JAIME) with 'network-centric complex, adaptive aerospace mission capabilities' employing both kinetic (weapons) and non-kinetic (electromagnetic) directed energy effects could assist in this, based on the successes with the use of MIL-HDBK-1763 [3] for 'simple' and 'complicated' aircraft stores compatibility flight clearance/certification.

In association with the MIL-HDBK, the TTCP GUIDE to Experimentation (GUIDEx) [24] is being investigated for its utility via questionnaires and case studies. The investigation is being conducted in collaboration with over 250 NATO RTO and other subject matters experts. To that end McKee and Tutty [25] reviewed the current national and international methods used for capability development and management and for systems-engineering and project-management practices and identified the key elements that could provide confidence in our future military capabilities being operationally suitable, effective and prepared needs to be evidenced-based and scientifically defensible.

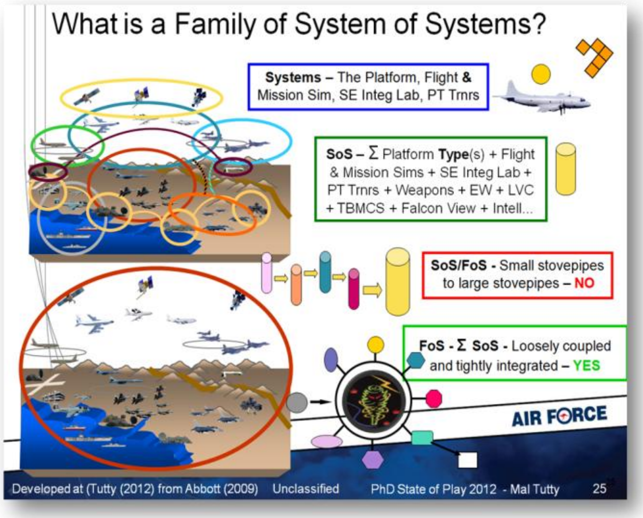

Fig 12, Systems, SoS and FoS.

A conceptual model of network-enabled, force-level armament systems, Sos and FoS has been proposed by McKee and Tutty [25] to achieve a balanced capability management that integrates the systems engineering, test and evaluation and the system-safety communities as shown at Figures 12 and 13.

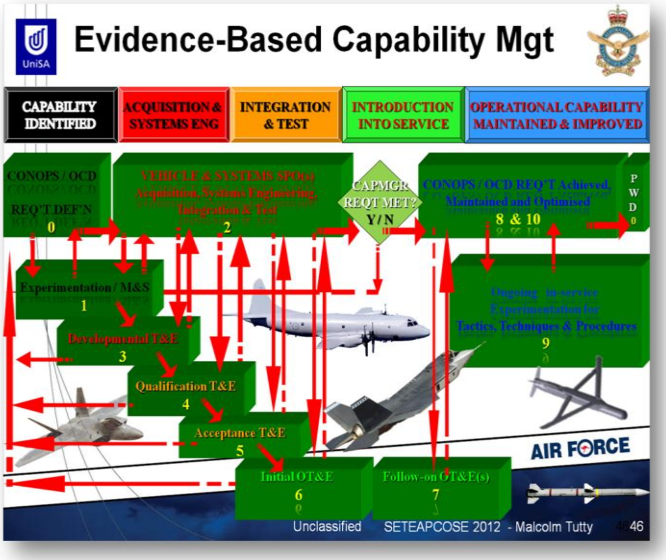

Fig 13. Evidenced-based Capability and Preparedness [25]

To effectively deal with the increasing network-enabling of current and future military systems, T&E and experimentation must evolve and be mature enough to detect undesirable and/or unexpected results in the application of kinetic and non-kinetic effects. Surprises in this complex, adaptive world will increase as the concepts of the systems of systems (SoS) and family of systems of systems (FoS) evolve.

To implement this strategy there will need to be a major change in focus by our current T&E and Research & Experimentation organisations so that they are able to also conduct scientifically rigorous testing, training and experimentation that build our confidence and remove risks in our military capabilities in doing secure, network enabled real time kinetic and non-kinetic Joint Fires at the Force Level. The ability to test and experiment independently of the systems, SoS and FoS using a scientifically defensible approach is critical. In the aircraft stores separations arena scientists and engineers will see the taxonomy at [25] being used for wind tunnel, ground, flight tests with increased use of CFD. Steinle et al [26] also proposes numerous improvements in wind tunnel testing and CFD modeling with the Live-Virtual-Constructive worlds via use of the Joint T&E Methods and synthetic battlespace as discussed in McKee and Tutty [25] while also doing the other more mundane roles. The ability to test and experiment independently of the systems, SoS and FoS is critical.

8 Conclusion

Over the past three decades, Australia and the US Navy collaboration in the areas of store separation has considerably improved their capabilities. These joint efforts have established credibility of the new tools, eliminated duplication and provided significant cost savings.

These collaborative efforts were both the result of international agreements (TTCP and RTO) and specialist conferences (AIAA, ICAS, ITEA), but also the agreements between individuals to do interesting work that would complement their respective agency priorities. Future 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 is operationally suitable, effective and prepared.

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