A RECENT HISTORY OF THE EVOLUTION OF AUSTRALIA’S AERODYNAMICS STORE SEPARATION CAPABILITY – THROUGH INDIGENOUS AND INTERNATIONAL PROGRAMS

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Abstract

For around three decades, the Royal Australian Air Force has used variants of the F/A-18 Hornet, and now the Super Hornet, aircraft as its primary fighter and weapons-delivery platforms. For stores clearance on these aircraft, Australia has used an approach 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. As described in this paper, Australia has worked on improving computational fluid dynamics, wind-tunnel testing, and flight testing for stores separation over the past three decades. Australia has benefited from participating in, and contributing to, international efforts to validate the use of CFD and modelling and simulation in the stores clearance process and these advances have led to more cost-effective clearances. The paper concludes that Australia’s future role in stores clearance will be through international sharing of clearance programs with allies and this can assist in reducing overall costs.

1 Introduction

For many decades, operators around the world acquired new air platforms and either used the original equipment manufacturer, or collaborated with the lead customer, for certification of aircraft-stores compatibility (ASC) and flight clearances. Separations compatibility ultimately determines an aircraft-stores configurations operating envelope, operational suitability, and effectiveness [6].

New acquisition and support models are required in an environment of shrinking Defence budgets and the rising costs of clearing stores, in part due to the increasing numbers of aircraft-stores combinations and release envelope conditions; in the ASC community cost-sharing is becoming increasingly important consideration, as is cost minimisation of flight-test validation.

The Australian experience provides a useful narrative on how improvements in aircraft-stores-separation assessment may be applied to other systems-engineered products. This paper focuses on the aerodynamic aspects of the ASC process and in particular on how the gains in computational fluid dynamics (CFD) and other types of modelling and simulation have aided in reducing costs.

2 Historical Background

Technical collaboration on ASC between Australia and international partners had its inception at an ASC meeting more than three decades ago. The initial stages involved a formal Air Standardisation Coordinating Committee, Mutual Weapons Development agreements, and international engagement through The Technical Cooperation Program (TTCP). Confidence was built in mutual capabilities through officer exchanges in which each of the services' processes and procedures were understood. 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 also developed at armament meetings and ASC conferences.

Following this, the technical specialists proposed joint work programs, often at a general tool-development or technique level [7]. 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). These provided useful multi-lateral paths to share the lessons learned, as well as to develop linkages outside the normal communities of practice. The latter 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 [8], 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 assessments and wind-tunnel and flight-testing results.

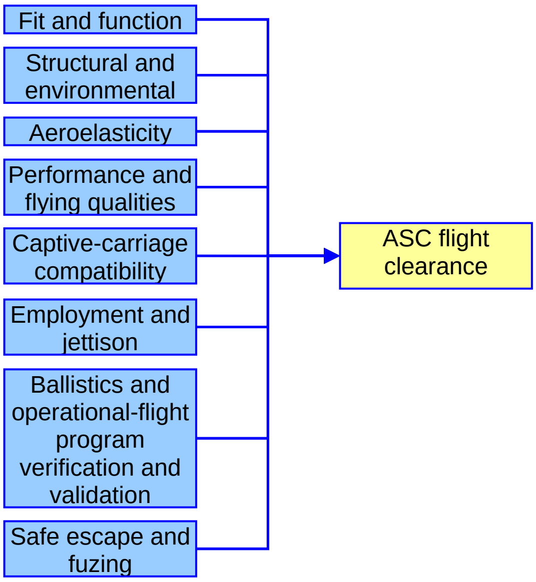

Fig. 1 MIL-HDBK-1763 process

Australian platforms assessed include the P-3 Orion, F-111 and F/A-18 Hornet and the ASC capabilities developed will underpin potential clearances on the P-8 Poseidon and F-35 Joint Strike Fighter (JSF). In addition, more fundamental changes will be required in the approach to future capability development because of the interdependencies within, and between, integrated and networked weapon platform systems.

3 Historical context of safe-separation assessment

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 long-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" [9]. Fig. 2 shows one such load-out for a RAAF F/A-18, carrying Joint Air-to-Surface Standoff Missile (JASSM) missiles and three fuel tanks [1, 10].

Today, aircraft are often flown in multi-role configurations, with additions such as high-resolution infrared targeting pods or electronic-warfare self-protection devices further disturbing the aerodynamic flowfields, and thus affecting aircraft-stores release.

The focus of this paper is the F/A-18, however examples are drawn from other aircraft including F-111. The latter has provided a platform for basic research on weapons-bay cavities, including safe separation studies. The analyses also provide background knowledge applicable to future platforms such as the P-8 and F-35 platforms, both these aircraft also having weapon bays.

Fig. 2 RAAF flight test F/A-18 Hornet with JASSM. © AOSG- RAAF from [1]

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

The first example of the Australian-International collaboration on ASC occurred in 1999, during the F/A-18/JDAM Applied CFD Challenge II [11, 12]. 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 [13]. The second Challenge was based on the existence of both large sets of wind-tunnel and flight-test-verification data for the F/A-18C and JDAM configuration. Importantly, the results showed narrow 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 [11]; and Australia presented a paper comparing the CFD predictions with the flight-test data [12]. A unique feature of this challenge was that representatives of national agencies in Canada, Australia and the US formed a judging panel that reported the results [14]; and, as previously noted, the participants were not given the flight-test results until their predictions were submitted. Figure 3 shows the computed GBU-31 trajectory from the F-18C/D aircraft [5].

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 inviscid Euler codes, in which numerical dissipation may have a fortuitous effect, leading to acceptable results with Euler codes only. 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/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 the collaborative program, Accelerated Development of Store Trajectory Prediction Techniques Using Flight Measurements ([15], pressure-sensitive paint (PSP) was used at the Canadian National Research Council's (NRC)

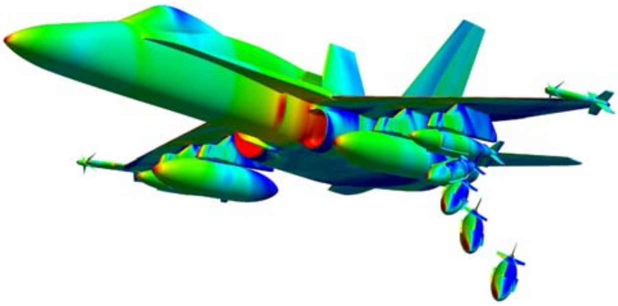

Fig. 3 GBU-31 trajectory from an F/A-18C/D aircraft at a Mach number of 0.96 from [5]

High-Speed Wind-Tunnel; and flight-test-trajectory data for the release of a single MK-83 low-drag store from a 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 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 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 extensive comparative CFD data highlighted limitations of the experimental technique, such as surface contamination and deterioration [15], as well as enabled the evaluation of minimum flow solver requirements.

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

With the advent of the JSF, P-8, and concepts for future UCAVs, all designed with internal weapons carriage, forward-looking research programs focused on the understanding of the complex aerodynamics and aeroacoustics 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 phenomenology of cavity flows with the Small Smart Bomb (SSB) in 2001 [16], including active separation control [4], and in 2005, dummies of Powered, Low-Cost, Autonomous Attack System (PLOCAAS) [2], shown in Fig. 5.

In the collaborative program, Analysis of the Release of the SSB from the F-111 Aircraft, neither the wind-tunnel results, nor CFD results matched the flight-test results. The wind tunnel results did not reflect the initial release trajectory from the carriage position because the aft store trajectories started some two feet (at full scale) from the carriage position, as shown in Fig. 4.

Fig. 5 F-111 Weapon bay with PLOCAAS in-flight. © AOSG-RAAF from [2]

Because a store 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 appear to have corrupted the subsonic and transonic results. Although this collaborative program did not resolve the issue of CFD applicability to internal weapon bays, it helped determine the wind-tunnel-testing methodology for future platforms.

Further, the work indicated that the lack of *a priori* information on sting effects could be minimised and/or quantified with CFD techniques; in this way, stings could be designed for minimal, or at least known, impact [17].

For these reasons, a new collaborative program, Weapon and Cavity Aerodynamics and

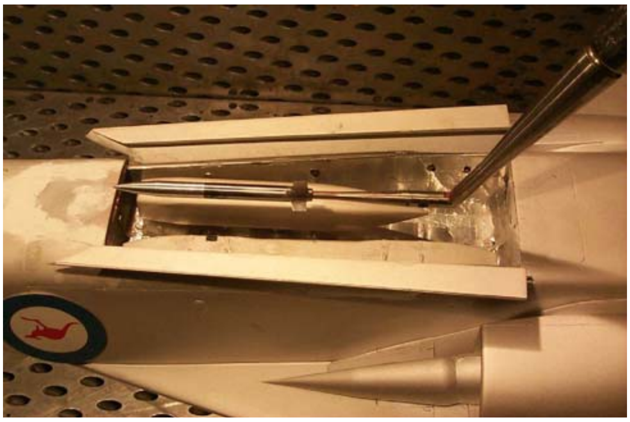

Fig. 4 Aft-sting arrangement for SSB in F-111 bomb bay similarly from [4]

Aeroacoustics [18], was initiated in 2008. The work in this case was based on the UCAV 1303 geometry [19]. This configuration has been widely studied, and significant experimental testing has occurred for a generic store in a rectangular weapon bay, along with complementary CFD. Recent results from this program 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 aeroacoustics.

7 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 aircraft external geometries and, in many cases, reduce the store-to-aircraft distances in critical areas.

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 desired flight certification of the Litening Pod and the associated pylon-mounting system on station 4, illustrated in Fig. 6. 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).

The following discussion illustrates a number of examples of weapon/pod mixes that demonstrate the evolution of the tools and techniques applied to the ASC problem.

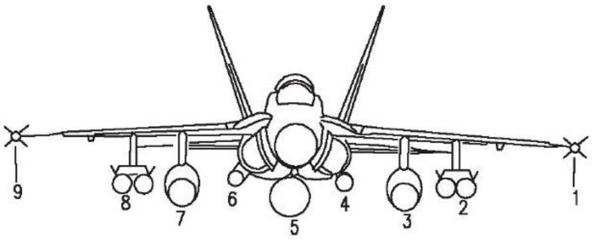

Fig. 6 F/A-18 store stations

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

During the first phase of the project, the lessons learned from the F/A-18/JDAM CFD Challenge, as well as from the program, Accelerated Development of Store Trajectory Prediction Techniques Using Flight Measurements, allowed CFD to be used to clear a number of weapons. These included 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, 20]. This validated the approach used and determined the next steps to augment the CFD with targeted wind-tunnel data for more complex configurations and conditions, such as missile-launcher-assembly jettison.

7.2 Wind-tunnel testing for clearance of stores on F/A-18

For the clearance of the Litening Pod, the DSTO Transonic Wind Tunnel (TWT) [20, 21] 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 [21]. For the F/A-18, a 9%-scale half-model can be used, resulting in a weapon Reynolds numbers of ~0.5 $\times\ 10^6$, based on store body diameter, for a JDAM store-separation test.

Wind-tunnel testing was used because high-angle-of-attack data for 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 flow-field.

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 a support arm, aft of the launcher (Fig. 7). 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 could be deduced.

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

In a follow-on program, freestream and grid data were obtained in the 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 Flight trajectories were then predicted.

Flight tests have been previously conducted for the MK-83 store, with excellent agreement flight-telemetry data.

This work is described in greater detail in References [20, 21].

8 Future multi-disciplinary systems approach

The previous sections have used a number of examples to illustrate the RAAF 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 framework will be required.

Fig. 7 Dual AIM-120 and LAU-127 launcher mounting system in the DSTO Transonic Wind Tunnel

As an example, the NATO Air Launched Weapons Integration study [22] recommended that a NATO Standardization Agreement be developed over the next 10–20 years to improve the reusability of aircraft-stores-certification criteria and to streamline the approaches used. The supposition was that a NATO ‘CODe of best practice for Experimentation’ (CODEx) for the 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) effects could assist in this, based on the successes with the use of MIL-HDBK-1763 [8] for simple and complicated ASC flight clearance and certification.

In association with the MIL-HDBK, the TTCP GUIDE to Experimentation (GUIDEx) [23] is being investigated for its utility via questionnaires and case studies. The investigation is being conducted in collaboration with over 250 NATO RTO members and other subject-matter experts. To that end, McKee and Tutty [3] reviewed the current methods used nationally and internationally for capability development and management and for systems-engineering and project-management practices, using ASC as a sample case in many instances. They identified the key elements that could provide confidence in future military capabilities being operationally suitable and effective, as well as being evidence-based and having scientifically defensible requirements.

A conceptual model of network-enabled, force-level armament systems has been proposed by McKee and Tutty [3] to achieve balanced capability management that integrates the systems engineering, test and evaluation, and system-safety communities. This model is illustrated in Figs. 8 and 9.

In order to effectively deal with the increasing complexity and interdependence of current and future network-enabled military systems, testing and evaluation (T&E) and ex-

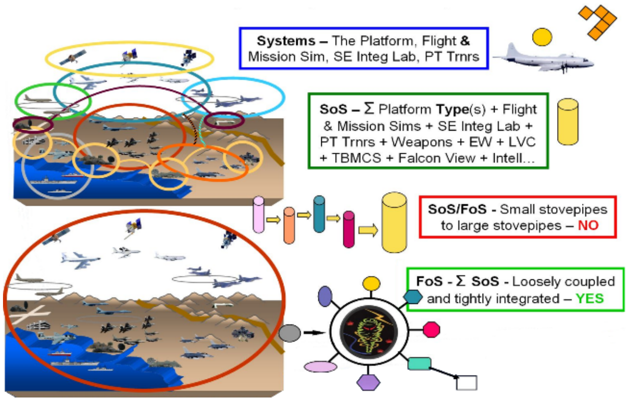

Fig. 8 Systems, systems of systems (SoS), and families of systems (FoS) © Malcolm Tutty 2012

perimentation must evolve and be mature enough to detect undesirable and/or unexpected results, *e.g.*, interdependencies of safe-separation certification with seemingly unrelated upgrades to mission-systems software. Surprises in this already complex environment will increase as the complexity of the systems of systems (SoS) and families of systems of systems (FoS) increase.

To implement this strategy, a change in focus by 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 is critical. In the aircraft-stores-separations arena, scientists and engineers will see a new higher-level, systems-engineering approach for wind-tunnel and flight tests with increased use of CFD. Steinle *et al.* [24] also propose numerous improvements in wind-tunnel testing and CFD modelling with the live, virtual, and constructive simulation via the use of the joint-T&E methods discussed in McKee and Tutty.

8 Conclusion

Over the past three decades, Australia has benefited through active participation in international collaborative programs in the area of store separation. These joint efforts have established confidence in tools and techniques, such as CFD and wind tunnel testing, eliminated duplication, and provided significant cost savings.

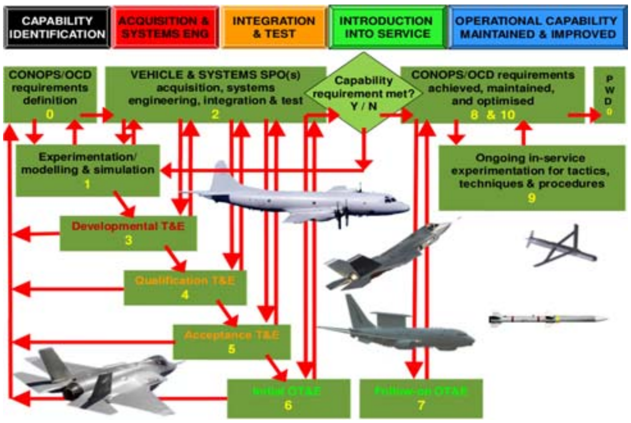

Fig. 9 Evidence-based capability and preparedness [3] © Malcolm Tutty 2012

These collaborative efforts were the result of international agreements (TTCP) and specialist conferences (AIAA, ICAS, ITEA), as well as agreements between individuals to do work that would complement their respective agencies' priorities.

Future families of systems of systems will require even more collaborative and cooperative methods for aircraft-stores compatibility to be part of a greater framework that is operationally suitable, effective, and prepared.

We believe Australia has made a significant contribution back to the international community and we hope to continue doing so in the future.

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