Developing the Inundu fast-jet electronics test and evaluation pod

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Abstract. The development of the Inundu fast-jet electronics test and evaluation pod is described as a case study in the development of technology demonstrators. This pod is required to provide a "laboratory" environment for its electronics payload despite the rigors of being carried by fast-jet aircraft. This requirement, along with the need to be easily integrated with a wide variety of carriage aircraft resulted in a challenging development project.

Introduction

The development of technology demonstrators is an essential part of research and development. It is through the process of developing, evaluating and using the technology demonstrator that new technologies are brought to maturity before committing to the costs and risks associated with the development of products. However, the technology demonstrator itself needs to be adequately engineered to function and perform throughout its intended lifecycle. The development time, costs, user-friendliness' and robustness of the demonstrator needs to be traded off against each other in view of the one-off nature of the design and the amount of use expected of it. This trade-off is a key responsibility for the systems engineers responsible for the development of the demonstrator. This tailoring of the SE process is a normal part of SE management as has been documented elsewhere (Horan and Belvin (2013).

The development of the Inundu fast-jet electronics test and evaluation pod by the Council for Scientific and Industrial Research (CSIR) in South Africa is described as a case study in the development of technology demonstrators.

Background

At the end of 2013 the radar and electronic warfare (REW) competency in the CSIR's Defence Peace, Safety and Security (DPSS) division decided to act on their long-realised need to be able to test, evaluate and demonstrate their advanced Digital Radio Frequency Memory (DRFM) electronic warfare capabilities in a fast-jet environment. This would facilitate the evaluation of this technology in more demanding scenarios and also provide a meaningful way to demonstrate these capabilities to stakeholders and clients. As electronic warfare (EW) systems are usually fitted to aircraft in the form of pods, developing and operating a pod would also expose staff at the CSIR to the practical considerations involved with supporting the development of an operational EW pod.

REW approached the Aeronautical Systems Competency (ASC) at DPSS, CSIR to assist them with developing a pod to address the following objectives:

- A fast-jet pod easily integrated with a variety of military and ex-military aircraft.
- Able to accommodate the current DRFM system.
- The pod must provide a “laboratory” environment for its payload despite the rigors of being carried by fast-jet aircraft.
- Highly reconfigurable with an easily exchangeable payload to facilitate different experiments over time.
- The pod’s payloads will fall in the following categories:
    - Electronic warfare test and evaluation
    - Electronic support applications
    - Experimental platform for other airborne electronics (e.g. Synthetic Aperture Radar (SAR))

The development of the Inundu pod

Concept definition. The pod’s concept was defined during a period of extensive consultations and workshops looking at how the pod would be used and what the payloads to be integrated into the pod would look like. As the pod is intended to be used for both internal R&D as well as a platform for supplying custom payloads to one-off customers, the application base is very diverse. The primary applications for the pod are to test and demonstrate the CSIR’s EW and radar capabilities in a fast-jet environment and to be a platform for selling specialised services and capabilities incorporating the CSIR’s electronics capabilities.

A user requirements specification was developed describing a baseline application scenario derived from one potential client’s Request for Proposals along with additional inputs to ensure that the pod will be applicable to a wide variety of applications. The CORE systems engineering software was used to capture the requirements, to perform functional analysis and to start the allocation of functions to components. The very diverse applications envisaged for the pod drove the selection of a modular and flexible system architecture.

The reason the payload was integrated into a pod is to make it as airframe independent as possible. Integrating a new store with an aircraft can be a very expensive and time-consuming exercise as the carriage loads, aeroelastic compatibility, aircraft handling and store jettison characteristics have to be evaluated. However, there is a way-out that is widely accepted by regulatory authorities: the use of the analogy principle. As (MIL-HDBK-1763 1998, clause 4.1.1) puts it, if the following attributes are sufficiently similar to the basis store it is possible to justify certification by analogy:

a. Aerodynamic shape (loads)
b. Mass properties
c. Structural characteristics
d. Operational characteristics
e. Installed in the same aircraft configurations as the certified basis store

It was decided to base the pod’s main physical properties on the largest store that is common to most of the available aircraft platforms. The store identified was the BL-755 cluster bomb (see figure 1). This store was widely used in the 1980s and 1990s and has been integrated with most of the generation of aircraft targeted by the Inundu pod. The selection of the BL-755 as the basis store established the geometry and mass constraints for the Inundu pod.

Figure 1. The BL-755 store (Brams, 2007)

Electrical integration with the aircraft is also a complex and expensive exercise. To facilitate integration, it was decided to design the pod to be electrically independent of the parent aircraft. This would be achieved either using by batteries or by installing a ram air turbine (RAT). The pod would be controlled remotely either from a ground station using a radio telemetry link or by the aircraft using a device in the cockpit. However, it was realised early-on that a suitable RAT did not exist and a two-phase incremental approach towards achieving electrically independent status was adopted. The Phase 1 (prototype) pod would be battery or aircraft-powered and a RAT would be installed in Phase 2. The Phase 1 pod would be designed to facilitate a later RAT installation without significant modifications.

The pod’s radio-frequency (RF) antenna is pointed towards the target despite aircraft manoeuvres using a gimbal. To steer the gimbal, the pod incorporates a combined satellite navigation and inertial navigation system (INS) that, coupled with the target’s position transmitted by the telemetry link, enables the line-of-sight to be computed continuously.

In addition to the pod and ground station, it was anticipated that the system would require transport crates and handling trolleys to facilitate handling and servicing the pod at airfields and other relatively austere locations anywhere in the world. The high-level system breakdown for the Inundu pod defined during the concept design phase is shown in figure 2. The CORE systems engineering software was used to perform functional analysis, design the architecture, manage traceability and to ensure that all the key interfaces were identified and managed.

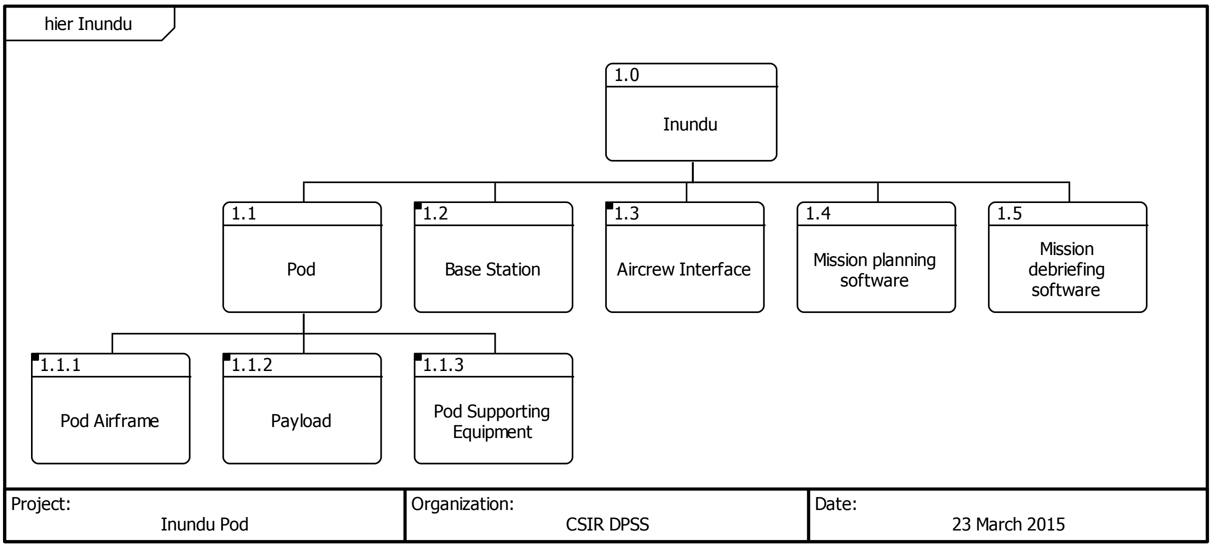

Figure 2. High-level system breakdown for the Inundu pod

The primary process model used in the project was the "vee" model (SEBOK, 2015) for concurrent engineering, decomposition, testing and assembling into the next level. An indication of how the "vee" model was applied to the Inundu pod is shown in Figure 5.

The pod specification captured the pod's functional requirements. The pod's environmental and design requirements were derived from the requirements for stores integrated on the BAE Hawk and the US military standards so that the pod would meet all requirements for stores integrated on military and ex-military aircraft. The operating environments for a number of key potential customers are some of the hottest in the world, so the pod is specified to operate in the hot-humid environment defined in MIL-STD-810G.

The concept design phase ended with the pod specification review and a concept design review.

Preliminary design phase. As the DPSS division of the CSIR does not specialise in the design and manufacturing of aerostructures, it was decided early on that the detailed design and manufacturing of the pod and all the internal components apart from the payload would be subcontracted. The preliminary design of the complete pod apart from the external shell would be done in-house to ensure that the complete pod layout and design met all the requirements.

Packaging all the components into the pod took considerable effort as the requirement for similarity with the BL-755 store dictated the external mould line of the pod and the use of existing payload components limited the available packaging options. The first phase of preliminary design involved understanding what could be achieved within the constraints of the available volume. Initially it was though there would be sufficient volume for both front and rear antennas. As the computer-aided design (CAD) model was developed it quickly became apparent that this goal was unrealistic due to the size of the RF power amplifiers and the volume required for the environmental control unit (ECU). As the entire payload is air-cooled while handling high levels of RF power, the ECU had to be bulky due to the limitations of air as a heat-transfer medium, the extreme operating environments and the high speeds that the pod is capable of. The ECU also protects the payload from exposure to dust and salt mist as some operational scenarios require low-level flight over the sea.

It was clear early on that the payload would not survive significant flight hours with the vibration levels specified for the pod and a vibration and shock isolation system was incorporated. This in turn requires the allocation of free volume for the payload to move relative to the pod shell to absorb shocks. A simple Matlab model was developed to facilitate the design and analysis of the pod's vibration isolation concept. Even though the RAT is not installed in the prototype, volume was set aside to facilitate its eventual integration.

The outer mould line of the pod follows the constraints of the BL-755 basis store, but many details were changed. An aerodynamic model of the BL-755 was created to help ensure that all the changes did not materially change the aerodynamic properties of the store. Within those constraints the fin planforms were simplified and changed to aerofoil sections to reduce the probability of transonic buffeting. The strong-back was faired over and additional fairings were incorporated for the GPS and Wi-Fi antennas. Intakes and outlets were incorporated for the RAT and the ECU. The vane-type fuse on the nose of the BL-755 was removed. A mock-up of the pod was made as part of the process of developing the moulds and this was used to support marketing efforts at the Africa Aviation and Defence (AAD) show in 2014 (see figure 3) and subsequently at other trade shows.

Figure 3. The Inundu pod mock-up at AAD 2014

During the preliminary design phase, mission creep appeared that had to be managed carefully. In addition to the pod's core roles, a new market for simulating anti-ship missiles for naval training was identified. This application requires high-g manoeuvring at high speeds at sea-skimming heights (see figure 4). The pod is designed to handle aircraft manoeuvring at 4.5g to support this mission profile.

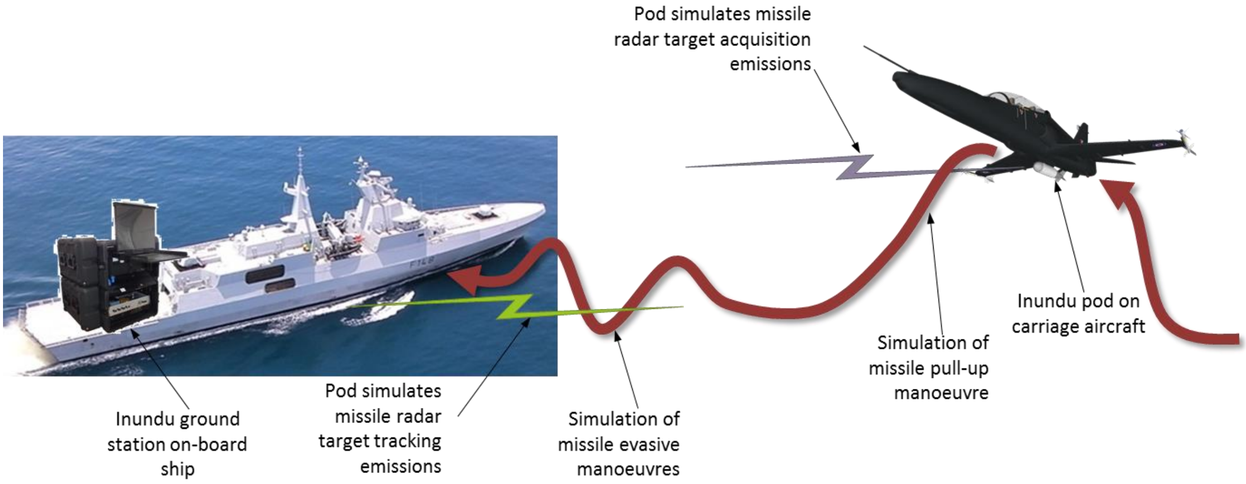

Figure 4. Mission profile for simulating anti-ship missile radar emissions

Detailed design phase. All sub-systems were allocated space for further development in the detailed design phase following the preliminary design phase. The design of the payload supporting frames set the space and payload movement constraints. The vibration springs are located on the frames and motion constraints were set for use in detailed design. The Environmental Control Unit (ECU) volume was allocated and placed in the tail section of the Pod. Space was allocated at the front radome to allow for the full motion of the RF transmitter gimbal.

The ECU concept changed during detailed design and a heat exchanger was adopted instead of filtered external air. External air is scooped in and flows through the heat exchanger. Internal air is circulated through the heat exchanger and flows internally in the Pod. The ECU ducting directs the air to the front of the Pod. The ECU includes circulation fans and a valve that recirculates internal air when it approaches the condensation temperature to retain heat. The performance of the ECU design was verified by ground testing before the design was accepted for installation in the pod.

During the detailed design phase, a single Solidworks CAD model was maintained that was constantly updated with inputs from the suppliers and designers as the design progressed. The CAD model was invaluable for managing the interfaces between the system assemblies and suppliers and for assessing the impact of design changes before they were accepted.

A surprise that arose during detailed design was the requirement for the pod to be jettisonable from some aircraft types in emergency situations. While the pod is aerodynamically stable, jettisoning requires a reliable disconnection of the electrical connector between the pod and the aircraft. The connector interface had to be designed to be compatible with lanyard connectors.

As the design of certain assemblies is completed, the drawings are progressively released for manufacturing so the pod is being built in a progressive manner as design proceeds in parallel. One of the challenges the CSIR encountered is that as it does not routinely develop advanced and highly complex technology demonstrators, it did not have the systems in place for monitoring the progress of a large number of long-lead components being manufactured or supplied by a number of suppliers. Until this was addressed by assigning a dedicated project manager, significant schedule slippages occurred.

Qualification phase. The structure of the pod's qualification followed the form of the "Vee" model as shown in figure 5. The qualification strategy is to first inspect and test the components against the component requirements before integration. The integrated subassembly is then qualified against its requirements and the integration process continues.

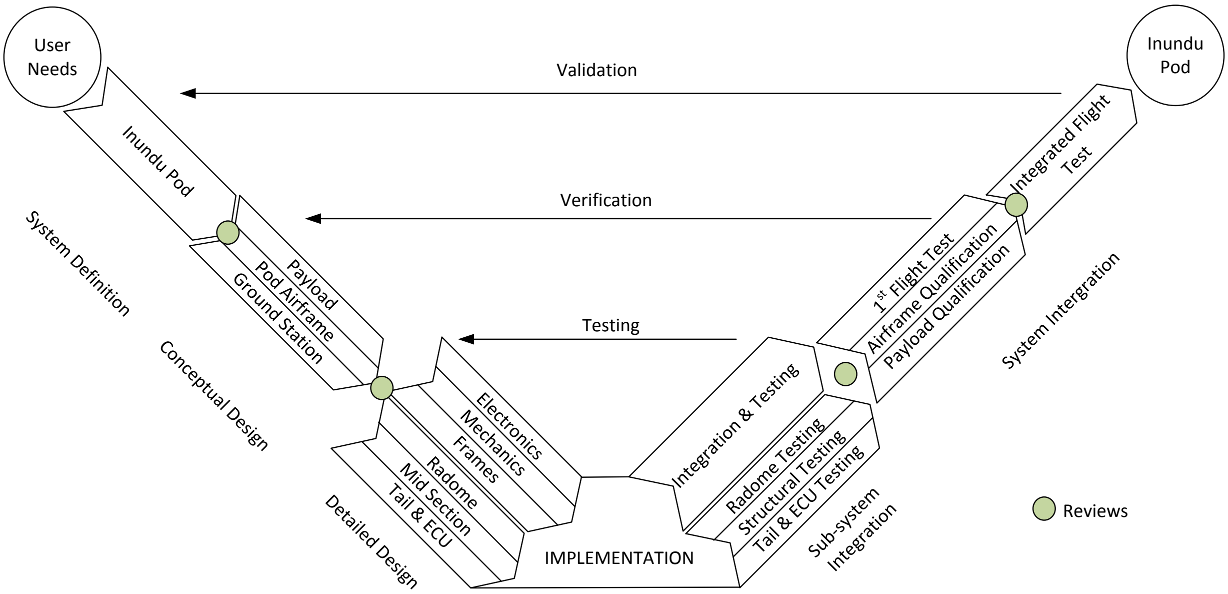

Figure 5. The application of the "vee" process model to the development of the Inundu pod (only some components and tests shown for illustrative purposes)

When the manufacturing of the Pod Shell was completed, it was structurally tested and hail tests were done against the radome. Upon completion of the payload support frames manufacturing, structural testing was performed to ensure the frames meet the structural requirements. The ECU was integrated into the Pod tail section and the tail structural test was performed. In order to verify the ECU operation, a functional test was performed at this level to simulate the ECU operational environment. The performance of the ECU can be evaluated and verified at this level.

To verify the pod's performance in flight, its compatibility with the Hawker Hunter aircraft and to measure the internal environment for the payload, an instrumentation flight test would be executed. The effectiveness of the vibration isolation on the payload support frames, the internal Pod temperatures and the effectiveness of the ECU will be evaluated. Mass and CG representative dummy payload masses would be used to simulate the real payload.

Upon completion of the instrumented flight test and in preparation for integrating the payload into the Pod shell, environmental testing on the Pod would take place. This excludes endurance testing at this stage, as this will be performed on the Phase 2 design. For vibration and shock, the Pod shell with supporting frames and ECU integrated, will be instrumented in a lab and subjected to the vibration and shock loads measured in the flight tests. The pod structure will be qualified for well beyond the anticipated flight test lifetime to provide assurance that the structure and systems are robust. The responses measured on the dummy payloads will be recorded and used as a baseline for vibration testing the payload. The payload would be subjected to the resulting loading separately..

The payload would be integrated on a bench and its operations verified before it is integrated into the Pod shell. Electromagnetic interference (EMI) testing will be conducted at the Payload level to verify compliance and to perform modifications if required. The testing shall be repeated on the integrated Pod to verify acceptable emissions.

Once payload operation and EMI compliance are verified, the payload will be integrated onto the payload mount frames and the frames assembled into the Pod. System testing will be performed and the EMI testing repeated. The integrated Pod would go through other environmental testing for other requirements verification. The integrated Pod will be flown for functional flight tests to verify its operation in flight with the payload installed. These tests also include its integration with the ground stations, both at the airfield and at the target area. The payload's operation will be tested by operating it against ECM receivers and tracking radars on the ground.

Conclusions

The application of systems engineering to the development of an airborne electronics tests and evaluation pod is described. The project is still underway but the application of SE principles has resulted in a pod design with many features that are attracting significant attention. Even though the pod was developed by a relatively small team, it is very complex and had to satisfy a wide range of stakeholders. Implementing a phased development program gave the project structure and provided clear decision points where the stakeholders could be engaged and could participate in setting the direction of the project. Following the "vee" process model worked very well in this case, allowing the concurrent development and testing og the pod, its payload and the ground station. By applying systems thinking to incorporate modularity, a benign environment for the payload and the ability to quickly integrate it on multiple aircraft plattforms, the pod is, despite its technology demonstrator status, attracting significant commercial interest.

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Biography

Kevin Jamison is an aeronautical and systems engineer with a bachelor’s degree in aeronautical engineering at the University of the Witwatersrand and an honours degree in structural dynamics from the University of Pretoria. He has 22 years of experience working at the CSIR, Epsilon Engineering Services, Denel (now Airbus) Optronics and the Pebble Bed Modular Reactor (PBMR) project. Along the way he has worked on a wide range of projects as an analyst, systems engineer and chief systems engineer, including the Rooivalk attack helicopter, stabilised optical turrets installed on helicopters, the helmet display system for the Dassault Rafale fighter aircraft and developing unique on-line nuclear fuel identification and burn-up measurement systems for PBMR.

He rejoined the CSIR Aeronautical Systems Competency in 2010 as a principal engineer where he develops technology demonstrators, leads aircraft weapons integration projects and provides modelling and simulation support to the SAAF.

Tshepo Nkodi is a mechanical and an aspiring systems engineer. He obtained his bachelor’s degree in electro-mechanical engineering at the University of Cape Town. He has experiencing in designing and building unmanned aircraft. He spent 4 years at Denel Dynamics working on unmanned aircrafts. He recently joined the CSIR.