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CRITICAL REVIEW OF THE KALKARA SYSTEM SAFETY AND HAZARD ANALYSIS

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1. INTRODUCTION

1.1 Purpose

1.1.1 A critical review has been conducted by Australian Flight Test Services Pty Ltd, of the Kalkara System Safety Hazard Analysis (SSHA), provided to the Commonwealth of Australia by Tracor Systems Division, as part of the contract requirements for the supply of the Kalkara Unmanned Aerial Target (UAT) system to the Royal Australian Navy. This document reports on that review.

1.1.2 The SSHA is a requirement of the Kalkara Statement of Work, paragraph 3.6.2 and the Data Item Description number 033. The critical review has been undertaken for the Directorate General Technical Airworthiness (DGTA) as part of the Type Certification programme for Kalkara (Reference A).

1.2 Scope

1.2.1 The Type Certification of the Kalkara is based upon the design proofing provided by the baseline MQM-107E system. In principle, therefore, the critical review covers the aspects of the UAT system, which are unique to the Australian acquisition and operational environment. The Australian operational environment includes seawater recovery, as standard procedure. As such, the critical review interrogates the baseline MQM-107E system.

1.2.2 The critical review has been based upon the documentation made available through DGTA and upon visits by AFTS personnel, to the Jervis Bay Range facility (JBRF) on 1st to 4th March 1999 and 10th March 1999 to gather information on system detail and observe Kalkara Australian Flight Qualification Trials Nos 18, 19 and 20.

1.3 References

A. AFTS 808/11/05/PROC-002, Document Control Procedure.

B. KALKARA SYSTEM SAFETY ASSESSMENT, Commonwealth of Australia Department of Defence Purchase Order and Contract Number 1N06CN, 5 February 1999.

C. System Safety Hazard Analysis for the Kalkara Target System. Tracor Systems Division, Document No TSD-0347, Rev A, 2 April 1998.

D. AFTS Letter Report 619/14/01 (12), 8 February 1999, Preliminary and Subsequent Review, Kalkara System Safety Hazard Analysis.

E. Statement of Work and Specification for Engineering Design and Production of the Project Kalkara Unmanned Aerial Targets, Tracor Systems Division Document Number TSD-0312 March 7, 1997.

F. System Specification for Guided Missiles, Target, Variable Speed, MQM-107E. Document No MIS 40174A, 25 February 1994.

G. Type Certification Strategy for Kalkara Aircraft. SCI/4520/211/01 (7), DGTA 099/98, 15 December 1998.. AIRCDRE N Schmidt.

H. Notice of Proposed Rule Making NPRM 9806RP: Unmanned Aircraft and Rockets. Civil Aviation Safety Regulation (CASR) - Part 101. July 1998.

I. Kalkara Structural Loads and Stress Analysis Report for the Kalkara Target Drone. Tracor Document No 2107590, January 9, 1998.

J. Kalkara UAT Sub Systems Electrical Test (Using Target Test Set). Document Number TP2107595, REV A.

K. Kalkara Sub Systems Engine Run Test Procedure (Using the Target Test Set or Ground Control Station). Document Number TP2107596, REV A.

L. Technical Airworthiness Management Manual. Royal Australian Air Force, Australian Air Publication 7001.053.

M. Aircraft Design Requirements Manual. Royal Australian Air Force, Australian Air Publication 7001.054.

N. System Safety Hazard Analysis, CDRL No. 1, DID 033, JP7 Acquisition Contract, 7th February 1997.

1.4 Amendments

1.4.1 This controlled document will be amended in accordance with the procedures detailed in Reference A.

1.5 Glossary of Terms

1.5.1 Abbreviations

AAP	Australian Air Publication
ADI	Attitude Direction Indicator
AFQT	Australian Flight Qualification Trial
AMTC	Australian Military Type Certificate
CAP	Centralised Annunciator Panel
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulation
COTS	Commercial-off-the-shelf
DAP	Digital Autopilot
DFCS	Digital Flight Control System
DGPS	Differential GPS

DGTA	Directorate General Technical Airworthiness
EAXA	Eastern Australia Exercise Area
EED	Electro Explosive Device
Fsd	Full scale deflection
GCS	Ground Control Station
HSI	Horizontal Situation Indicator
HUD	Head-up Display
JBRF	Jervis Bay Range Facility
KIAS	Knots Indicated Airspeed
LOC	Loss of Carrier (Command)
LRU	Line Replaceable Unit
MAGIC[2]	Multiple Aircraft GPS Integrated Command and Control
NPRM	Notice of Proposed Rule Making
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RATO	Rocket Assisted Take Off
SSHA	System Safety Hazard Analysis
TAA	Technical Airworthiness Authority
TM	Telemetry
UAT	Unmanned Aerial Target
UAV	Unmanned Aerial Vehicle

2. BACKGROUND

2.1 The Commonwealth of Australia has contracted Tracor Systems Division to provide Kalkara Unmanned Aerial Target (UAT) systems to the Royal Australian Navy, for the replacement of the Jindivik target aircraft. The UAT are to be operated from two sites in Australia for training purposes, for the RAN and the RAAF. The aircraft are currently undergoing Australian Flight Qualification Tests at the Jervis Bay Range Facility (JBRF).

2.2 As the Technical Airworthiness Authority, Directorate General Technical Airworthiness (DGTA) is responsible for recommending that the Airworthiness Board issue an Australian Military Type Certificate (AMTC) for the Kalkara system. In this context, all engineering and technical documentation review processes are part of the Kalkara Type Certification programme, managed by DGTA.

2.3 The original airframe for the target aircraft was designed by Beech Aircraft (now Raytheon) and operated by the US Army. Designated the MQM-107, the aircraft was a land-launched and, primarily, land-recovered target. The MQM-107 aircraft has been modified substantially over the years. The latest version is the MQM-107E, which is to enter service with the US military. The Kalkara system is based upon the MQM-107E system. Significant differences are known to exist in the following areas of the system design:

a. aircraft:
   (1) wing structure,
   (2) aircraft command and control system,
   (3) aircraft configuration:
      (i) wing payloads, or 'targets',
      (ii) missile 'near-miss' antennae, wingtip-mounted and upper-fuselage mounted (as shown in the following photographs);

b. Ground control station (GCS):

(1) command, control, data acquisition and storage system;

c. operations:

(1) seawater recovery is the normal mode of recovery.

2.3.1 To enable water recovery of Kalkara, a Water Seal Kit, provided by the manufacturer, has been installed in each aircraft. In addition, flushing, water-removal and aircraft/engine reconditioning processes have been instituted after each recovery, based on the manufacturer's maintenance manual. Following re-assembly, the engine undergoes a Sub System Engine Run Test Procedure (Reference K). However, the Procedure is a functional test procedure only and it does not provide a thermodynamic operating point (and, thereby, thrust assurance) comparative check, against an engine performance computer deck, although this would be a straight-forward matter.

2.3.2 The purpose of the Water Seal Kit is to waterproof the nose avionics compartment, by sealing about the side access panels, and about the nosecone attachment. In practice, a substantial amount of seawater has often been found in the nose compartment, following aircraft recovery.

2.3.3 The control surface servos, Flight Control Box and Electro-Explosive Device LRUs are subject to seawater immersion, upon every recovery. Following recovery, all LRUs are returned to service under an 'on-condition' basis. The 'on-condition' criterion is basically a 'Pass' on the Electrical Sub-System Test Procedure (Reference J). It is possible that the Procedures might not adequately uncover all LRU unserviceabilities or latent unserviceabilities. The yaw rate gyro indication failure and dutch roll instability on FQT 18 is a likely example of this possibility. As a result, LRUs might be returned to service, with seawater internal within the LRU.

2.4 As of the date of this report, twenty flights of Kalkara aircraft had been conducted. The flights have been shared by five aircraft. Serial number N28-002 has completed eight flights; serial number N28-003 has completed six flights, serial number N28-005, four flights, serial number N28-006, one flight, and serial number N28-008, one flight.

2.5 The flights have been conducted with Tracor and Boeing personnel acting as Controllers and Trainee Controllers, Navy personnel for conducting range safety operations, Navy Aviation Systems Project Office personnel for controlling aircraft airworthiness and configuration, for each flight. Boeing has been contracted to provide aircraft and target maintenance and reconditioning services.

3. REVIEW OF DOCUMENTATION

3.1 List of Documents

The following documents have been used in the critical assessment of the Kalkara System Safety Hazard Analysis:

a. System Safety Hazard Analysis – Reference A.

b. Type Record Introduction.

c. Kalkara Aerial Target Type Record Annexes A to G.

d. Kalkara (Annex H to the Type Record) Ground and Flight Test Report MFS-0400 Book III, Supporting Data.

e. Kalkara Type Record Update

f. UAT/Target Scoring System Supplemental Information Type Record

g. Payload Equipment Type Record

h. UAT Vector Scoring ARMS Type Record

i. Ground Control Station Shelter Type Record.

j. Ground Support Equipment Type Record.

k. Kalkara Target Scoring Manual

l. Kalkara Target Controllers Manual.

m. Kalkara Performance Data.

n. Kalkara Maintenance and Design Documentation.

o. Kalkara Pre-launch and Launch Sequence of Events.

p. Kalkara Investigation Reports.

q. Kalkara Unmanned Aerial Target System Acceptance/Qualification Test Plan. Document No TSD-0369 Rev A, 1 June 98.

r. System Specification Document for Guided Missiles, Target, Variable Speed, MQM-107E. Document No MIS 40174A 25 Feb 1994.

s. System Performance Document for the Kalkara Unmanned Aerial Target System. Document No TSD-0325, 11 Sept 1997.

t. Statement of Work and Specification for Engineering Design and Production of the Project Kalkara Unmanned Aerial Targets. Document No TSD-0312, March 7, 1997.

u. Development Statement of Work and Specification for the JP7 Target Control System. Document No TSD-0282 Rev B, June 26 1997.

v. Interim Certificate of Design.

w. Kalkara Structural Loads and Stress Analysis Report for the Kalkara Target Drone. Document No 210759, 9 Jan 1998.

x. Kalkara Flight Test Reports for AFQT-01 thru to AFQT-11.

y. TFSI Failure Analysis Reports FRAUS0198 thru to FRAUS7099.

z. Record of Unserviceabilities and Component Changes (RUCC) for Kalkara Serial Nos 002, 003, 005, 006 and 008.

aa. Interface Control Document for the Kalkara Airborne Transponder/Target Interface. Document No TSD-0297 Rev F, 26 June 1998.

bb. Kalkara Target System (KTS) Operation and Maintenance Manual for Target. Document No TT-97107E-2-1.

cc. Kalkara Target System (KTS) Illustrated Parts Breakdown for Target. Document No TT-97107E-4-1.

dd. Kalkara Target System (KTS) Operations and Maintenance Manual for Test, Ground and Support Equipment. Document No TT-97107E-2-2.

ee. Kalkara Target Systems (KTS) Illustrated Parts Breakdown for Test, Ground and Support Equipment. Document No TT-97107E-4-2.

ff. Kalkara UAT Sub System Electrical Test (Using Target Test Set). Document No TP 2107595.

gg. Kalkara Sub System Engine Run Test Procedure (Using the Target Test Set or Ground Control Station. Document No TP 2107596, Rev A.

hh. Operation manual for Mobilised Systems' Model SR1601-01/02.

ii. Technical Description – MRL-25 and MRL-25A Reeling Machine Launcher. Document No TD-87-9234-04.

jj. Magic^2 User Guides.

kk. Magic^2 Commercial Manuals Volumes I, II and III.

ll. Magic^2 Ground Control Station Model 6304-1/2 System Training.

mm. Kalkara GCS Shelter Manual.

nn. Flight Qualification Test Plan for the MQM-107E Target Guided Missile.

oo. MQM-107E Flight Qualification Test Report.

pp. Addendum to the Flight Qualification Test Report for eh MQM-107E Target Drone.

qq. Flight Qualification Test Reports (MQM-107E).

rr. Failure Analysis Corrective Action Report.

3.2 Overall Assessment of Documentation

3.2.1 The quality of the documentation provided is varied with the contract documentation of a reasonable standard, appropriately controlled and titled. The Type Record documentation is in many folders with each folder well presented, however there is no overall index nor is it well structured making it difficult to assess its completeness. Some documentation had pages missing, predominantly the cover page. The type record data for the airframe was not provided (although AFTS understands design drawings are available) making it difficult to assess the physical differences between the Kalkara wing and the MQM-107E wing, the design stress levels and the wing profile form. As a Type Record against which to issue a Type Certificate, it is lacking in organisation and completeness of data - including some fundamental data, such as the Design Flight Envelope.

3.2.2 The practice of defining the required documentation in a Contract can, at times, backfire on the intent of that requirement with the tenderer producing documentation to fulfil the contract requirements without embracing the controls and procedures which would generate the final document. For example the requirement to produce a System Safety Hazard Analysis report has resulted in the writing of that document specifically to meet the requirements of the contract, whereas, there should have been in place a system safety program throughout the development process to identify and resolve safety issues. The end-result of that program would have been the System Safety Hazard Analysis report with appropriate references back to tests and other investigations and analyses undertaken during the program.

4. SSHA CRITICAL REVIEW MAJOR ISSUES

4.1 General

4.1.1 There are a number of major issues, in relation to the philosophy of the technical data presentation in the System Safety Hazard Analysis:

a. Contractual Document;

b. A Living Technical Document;

c. Technical Referencing;

d. Design Basis for Certification;

e. Associated Type Certification Environmental Envelope;

f. Lack of multiple failures, whether collateral, related, sequential (of reasonable probability) or missile/cannon; and

g. Visibility of Environmental Qualifications, General.

4.2 Contractual Document

4.2.1 The content 'tone' of the System Safety Hazard Analysis is contractual, rather than technical. For the Commonwealth, the supply of the SSHA satisfies the contractual Data Item Description No. 033. For example, the technical content of the SSHA is general, rather than detailed, failure classifications are unsubstantiated within the document, and conclusions general, rather than specific.

4.3 A Living Technical Document

4.3.1 Every aircraft system Type Certification programme involves some degree of developmental engineering. Typically this occurs during the ground/flight test and evaluation phases of the certification programme. As a consequence, the Type Record is a living document, which, often, is completed within a limited period, following the award of Type Certification.

4.3.2 Similarly, the SSHA must reflect the progression of the Type Design through all test and evaluation phases of the engineering programme. In other words, the SSHA is a 'living' technical document, which should include all failure possibilities, probabilities, corrective and preventative measures, such as they have occurred through the engineering programme. This is a requirement of MIL-STD-882C, which is reinforced in the suggested Safety Program Structure of Table 1-3, Section 2, Chapter 1 of AAP 7001-054 (Reference M).

4.3.3 It would appear that the SSHA has been a 'closed' document, preceding the AFQT flight testing at the Jervis Bay Range Facility. As a result, the document does not include many of the failures, which have occurred during the AFQT flight testing.

4.4 Technical Referencing

4.4.1 As a technical document, supportive of Type Certification, the SSHA should 'close' the justification of engineering decisions. Typically, the closure can be by-way of engineering documentation referencing, in which case, for example, structural failure clauses should reference Structural Loads Reports and Stressing/Structural Test Reports; similarly, aeroelasticity clauses should reference the Aeroelasticity Report.

4.5 Design Basis for Certification

4.5.1 Under the process cited in Reference G, the Design Basis for Kalkara Type Certification as the MQM-107E plus Kalkara Design differences: the MQM-107E Design is to be accepted *a priori*, without additional engineering vetting, whilst the Kalkara Design differences are being technically assessed for Type Certification.

4.5.2 The SSHA reflects this Design Basis, insofar as the justification for low failure probability classifications, in a large number of system failure possibilities, is based upon the design 'proofing' provided by the MQM-107E. Even if the pre-existing design has been 'proved' (which should be referenced, see 'Technical Referencing' above, so that the justification is traceable), the justification would only be valid, if it was based upon similar operational environments.

4.5.3 Such a Design Basis approach acknowledges the proof-in-service of the MQM-107 Design. However, the Type Certification procedures of the TAA (AAP 7001.053, Reference L) are based upon the Design Requirements of AAP 7001.054 (Reference M) being complied with, including, in accordance with contemporary practice, the requirement that the design environmental envelope of an existing design must cover the environmental envelope for which an AMTC is to be issued.

4.5.4 As revealed by the AFQT flight tests, this Design Requirement presents a number of difficulties, in relation to Kalkara Type Certification. The MQM-107E is designed for land recovery, as a matter of course. In particular, the airframe structure, moving parts and aircraft system components and assemblies, including the flight control and parachute recovery systems, have been designed for a land recovery environment. Kalkara, on the other hand, is intended to be recovered in seawater, as a normal operational procedure. Herein lies the difficulty, which has presented the fundamental flaw to the stipulated process, Reference J, for Kalkara Type Certification.

4.6 Recovery Environmental Envelope, for Certification

4.6.1 <u>Environmental specifications</u>

4.6.1.1 Due to the normal sea recovery operational procedure of Kalkara, as a system environmental specification requirement, it is appropriate that the Kalkara design specifications require:

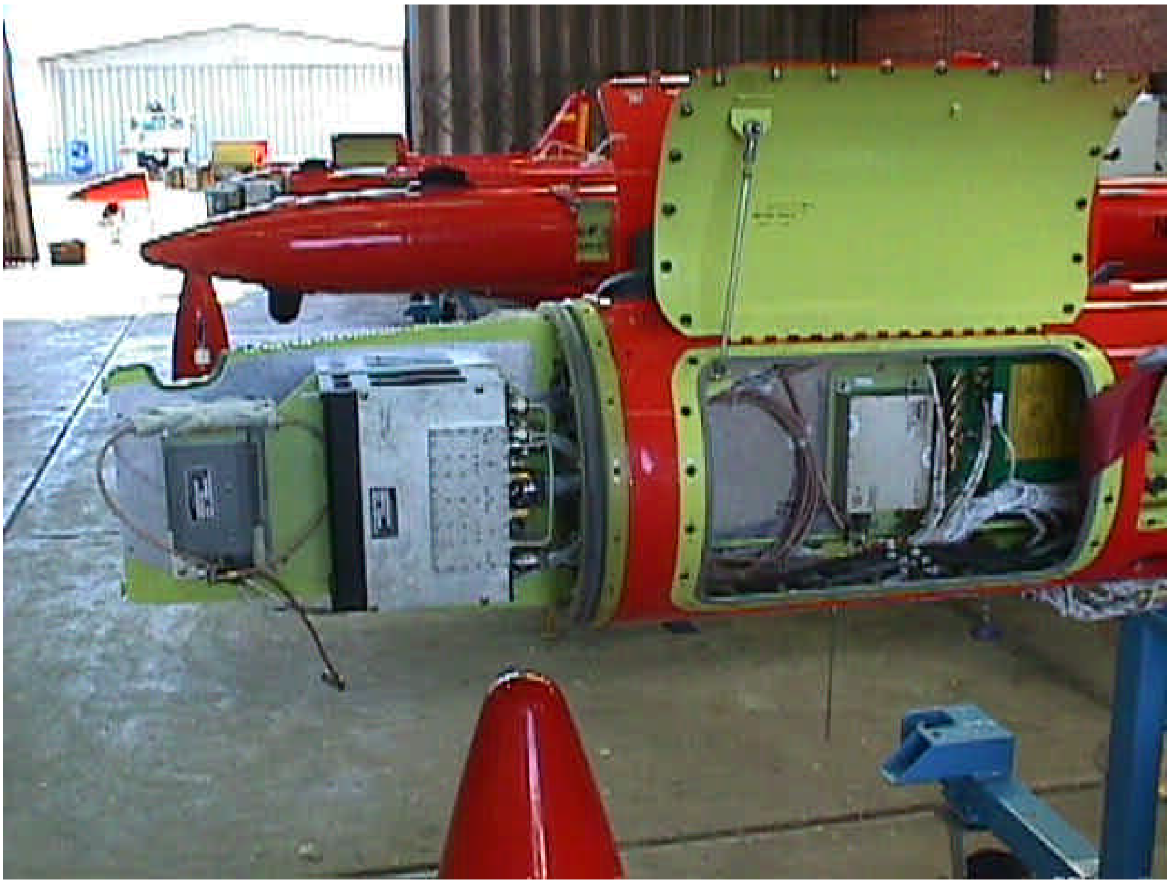
a. for many system components, an environmental specification and qualification for seawater immersion; the components include:

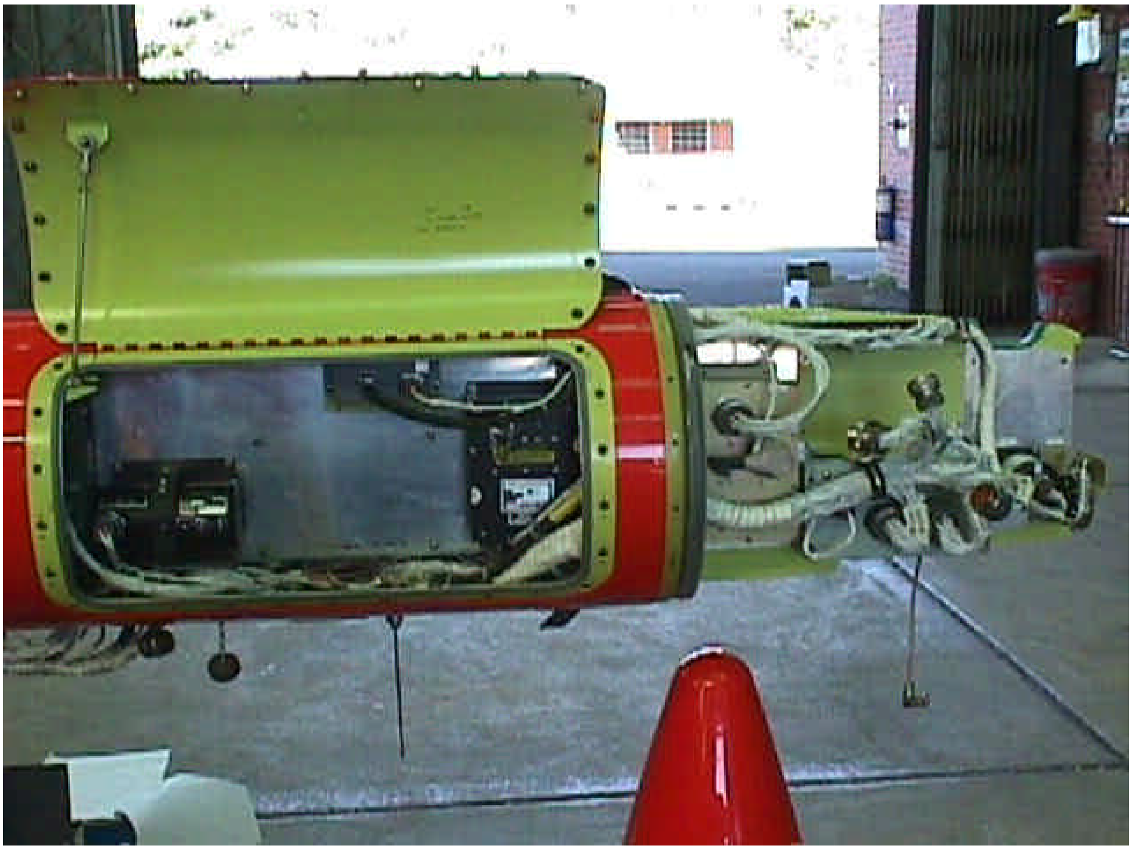
(1) EED,

(2) Magnetometer,
(3) Control surface servos,
(4) tailcone micro-switch,
(5) drogue and parachute actuation system, including electro-explosive devices, and
(6) flight control box;

b. for many more system components, on the presumption that the nose avionics compartment is water-proof qualified, an environmental specification and qualification for saltwater contact; the components include those located in the avionics nose compartment, notably:

(1) yaw rate gyro,
(2) vertical gyro,
(3) batteries,
(4) power distribution boxes,
(5) MAGIC[2] boxes, and
(6) DAP/transponder.





4.6.1.2 Without such environmental specifications and qualifications, a substantive justification is required, as to why, without reconditioning, all seawater-exposed components should not be one-flight usage, only. Through the flight test programme, the components have been used, for any number of flights:

a. on-condition; and

b. subject to passing a limited Electrical Sub-System Ground Test Procedure.

4.6.1.3 Several effects of seawater immersion/contact upon component serviceability have been identified during the AFQT programme, as conducted to date. These are discussed later in the report.

4.6.2 <u>Structural specifications, pertinent to the environment</u>

4.6.2.1 The change in operational environment also has an impact upon aircraft structure. As structural environmental specification requirements, it is appropriate that the Kalkara design specifications require:

a. *Water drainage holes:* for example, the left and right halves of the elevator control torque tube are joined centrally by a fabricated universal joint, the attachment bosses of which are inserted and riveted into the torque tubes - therein, they present a step, against which seawater can become trapped, through normal post-recovery flushing and water eradication procedures.

b. *Corrosion protection:* for example, the elevator torque tube connecting universal joint is fabricated from steel, with no apparent surface treatment finishing. On all aircraft, including those in-store and not yet flown, the universal joints had undergone corrosion; on aircraft which had flown, the corrosion extent was hastened. With due regard to the water-entrapment probability of the internal steps, it is quite likely that seawater ingress between inner torque tube surfaces and the universal joint boss' surfaces will lead to hastened and marked corrosion, in an area which is very difficult to visually inspect. On this aspect in particular, the critical in-service parameter would not be the number of flights, but the total in-service time since the first flight - as the extent of corrosion deterioration would be likely to increase with time, moreso than with the number of flights (the outboard end of the elevator control torque tube is shown in the following photograph).

c. *Damage tolerance and fatigue:* the Kalkara aircraft may presently be without a fatigue qualification, however damage tolerance could be a more critical requirement of airworthiness, especially structural damage that could occur during/post-splashdown or recovery; damage may, and has, occurred due to failure of the parachute to release upon splashdown, and due to the recovery procedure, onto-boat, thence off-boat and onto/off-lorry; corrosion damage tolerance is a further aspect of the structural integrity of the Kalkara airframe, worthy of special consideration in the SSHA; corrosion of the elevator torque tube universal joint, in the first instance, may give rise to hastened wear of the bearing race, in turn increasing the mechanical backlash of the elevators, and hence reducing the damping of some structural vibratory modes - thereby, reducing the flutter margin of the aircraft, in various under-wing target configurations. An example of recovery damage to the airframe is illustrated in the following photograph, of the N28-005 starboard wing - the damage includes a leading edge dent and wing upper surface dimples, both of which have fundamental aerodynamic significance and should be repaired between flights (also observed in the photograph is the wingtip access panel skin joint, which is of variable surface-profile matching, and is therefore, also aerodynamically significant).

4.6.2.2 The above considerations have had an impact upon the structural serviceability, during the AFQT programme conducted to date.

4.6.3 Impact upon the SSHA

4.6.3.1 It is appropriate that the environmental considerations, such as those cited above, be included in the System Safety Hazard Analysis, due to their potential impact upon failure modes and failure rates. However, the SSHA does not address the differing environmental implications of the differing normal recovery, land and seawater, between the MQM-107E and the Kalkara aircraft. Due to the differing environments, there are many areas of the SSHA, which require technical re-justification, *in lieu* of citing the predominantly land recovery MQM-107E design, only.

4.7 **Absence of multiple failure consideration**

4.7.1 For manned aircraft, appropriate airworthiness requirements codes mandate system safety consideration, in the event of reasonable combinations of failures, for example FAR/JAR 23/25.1309. In the case of Kalkara, the following are important considerations, which support the expectation that the SSHA should cover appropriate multiple failures:

a. considering the operational requirements for the System, the Kalkara aircraft may be subject to missile or cannon shell damage, which could result in an uncontrollable aircraft, by disabling the singular autopilot system, singular control surface servos, or singular flight control box (*ie* engine control), and render the recovery system inoperative;

b. due to the relatively high failure rates of some components, to date, there are several reasonable combinations of failures which should be considered in the SSHA, notably a failure condition leading to an uncommanded recovery, in combination with a failure of the EED or parachute.

4.8 Absence of Environmental Qualifications, General

4.8.1 The SSHA does not provide visibility of system component environmental specifications and qualifications. The System Specification document provides an over-arching environmental specification only, whereas individual system components are subject to differing environments, notably those components located in the 'water-proof' nose compartment and those located elsewhere in the aircraft.

4.8.2 Of particular concern to a System Safety critical review, is the lack of visibility of EMI/EMC environmental specifications and qualifications. AFTS understands that AFQT flight tests have raised the question of possible EMI occurring on the aircraft TM system, from the launch-pad electrical power generator.

4.8.3 Another example of a system environmental specification which lacks visibility is a load factor specification, covering, in particular, peak longitudinal acceleration on launch - most probably, a critical load factor for many system components.

5. CERTIFICATION BASIS - APPLICABLE CODES OF AIRWORTHINESS REQUIREMENTS

5.1.1 Contractual documentation that has been sighted by AFTS, to date, does not cite a Certification Basis for the Kalkara system. In conducting the SSHA critical review, AFTS has applied a pragmatic view of the Type Airworthiness Design Standards, which underpin the application of MIL-STD-882C to the SSHA – namely, the Design Standards should generally conform to an appropriate Code of Airworthiness Requirements.

5.1.2 Although Kalkara is a UAV, by definition, an applicable Code of Airworthiness Requirements is one which covers the size and overall design characteristics of the Kalkara aircraft. For example, as a '1400 lb' fixed wing sub/transonic aircraft, the Kalkara aircraft is in the class of FAR/JAR 23 aeroplanes.

5.1.3 Within the Australian realm (and, generally, for the world at large), airworthiness requirements for UAVs are presently in a formative stage. CASA NPRM 9806RP (Reference H) addresses the topic. Under the UAV definitions of the NPRM, Kalkara would be classified as a large UAV. For large UAVs, the NPRM has drafted a requirement that:

> *No person will be permitted to operate a large UAV unless it has either a standard or special certificate of airworthiness issued under Part 21 of the CASRs.*

5.1.4 Part 21 of the CASRs requires Type Certification to be conducted, using an Airworthiness Requirements of suitable applicability. Therefore, this position of the CASA is in accordance with the above philosophy, as it has been applied by AFTS to the Critical Review of the Kalkara SSHA.

6. PARTICULAR AIRWORTHINESS REQUIREMENTS AND ACCEPTABLE DEVIATIONS

6.1 General

6.1.1 In the areas of aerial vehicle design, an unmanned aircraft Type Design which conforms to a contemporary airworthiness requirements code, appropriate to the size/configuration of aircraft, generally would possess a level of airworthiness, which will serve to underpin the level of system safety inherent to the design. However, if the Type Design deviates substantially from the airworthiness requirements code, without providing equivalent safety determinations in the areas of the deviations, system safety will start to lose its underpinning, requiring a greater effort at system safety and hazard substantiation and justification.

6.1.2 The following sections discuss particular aspects of Airworthiness Requirements codes, with which UAV design can be expected to conform, or against which, requirements deviations can be reasonably applied to the UAV design. In particular, deviations would require an equivalent level of safety. For many deviations, the equivalent level of safety might be provided by a digital auto-flight system.

6.1.3 The sections also address areas of the Kalkara Type Design, which present shortfalls against Airworthiness Requirements codes.

6.2 Flight Envelope

6.2.1 In principle, the flight envelope requirements of an Aircraft Airworthiness Code should be applicable to a UAV, without any deviations, peculiar to the UAV *genre* of aircraft. The flight envelope will undoubtedly be established by the flight performance specification for the UAV design. The load factor limits of the flight envelope are generally established by the manoeuvre specification for the UAV design.

6.3 Structural strength

6.3.1 For in-flight static structural strength design, the normal load factor limits will be dictated by the manoeuvre specification for the UAV design, with a margin, appropriate to the control, including overshoot/damping characteristics of the auto-flight control system of the aircraft. In the case of the Kalkara aircraft, the manoeuvre specification calls for steep turn manoeuvres at load factors up to, and including, 6g. The longitudinal structural strength, in the case of Kalkara, is established by the longitudinal peak acceleration experienced during the launch sequence. This acceleration would be greater than that experienced during the launch of a manned aircraft.

6.3.2 Furthermore, water recovery-induced loads are extraneous to manned aircraft airworthiness requirements codes. With due regard to the re-useable requirement for the Kalkara aircraft, the splashdown loads, in the event of system failure conditions, could generate the critical structural strength design requirements, including:

a. a failed parachute, could become critical peak structural design loads for skin panels, fuselage and wing primary structure; and

b. failure of a normally-deployed parachute to release from the aircraft, following splash-down, the result of which is the dragging of the aircraft backwards through the water.

6.3.3 As structural design requirements, neither of these conditions has visibility in the SSHA. If the underwater dragging loads have not been considered as a design requirement, then the occurrence of such loads would constitute a design exceedance condition, which has damage tolerance and airworthiness implications, requiring, for example:

a. inspection procedures, for the identification of structural damage, resultant from the design load exceedance encounter;

b. repair procedures, detailed in the Structural Repair Manual, for all the resultant damage; and

c. damage tolerance analysis, for tracking the consequences of such design load exceedances, upon structure, which is inaccessible to inspection.

6.4 Damage tolerance and fatigue of structure

6.4.1 It is appropriate, that a large re-useable UAV comply with the damage tolerance and fatigue requirements of an appropriate aircraft airworthiness code. Given the re-useable requirement for the Kalkara aircraft, the following design coverage and operational environmental envelope should be considered:

a. structural fatigue analysis and justification; and

b. a high probability of design load exceedance encounters, such as
   (1) splashdown loads, with parachute failure,
   (2) post-splashdown, with attached parachute, and
   (3) 'bump' loads, occurrent during retrieval from the sea, boat, and lorry;

damage tolerance and fatigue characteristics of the Kalkara aircraft structure require special consideration.

6.4.2 Each Kalkara aircraft is to be operated 'indefinitely', on-condition. Without the determination of a fatigue life, either by number of flights or accumulated flight-time or, manoeuvre and shelf life (with due regard to the corrosion of some structural elements), a clearance-to-fly requires full accessibility for the required on-condition structural inspections. Wing centre-structure and elevator drive torque-tubes are two examples of structure which is inaccessible for visual or other inspection.

6.5 Flight characteristics - performance

6.5.1 <u>Takeoff</u>

6.5.1.1 A FAR/JAR 23 aeroplane is required, under 23.53, to have an airspeed margin above stalling speed. Generally, a 20% margin is demonstrable, but rarely lower. For an unmanned aircraft, which has an automated takeoff/launch sequence of flight control, a lower margin could be acceptable for Type Certification, if the following conditions are met:

a. It is demonstrated by flight test that the automated system results in greater repeatability of significant aerodynamic parameters through the takeoff/launch phase, particularly peak incidence (angle-of-attack); together with the standard deviation in peak incidence of the flight test data-set, the margin should result in an exceedance probability which is no greater than that of manned aircraft;

b. The selected margin should be sufficient to account for the combined effects of:
   (1) Design wind gusts, in tailwind and headwind conditions,
   (2) Production tolerances.

6.6 Flight characteristics - handling

6.6.1 Stalling

6.6.1.1 Manned aircraft airworthiness requirements, applicable to FAR/JAR 23 classes of aeroplanes, require, in relation to stalling, that:

a. any uncommanded rolling motion is correctable by aileron application, and, does not exceed a roll displacement of 15°, when the aircraft is recovered from the stall, upon recognition;

b. in a turning-flight stall, a roll displacement of 30° into the turn, or 60° out of the turn, and no spin tendency.

6.6.1.2 The stalling characteristics of the Kalkara aircraft have an implication upon System Safety and Hazard Analysis. Typically, the stall handling qualities of swept-wing aircraft exhibit roll/yaw accelerations and coupling to a much greater extent than straight-wing aircraft. Furthermore, the combination of a long fuselage and short-span/swept-wing can lead to a departure, or spin tendency, at the stall. Kalkara could fall into this category of handling qualities.

6.6.2 Manoeuvrability

6.6.2.1 An aircraft, which could exhibit a spin tendency at the stall, but does not have stall warning or protection, has an inherently greater risk of stall-departure during flight. Of particular concern, is the margin from stall incidence, during the conduct of steep turns. Flight testing (AFQT 18) has demonstrated that, upon entry to a 6g turn at 280 KIAS, the peak incidence achieved an estimated value of approximately 95% of the 1g stalling incidence (refer, Annex A), which is a low margin.

6.6.3 Static lateral stability

6.6.3.1 Airworthiness codes for fixed-wing manned aircraft generally require positive dihedral effect, or stick-free static lateral stability derivative, for FAR/JAR 23 aeroplanes, at airspeeds above $1.2V_{SI}$, and, for FAR/JAR 25 aeroplanes, at airspeeds above $1.2V_{SI}$, with the exception that, above V_{LE}/V_{FE}, the static lateral stability may gradually diverge to negative values. Aerodynamic analysis of the AFQT flight tests of Kalkara has indicated (Annex A) that the aircraft has negative static lateral stability, of potentially significant magnitude. This may be an acceptable flight handling quality for an automated aircraft, if equivalent safety is provided by an automated digital flight control system (DFCS).

6.6.4 Dutch roll damping

6.6.5 Manned aircraft handling requirements dictate a dutch roll damping ratio of about 0.35, in order that excited dutch roll oscillations will dampen in seven cycles. For an automated unmanned aircraft, an equivalent level of safety may be provided by a full authority and full-time DFCS, which dampens dutch roll oscillations by active control surface movements.

6.7 Flight control and system status displays

6.7.1 The GCS Controller Display presentation is an important part of the Kalkara system design, for the following reasons:

a. The Kalkara is a high performance aircraft;

b. Presently, until further resolution, manual flight intervention is occasionally required, due to limitations in aircraft aerodynamics and DFCS design; and

c. The controller is working very much in a sensory-deficit environment, insofar as there is no tactile or aural feedback, and very little motion perceptive feedback.

6.7.2 In this sensory-deficit environment, maximising the effectiveness of visual feedback, *via* controller displays, assumes the position of being a fundamental design requirement. In fact, the design requirement assumes greater importance than it does on a manned aircraft, for which the presentation of the displays complies, for example, with 23/25.1321. The Kalkara Controller Flight Display design does not comply with a 23/25.1321, for example. The results of the non-compliance have been evidenced through the course of the AFQT flight tests, and has had a serious effect upon System Safety. The non-compliances and design deficiencies are discussed in-depth, later in the report.

6.8 System integration and compatibility

6.8.1 With due regard to those areas of deviation from an airworthiness requirements code, where an equivalent level of safety is provided by an auto-flight system, the installation integration and compatibility, normally guided by 23/25.1309 for a vehicle of this size, should be designed and assessed to a greater level of integrity, than otherwise would be the case if an equivalent safety determination were not being sought. For example, in the present context, 25.1309 (a significantly higher level of airworthiness than 23.1309) would be more appropriate than 23.1309.

7. ENVIRONMENTAL QUALIFICATIONS - CERTIFICATION CRITICAL PATH

7.1.1 Comparing the MQM-107 and Kalkara, the normal operational environment has changed, from land recovery for the MQM-107, to sea recovery for Kalkara. The engineering documentation, including Type Record, for Kalkara, does not provide visibility of an inculcation of the change of environment. The AFQT programme has been embarked upon with a land recovery aircraft design, and with an approach of solving problems along the way. Such an approach leads to an open-ended programme, which is not supportive of a conclusive Type Certification flight test programme. In this regard, the environmental envelope issue for aircraft system components is the Type Certification critical path 'bottleneck'.

7.1.2 An appropriate design and certification procedure for components of the aircraft systems can be summarised, as follows:

a. Environmental specification - altered to reflect the seawater recovery environment, which leads to:
   (1) Aircraft configuration design specification changes - the incorporation of a water-proof avionics section in the aircraft (done), an important design feature, given the COTS nature of many system components,
   (2) Component environmental specification changes - to include seawater immersion, for the EED, flight control box, servos, tailcone, parachute deployment and parachute jettison 'squib' assemblies;

b. Environmental test definition, for design qualification:
   (1) For the aircraft waterproof compartment:
      (i) a 'driving rain' test, using seawater, to simulate the splashdown event,

(ii) an immersion test, using seawater, to simulate immersion, with the simultaneous application of appropriate vibration and shock load spectra;

(2) Depending upon the outcome of (1), for system components within the waterproofed compartment:

(i) a 'driving rain' test, using seawater, to simulate the splashdown event,

(3) For components subject to immersion:

(i) a 'driving rain' test, using seawater, to simulate the splashdown event,

(ii) an immersion test, using seawater, to simulate immersion, with the simultaneous application of appropriate vibration and shock load spectra; and

c. Proceed to flight test validation of the test-cell-qualified seawater-proofness and seawater resistance of system components.

8. ANOMALIES AND FAILURES

8.1 Flight Test

8.1.1 During the Australian Flight Qualification Trials, a variety of anomalies and failures have occurred which have a safety and hazard implication. The following is a brief summary of the flight tests and those events which are considered to have safety implications:

8.1.1.1 AFQT-01. Aircraft S/No 002. Uncommanded right roll (5º - 10º roll) after separation of the RATO, corrected by the DAP.

8.1.1.2 AFQT-02. Aircraft S/No 003. Uncommanded right turn (20º roll) after separation of the RATO.

8.1.1.3 AFQT-03. Aircraft S/No 002. Uncommanded right turn (significant roll) after separation of the RATO, corrected by the controller after some delay.
Separation of Left Pod shortly after launch.
Tail Cone micro-switch failure.
Failure of the Power Distribution Panel resulting in an uncommanded recovery when the battery voltage dropped below 22 VDC.

8.1.1.4 AFQT-04. Aircraft S/No 003. Uncommanded right turn (significant roll) after separation of the RATO, corrected by the controller to maintain the aircraft within the launch corridor.

8.1.1.5 AFQT-05. Aircraft S/No 002. Uncommanded right turn, after separation of the RATO, controlled by the controller. Aircraft stayed within the launch corridor.
Right tow separated after launch due to tow cable failure.

8.1.1.6 AFQT-06. Aircraft S/No 005. Uncommanded recovery due to LOC.

8.1.1.7 AFQT-07. Aircraft S/No 002. Uncommanded left turn (25º Roll) corrected by the DAP, pitch attitude on launch higher than normal (Approx 30º).

8.1.1.8 AFQT-08. Aircraft S/No 003. Pitch Attitude higher than normal (34.8º), however straight launch.
Separation of a deployed Tow from its tow cable.

8.1.1.9 AFQT-09. Aircraft S/No 002. Apparent GPS failure resulting in loss of aircraft position by the controller. Aircraft flew outside of the EAXA exercise area. Investigation showed that the fault was in the GCS software and the GPS was functioning correctly.

8.1.1.10 AFQT-10. Aircraft S/No 002. No safety related anomalies or faults.

8.1.1.11 AFQT-11. Aircraft S/No 003. Uncommanded right turn, corrected by the controller. Aircraft stayed within the launch corridor.

8.1.1.12 AFQT-12. No report available.

8.1.1.13 AFQT-13. No report available.

8.1.1.14 AFQT-14. No report available.

8.1.1.15 AFQT-15. No report available.

8.1.1.16 AFQT-16. No report available.

8.1.1.17 AFQT-17. No report available.

8.1.1.18 AFQT-18. Aircraft S/No 005. No report available. Flight witnessed by A. Brown (GCS) and the following noted:
Uncommanded right turn (25º roll), corrected by the DAP.

8.1.1.19 AFQT-19. Aircraft S/No 003. No report available. Flight witnessed by A. Brown (launch pad) and N. Frost (GCS) and the following noted:
Left and right roll excursions starting before RATO separation and up to ±25º (Dutch Roll), corrected by DAP after approximately 20 seconds.

8.1.1.20 AFQT-20. Aircraft S/No 002. No report available. Flight witnessed by A. Brown (GCS) and N. Frost (launch pad and lighthouse for recovery) and the following noted:
Uncommanded roll instability and roll offset resulting in a right turn (+40º roll) through an estimated 130º well-outside the designated launch and departure corridor. This deviation was controlled and the mission successfully completed. Recovery was normal.

8.1.2 The anomalies and failures listed above represent safety hazards based on the engineering rationale and logic, presented in the following sections.

8.2 Inherent Aerodynamic Stability, including launch stall margin

8.2.1 Annex A presents a detailed aerodynamic state analysis, in particular incidence and sideslip, of the launch flight paths of the AFQT test flights of Kalkara. The analysis results in several conclusions and recommendations, presented in Annex A. In particular, the peak launch estimated incidence appeared to be of a similar order of magnitude to the probable stall incidence. The uncommanded rolling motions displayed by the aircraft on many occasions, were symptomatic of asymmetric wingtip flow separation.

8.2.2 Although flow reattachment variably occurred, the extent of aerodynamic hysteresis and its effect upon dihedral effect, or static lateral stability, is uncertain. Following an extent of reattachment, the DAP generally did not control the roll angle to wings-level. The analysis indicated that, in this quasi-steady condition, the static lateral stability margin was negative.

Correct aerodynamic modelling, with due regard to potential changes in the margin introduced by configuration changes, such as wingtip 'near-miss' antennae and underwing target differences, may be a factor in the ineffectiveness of the DAP to level the wings, following the roll excursion, most probably induced by flow separation.

8.2.3 The impact upon System Safety concerns:

a. the ability of the Kalkara aircraft system to maintain controlled flight, following the achievement of peak incidence; and

b. the ability of the Kalkara aircraft system to maintain a launch corridor, following the occurrence of roll excursions;

during the initial launch phase, particularly under aggravated aerodynamic conditions imposed by surface wind gustiness (the Flight Manual wind envelope for launch includes 50 knots headwind, 27 knots tailwind and 20 knots crosswind - a wide envelope) and with considerations of such variables as production tolerances and airframe surface condition, eg skin dents or dimples, fairings ‘spreading’ due to fastener hole wear etc.

8.2.4 As the EAXA for Kalkara is planned to be the JBRF, a National Park with residential areas within a few kilometres of the launch site, then there is a probability of endangering human life due to such potential flight path excursions at launch.

8.2.5 Furthermore, the extent of aerodynamic disturbance is such that, appropriately, the flight test programme has not covered the full range of target configurations (and, nor should it, until further investigation, analysis and configuration development, as detailed in Annex A), denying the system full operational capability.

8.3 Stall margin, g turns

8.3.1 AFQT provided flight data on a 6-g turn entry, followed by a level-flight stalling manoeuvre, engine-OFF. Analysis of the data indicated that the peak incidence during the 6-g turn entry was a similar order of magnitude as the stall incidence. The aerodynamic stall was defined by a roll-break similar to the flight motion dynamics of the launch phase. Note, the configuration was aerodynamically asymmetric at this stage due to the failure-to-release of a target tow-line resulting in aileron deflection in order to balance.

8.3.2 As it stands, therefore, there may be a risk of departure during high-g turn entries, moreso during lower mid and low level manoeuvres, where wind gust magnitude can be expected to be generally greater than upper mid levels. This has an implication on the area of operations for such manoeuvres.

8.4 Recovery

8.4.1 Coupled with the uncommanded turns, loss of position reporting in the GCS and loss of battery voltage, there is a non-remote probability of an uncommanded or unscheduled recovery occurring at any point during a Kalkara flight. With due regard to failures that have occurred during the AFQT flight test programme, there is a serial probability of failure of the parachute recovery system to operate correctly (in spite of some redundancy in the parachute deployment system). This system is not fully redundant, but remains 'single-path', by virtue of the singular EED and single tailcone micro-switch. This serial probability of failure exists for the following reasons (all of which have occurred, during the AFQT flight test programme):

a. Failure of the EED;

b. Failure of the tailcone micro-switch; or

c. Failure of the parachute to deploy.

8.4.2 Of the failures, several EED failures have been caused by seawater ingress; the micro-switch (an unsealed type of switch) reportedly due to the combination of overload upon installation and water ingress; and the deployment failure reportedly due to packing problems.

8.4.3 The SSHA does not consider any multiple failure sequences, whether collateral, related, or reasonably sequential. In this case, although serial failures, such a failure scenario (uncommanded recovery with parachute/deployment system failure) should be fundamentally addressed in the SSHA, particularly as the end-result could be a high-energy (kinetic and chemical, due to unused fuel) ground or sea vessel impact.

8.4.4 As the system is presently designed, and exhibiting component failures at present rates, it is appropriate that Kalkara fly, as far as possible, over land/sea surfaces, which are clear of people. The present philosophy of clearing the area for target tow-line dropping should be extended, for the cases of:

a. Uncommanded recovery (as discussed above);

b. Unscheduled recovery;

c. Failure of a target tow-line attachment, or structural failure of the target attachment, resulting in the unscheduled release of a target; and

d. Failure of a target to release, when commanded.

8.4.5 The case for extending the philosophy is simply based upon the high cumulative frequency of above failure cases, in the AFQT flight test programme. The situation is compounded by the present controller display which lacks:

a. positive annunciations of the full deployment of all towed targets; and

b. positive indication of jettison of the towlines of long-tow targets.

8.4.6 With towed targets still attached, the failure propensity for the parachute recovery system to correctly operate and deploy is increased, due to the possibility of entanglement and the different dynamic motion characteristics. The implication of the lack of such configuration annunciation is that, unless separation can be visually confirmed (by a chase aeroplane), every recovery should be considered as having a reasonable failure probability, and the impact CEP be treated accordingly for recovery area clearance.

8.4.7 An example of an occurrence is the unscheduled recovery on FQT 18. The on-task flight track for the aircraft was 'cleared' for towline releases, but not for overpasses. In particular, a yacht was observed in the southern part of the track. The decision was taken to confine tow-line releases to the northern region, but to maintain track, so that overpasses in the vicinity of the yacht continued. Following engine failure, in response to a negative-g pitch-down, with a 50% fuel load in the centre-tank, during exit from an aborted 6-g turn entry, an unscheduled recovery was conducted, in the approximate vicinity of the earlier sighted yacht.

8.4.8 In addition, considering full operational service (for which, it is assumed, launch stall margins shall be satisfactorily developed and validated) and with due regard to the possibilities of:

a. RATO hang-up on launch; or

b. Engine failure on launch;

it is considered entirely appropriate to install gates on the road running past the eastern end of the Jervis Bay aerodrome, at the intersection of the launch splay plus buffer, with GCS controlled booms, so that road traffic will be inhibited from entering the launch safety zone during Kalkara launches.

8.4.9 Concerning all issues of clearing operating and recovery areas, DID No. 033 (Reference N) specifies full clearance of unauthorised vessels, and minimum RAN vessel/RAAF aircraft separation criteria. It does not specify a cleared launch/departure corridor, however. With due regard to the above considerations, AFTS firmly recommends that such a procedure is specified and instituted. Furthermore, AFTS recommends that reasonable multiple failures be included in the SSHA, following which the separation criteria from vessels and aircraft be reviewed in light of such realistic multiple failure conditions.

8.5 Payload attachment structural failure

8.5.1 Of fundamental concern to System Safety, failure of the structural attachment of the wing-mounted targets have occurred, basically due to sideloads (most probably, dynamic) and have resulted in re-design, consisting of:

a. Pylon boattail extensions; and,

b. Target locating spigot installations, using the pylon extensions.

8.5.2 Such structural failure possibilities are not considered in the SSHA. This raises some concern as to the guidance from the manufacturer on structural damage tolerance and inspection for such considerations as fatigue effects.

8.5.3 On the matter of the overloads and structural failures, AFTS considers that the tangent-ogive boattails to the RF tows could be contributory to high dynamic loads due to asymmetric harmonically non-steady vortex shedding from the boattails (refer to the following photograph). A truncated boattail, which 'anchors' flow separation and prevents the establishment of harmonically unsteady flow separation, would result in lower dynamic loads.

8.6 Structural integrity

8.6.1 As discussed earlier, there are a number of issues, associated with the operational environment (particularly the seawater-recovery environment, which impact upon the structural integrity of the airframe, including:

a. dynamic loads definition,

b. water drainage, from internal recesses,

c. corrosion, and

d. other damage tolerance, for example, mission-induced damage.

8.6.2 It is possible that a minor structural deficiency could have a significant impact. An example is the elevator torque-tube universal joint which is fabricated from steel with no apparent corrosion protection. Under accelerated wear, due to corrosion, backlash could be introduced to the elevator, reduced aerodynamic damping, and possibly, a reduced flutter margin. Therefore, the SSHA should cover the possibility of a reduced aeroelastic margin, and the resultant impact upon System Safety.

8.7 Maintenance and Reconditioning

8.7.1 It is apparent from the twenty flights that there have been teething problems with the reliability of the LRUs and “finger trouble” during the maintenance, reconditioning, and flight preparation. While these issues may be resolved as part of the flight test program, they can have safety implications and those in that category are reported as part of the Critical Review.

8.8 Component failure

8.8.1 The leakage of water past seals and into LRUs has caused problems during the AFQT. Some LRUs, in particular the EED panel, have been replaced after almost every flight due to failure to pass the sub-system electrical test. It is considered possible that water could still be present in the enclosure for the EED panel even if it passes the test, thereby causing a failure as the water “slops” around inside the box. To date there have been a total of seventy one LRU failure reports raised which include those due to water ingress.

8.9 Radar altimeter

8.9.1 The radar altimeter system is undergoing re-design, in order to improve the receiving antenna signal reliability. This modification programme has been a direct result of the AFQT flight tests. It is an example of the developmental aspect of the AFQT programme, and hence, of insufficient Type Design maturity for the award of Type Certification, at the moment.

8.10 Display-induced controller errors

8.10.1 Given the sensory-deficient operational environment for the Kalkara Controller, it is important that the Controller Display maximises the sensory cues for the Controller, especially for the control of a high-performance UAV. Maximisation of sensory cues will be obtained by standardising the Display to aircraft instrument display requirements, particularly as it is appropriate that the Controller be an experienced pilot; for example, as drafted in Reference H:

The proposed new Part will require the operator of either a small UAV intending to operate above 500 ft AGL or a large UAV to be the holder of a pilot licence.

8.10.2 Presently, the MAGIC^2 Controller Display presentation does not comply with the electronic display and arrangement/visibility requirements of an appropriate aircraft airworthiness requirements code, such as 23/25.1311, Electronic display instrument systems, and 23/25.1321, Arrangement and visibility, relating to the installation of flight and navigation instruments, notably in the following areas:

a. 23.1311(a)(6): the sensory cues, provided by the Display, are inadequate; in particular, the choice of a fixed-card compass (with larger heading tags at 15° intervals and smaller tags at 5°), although in accordance with the 'North-upwards' orientation of the adjacent Nav Display, is in disagreement with the ADI, which has heading indicated, appropriately, as 'aircraft-nose' orientated, and can lead to laterality errors, particularly in turn direction. Laterality errors have occurred during the AFQT flight test programme. An appropriate compass format would be a rotating card/lubber-line, with larger heading tags at 10° and smaller heading tags at 5° intervals.

b. 23.1311(a)(7): the Display does not incorporate, *in toto* or adequately, visual displays to alert the Controller to abnormal 23.1542 to 23.1553 parameter values (relating to flight and engine parameters; appropriate changes to alerts should include:

(1) *EGT:* presently, the EGT indicates Fsd for two conditions: engine-OFF and engine over-temperature; no over-temperature conditions have occurred, whereas every launch is preceded by several hours of Fsd-red colouration; therefore, the Controller is conditioned to Fsd-red being an expected condition; for the red to be an effective alert, in compliance with 23.1321(a)(7), an appropriate colouration of the EGT tape would be:
(i) non-operating, no visible indication,
(ii) below self-sustaining - amber (indication to be coupled with a CAP ENG FAIL indication),
(iii) within the normal operating range - green, and
(iv) above the EGT maximum operating limit - red;

(2) *Caution conditions:* presently, for example, the busbar voltage indicator is a horizontal tape, which changes colour to yellow in an under-voltage condition; standardisation to 'amber' for all caution indications would comply with 23.1322;

(3) *RPM:* similar colouration on the RPM indicator would be appropriate;

(4) *Engine Alerts:* associated with the EGT and RPM indications, CAP-located ENG FAIL (amber) and ENG FIRE (red) annunciators would provide high visibility indications of engine abnormality conditions, in compliance with 23.1311(a)(7)

(5) *Stall warning:* as previously discussed, a stall warning system is necessary, and stall protection is highly desirable; stall warning can be provided by an amber colouration change on the airspeed tape, below stall-warning airspeed V_{SW} (computed in software, including a g-level input into the algorithm), plus an aural warning; stall protection could be provided by an automatic switch to airspeed-hold at V_{SW}, until the throttle is advanced;

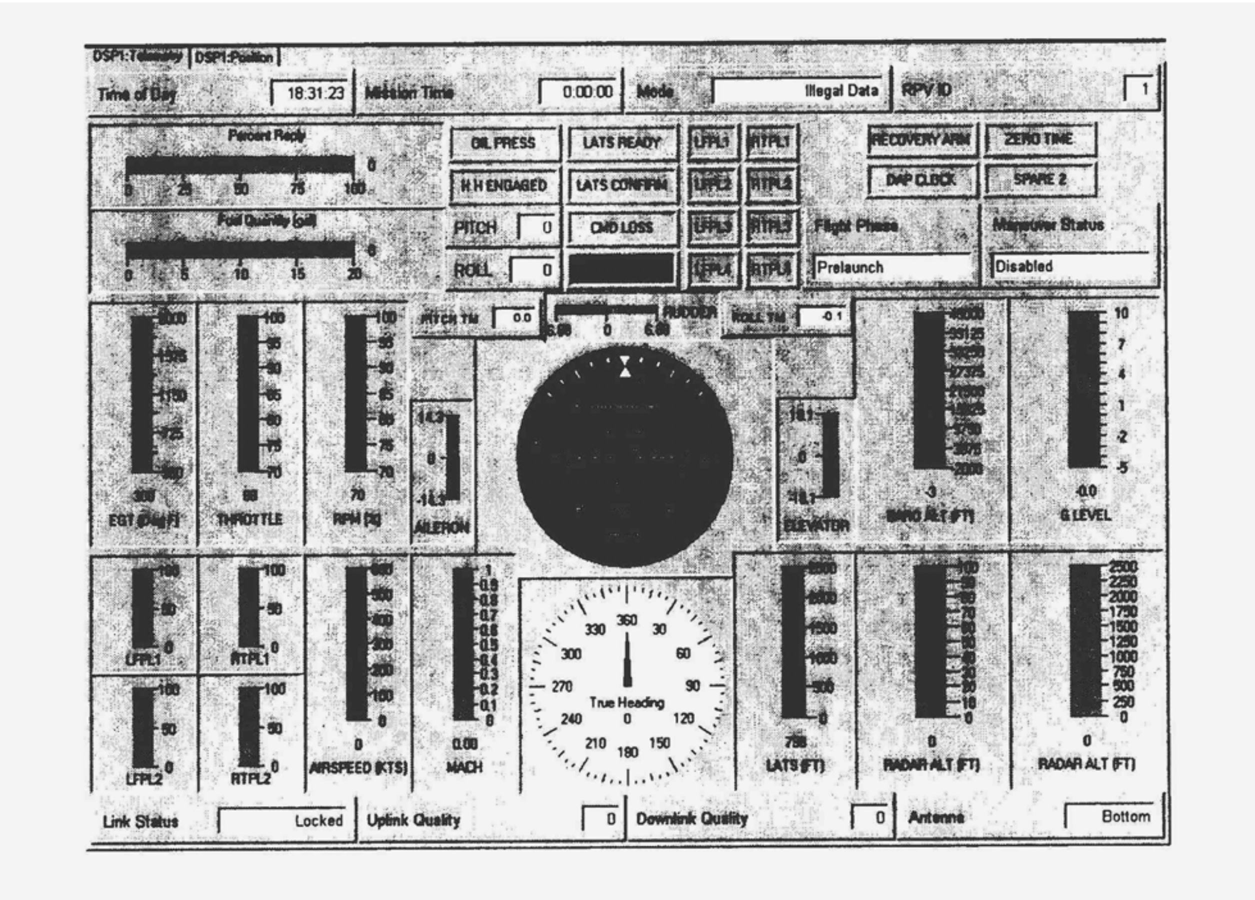
(6) *Aural alerts:* the following aural alerts accord with contemporary aircraft design practice, and would assist the Controller to avert/manage emergency situations (all warnings could be generated in software):
(i) stall warning,

(ii) engine fire bell, and

(iii) Mach overspeed clacker.

c. 23.1311(b): considering Loss of Display, a failure which has occurred during AFQT flight testing; under this requirement, an automatic changeover to the range Safety Officer Displays is required.

d. 23.1321(a): presently, the Controller's Primary Display does not contain any navigation information; rather, in order to maintain a navigational awareness, the Controller must refer to the Controller's Navigation Display, adjacent and to the left of the Primary Display. The Navigation Display is oriented 'North-upwards'. This is appropriate for situational awareness, during area operation. However, during high-gain controlling, particularly launch, referral to the Navigation Display, in order to maintain an awareness of launch tracking, can result in laterality errors when course correction inputs are made by the Controller, *i.e.* turning the wrong direction. Laterality errors have occurred during the AFQT flight tests. An appropriate navigation display on the Primary Display would be a Horizontal Situation Indicator, where the Course Deviation Indicator scales to full_scale_deflection = launch_tolerance_splay_edge (excluding buffer). With such a nav display on the Primary Display, the Controller would have no requirement for looking at the Navigation Display during the launch phase.



e. 23.1321(d): requires the 'standard-T' presentation of flight instruments, with which the Primary Display does not presently comply; the present display is illustrated in the following diagram.

8.10.3 In order to comply with a 23.1321(d) presentation requirement, the basic flight parameters of airspeed and altitude need to be moved to the left and right positions, adjacent to the ADI. The following example of a compliant presentation follows the contemporary standard for HUD displays, namely counter-pointer indicators for airspeed and altitude, with Mach Number and load factor alphanumerically indicated, below the airspeed indicator, and radar altitude and LATS datum radar altitude, indicated alphanumerically, below the altimeter indicator. This standard presentation declutters the flight instrument section of the Controller's Primary Display.

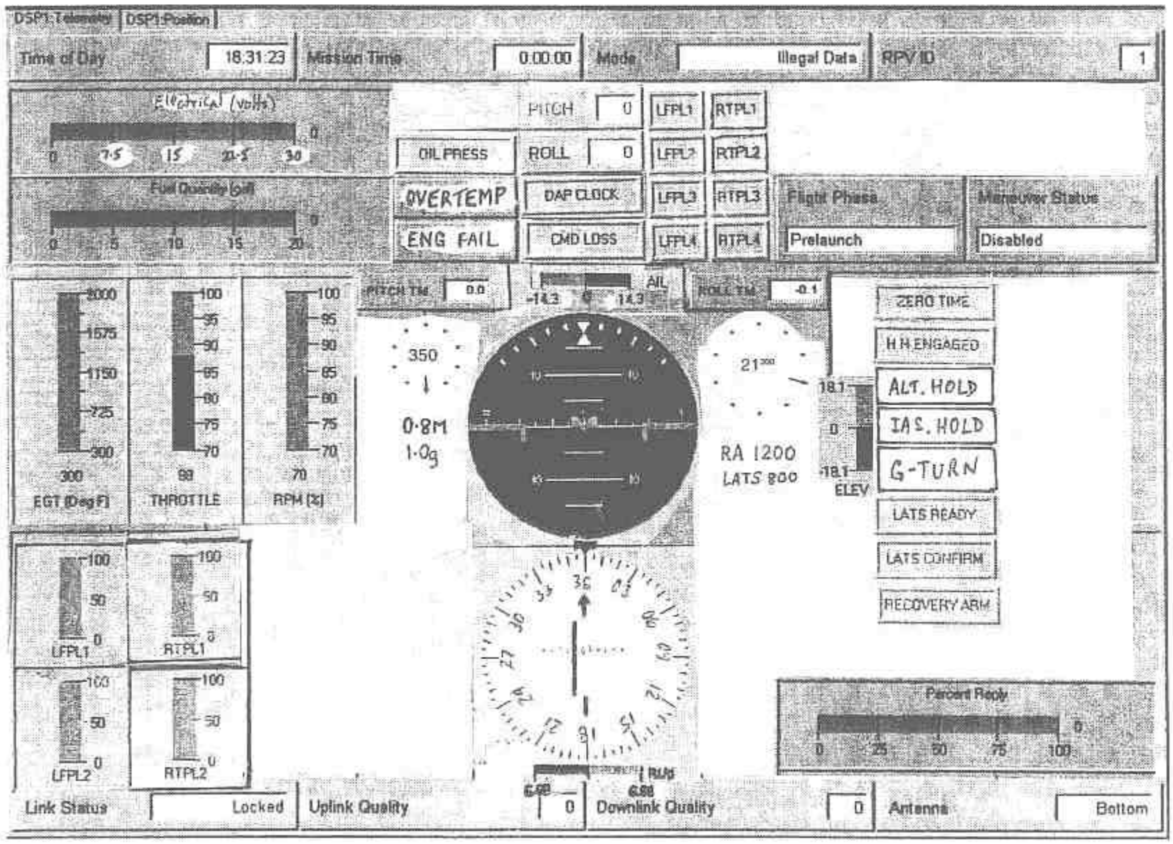
8.10.4 The navigation instrument presentation requirement is satisfied by the transformation of the compass indicator to an HSI. The engine and related instruments (fuel and busbar voltage indicators) are grouped together. Although the engine instruments are located in the non-standard position to the left of the airspeed/Mach indicators, being adjacent to the airspeed indicator maximises sensory perception of the power/performance relationship; engine OVERTEMP and ENGine FAILure annunciators have been added to the CAP, and normal autoflight system status annunciators (coloured green, as opposed to the two emergency conditions, LOC and loss of DAP clock, coloured red) grouped alongside the primary flight display section of the Display.

8.10.5 In the design of the annunciators, the contemporary 'quiet and dark' standard of aircraft design should be applied, namely that the annunciators remain unlit until activated ON by a status or condition. The Percent Reply indicator has been grouped with the UPLINK and DOWNLINK status indicators, along the bottom of the Display.

8.10.6 The aileron, elevator and rudder deflection indicators have been re-positioned, so that their sense of motion corresponds to the associated response of the aircraft.

8.10.7 All such changes to the Display presentation could be made in software, including activation of the engine emergency condition annunciators; for example, software sensing of an uncommanded RPM rollback could be used to activate the ENG FAIL annunciator.

8.10.8 The proposed changes to the Display presentation are to be seen against the yardstick of improving system safety, by reducing the propensity for the Display presentation to induce Controller errors. Some elements of the changes constitute the extent of contemporary indicator symbology (*viz.* Head-up display symbology) which can be integrated with the existing basic ADI and compass-card displays. However, given the usage of DGPS in the Kalkara system, the Display is ripe for a 4-D 'highway in the sky' integrated attitude/direction/flight path display, including an aircraft-perspective presentation of terrain surrounding the two launch-sites, generated from a look-up data-base, triggered by the DGPS position. Such a display would reduce the propensity to induce Controller errors by an order of magnitude, or greater.



8.10.9 In addition to the Primary Display, the Controller's switch panel is a further Type Design matter, which has a detrimental impact upon System Safety, by inducing Controller errors, in normal and emergency selections. Pertinent features of the panel and improvements, which would reduce the propensity for inducing errors, and hence improve System Safety, include:

a. Presently, the selector switches are:
   (1) Closely grouped,
   (2) Not separated into sections (targets/recover/auto-flight),
   (3) All similar,
   (4) Push-button, lacking in texture, or other tactile presentation.

b. Auto-flight control switches should be grouped, so as to be selected by the 'flying hand', in other words, located to the right of the control column; presently, it is located to the left of the column, amongst the other switches; being a 'flying control', the present location opposes the natural tendency for the Controller to use the right hand (the 'flying hand'), resulting in a tendency to cross-hands, in order to activate the g-turn, as has been witnessed by AFTS, resulting in obscurity of the switches and a likelihood of subsequent incorrect selections.

c. Being of the same design as, and co-located with, other switches, primary emergency selectors are difficult to select, in emergency situations; rather, by design, the primary emergency selectors should be separated by location and tactile presentation; in particular, in order to prevent incorrect selection during an aborted launch manoeuvre, it is appropriate that the emergency parachute deployment selectors should be, either an isolated 'mushroom-head' switch, activating differently-timed relays simultaneously, or a guarded 'pickle', performing the same function.

9. OMISSIONS FROM THE SYSTEM SAFETY HAZARD ANALYSIS

9.1 General

9.1.1 AFTS has reviewed the System Safety Hazard Analysis, Reference C, against the requirements of Reference B. A number of significant omissions have been noted. Much of the preceding discussion is relevant, to the following list.

9.2 SSHA as reflective of a System Safety Program

9.2.1 The SSHA appears to have been raised to satisfy the requirements of the contract to provide the Kalkara System. It does not appear to be the result of a System Safety Program, instituted at the beginning of the development as required by Mil-STD-882C. Consequently, the historical development of the design, the tests and evaluations of failures during development or product improvement over the five variants is not reflected in the SSHA.

9.3 Multiple failures

9.3.1 The SSHA, paragraph 1.2, states that ”multiple failures are not specifically listed”. As multiple failures are possible, analyses that determine a probability of all failures occurring through a hazard path needs to be provided for the Commonwealth to have disclosure, and therefore, develop confidence or otherwise, in the assessment of the significance of such failures. A definition for the combinations of probability would be required in order to establish a qualitative description of the resultant probability. A sample of suggested combinations of probabilities is as follows:

Incredible + Incredible = Incredible

Incredible + Improbable = Incredible

Improbable + Remote = Incredible

Remote + Probable = Improbable

9.4 Payloads

9.4.1 The SSHA does not address the differences in airframe or payloads between the MQM-107E and the Kalkara. A photograph of the Kalkara payloads is shown below. While the description of the differences is included at the upper level of Reference E, there is little in the way of detailed information or any analysis of the actual difference (some analysis of the wing modifications are provided – Reference I) or a reliability analysis of the new equipment and components installed in Kalkara.

9.5 Hazard Severity Categories

9.5.1 The Hazard Severity Categories are not tailored to Kalkara operations. While it is understood that these Categories were specified by the Commonwealth, those listed make it difficult to relate the possible hazard severities to the hazards associated with the operation of the Kalkara. Category I, for example, would be easier to relate to Kalkara if it read "death or serious injury, destruction of vehicle, mission failure or major property damage" rather than "Multiple deaths". References to illnesses in the Accident Severity Categories, where there is no likelihood of illnesses due to Kalkara operations, does not provide for a clear definition of the hazard severity.

9.6 Coverage of flight test failures/occurrences

9.6.1 The SSHA does not address the known problems with the Kalkara: *e.g.*

a. roll instability and residual roll angle on RATO release (as has occurred on many flights of the twenty flights);

b. loss of position reporting in the GCS;

c. water ingress in LRUs; and

d. failure of payload interface connection.

9.6.2 While these may not have been reported during US Flight Qualification Trials due to the different category of the aircraft (ie a Guided Missile in the US versus a Target Aircraft in Australia), there should, nevertheless, have been an analysis of the known failures of the flight control system and the recovery system and, in addition, an assessment of the aerodynamic performance of the aircraft to provide a justification for the stated hazard severity and probability range. Reference to flight test reports, analysis and past problems and performance for the airframe would provide confidence in the chosen levels. A detailed analysis of the launch flight dynamics and mechanics, based on the twenty Australian AFQT, is provided at Annex A.

9.7 Auto-recovery system

9.7.1 The hazard analysis depends heavily on the auto recovery function to mitigate the risks. The parachute deployment has many redundant systems, however, the parachute may still fail to open. Failure of the parachute to open is covered in the SSHA, however, there is no justification for the probability of "improbable".

9.7.2 Several parachute failures have been reported in US operations and there has been one instance of parachute failure-to-open during the twenty flights in Australia– a probability of 0.05 which does not equate to "improbable" and is unacceptable, for Type certification. Although a loss of the target has been indicated for this event, the question arises as to whether this applies to a land recovery or does this failure cause loss of the aircraft on impact with water also? Indications are that it may not. What are the probabilities of a parachute failure-to-open combined with an emergency recovery due to an aborted take off over land (populated areas)?

9.8 Accident Severity Categories

9.8.1 No justification has been provided for the Accident Severity Categories and the Probability Ranges that have been selected for each event. In many cases, the success of the unit in past operations has been cited with no further explanation or reference to other data.

9.8.2 The auto-recovery process is initiated by the Transponder and operates through the DAP. There is no information provided on the probability of hardware failure in the transponder or DAP, how such failures would affect the control of the target or other consequences of such a failure. In addition the failure of the EED panel due to water ingress from a previous flight could cause the failure of the parachute to deploy, or an uncommanded deployment of the recovery system, at any point from launch of the target aircraft.

9.9 Engine/RATO failure on launch

9.9.1 Due to the launch being close to populated areas, the launch sequence is most critical. No probability analysis has been provided for the failure of the RATO or engine during the launch phase. Similarly no analysis has been presented for the determination of the probability of failure of payload attachment (other than an investigation for a failure that has occurred).

9.10 Airworthiness standards

9.10.1 Airworthiness of the Kalkara system has obviously been difficult to assess as there are no known airworthiness standards for target aircraft. Application of airworthiness standards for military or civil aircraft may not be appropriate and would therefore require tailoring. The System Specification for the MQM-107E (Reference F) provides some standards for target aircraft, however this standard is based on the concept that the MQM-107E is a guided missile rather than an aircraft with the ensuing limitations of airworthiness incumbent in that type of vehicle, *e.g.* there are no requirements for environmental tests that cover immersion in water.

9.10.2 Nevertheless, to provide a metric for the airworthiness regulatory process, a commonsense standard must be applied, with measures to ensure an airworthy aircraft throughout its life. Some of the factors which should be considered in addition to the launch, flight and recovery forces are the effects of salt water on the airframe and its components, the effects of the freshwater pressure washes, the effect of stripping and reassembly process after each flight and the constant handling, hoisting and transport shocks. All of these will cause a deterioration of the airworthiness of the aircraft.

9.10.3 The effects of some of these have already been witnessed, such as the ingress of water into the electronics bay and some LRUs, unprotected components and corrosion (eg the elevator torque tube link mechanism, deterioration of engine wiring looms due to the removal of the alternator for flushing and reconditioning after each flight, sheared fasteners, seized fasteners, dented wing leading edge). These are continuing airworthiness issues, however, hazards can develop due to deterioration of the aircraft which should be addressed as part of the SSHA.

10. SPECIFIC COMMENTS ON SSHA

10.1.1 The review of the SSHA has been covered by comments against each log entry where it is assessed that additional information or justifications are warranted, or that the stated severity categories and probability ranges are inconsistent with observations or explanations. These comments are tabulated below against the original log number, system event phase and hazard description. Due to the time constraints on this report, the list is not exhaustive.

No	SYSTEM EVENT PHASE	HAZARD DESCRIPTION	COMMENT
2.04	Pre-flight	Fuel tanks over pressurised while target is on the launcher.	Requires failure of regulator and safety valve; ie multiple failure – requires re-assessment of severity category based on the dual failure.
2.07	Pre-Flight	RATO ignition after being attached to target, but prior to launch time.	The hazard log “remarks” lists” possible injury to personnel and probable destruction of target”. Risk Class is shown as “Tolerable with the endorsement of normal Project reviews”. The remarks are inconsistent with the Risk Class. Needs review of severity category and probability range taking into account the cited multiple failures.
2.08	Pre-flight	RATO ignition prior to being attached to the target	The hazard log “remarks” lists “possible destruction to personnel or equipment”. Risk Class is shown as “Tolerable with the endorsement of normal Project reviews”. The remarks are inconsistent with the Risk Class. Needs review of severity category and probability range taking into account the cited multiple failures.
3.00	Launch	Engine disintegrates after target leaves launcher	With known uncontrolled flight characteristics on launch, target could depart from launch corridor with emergency recovery over populated areas. Probability needs to be determined.
3.01	Launch	Fuel tanks over-pressurise after target leaves the launcher	Multiple failures required to create a hazard. Probability needs to be determined.
3.02	Launch	Launch programmer fails (s/w internal to DAP)	Emergency recovery commanded over launch area. Due to possible flight over populated areas or pleasure craft, severity category and probability range need to be reviewed.
3.03	Launch	Loss of command at launch	Auto recovery after automatic launch. Due to loss of command, target may fly out of launch area and over populated areas before recovery is initiated. Severity category and probability range need to be reviewed.
3.05	Launch	Target out of control before T +20.5 seconds, not failed launch programmer	Controller commands emergency recovery when aircraft may be outside launch corridor and over populated areas or pleasure craft. Severity category and probability range need to be reviewed.
4.01	Operating	Antenna switch failure – neither antenna selected	Due to loss of command, possibility of flight up to 4.5 nautical miles before recovery, may be over coast & populated areas. Severity category and probability range need to be reviewed.

No	SYSTEM EVENT PHASE	HAZARD DESCRIPTION	COMMENT
4.04	Operating	Command panel failure at GCS.	Due to loss of command, possibility of recovery over coast & populated areas. Severity category and probability range need to be reviewed.
4.05	Operating	Command/Telemetry Equipment failure at GCS	Due to loss of command, possibility of recovery over coast & populated areas. Severity category and probability range need to be reviewed.
4.10	Operating	Emergency Recovery (Crash Safety)	Due to known flight deviations at launch and loss of position display in the GCS, severity category and probability range need to be reviewed. Effects of known defects such as failure of the tail cone microswitch (1 failure) and EED panel (15 failures) should be analysed and the results presented in the log.
4.11	Operating	EMI/EMC Hazards approach airborne UAT.	Possible LOC condition detected in transponder. DAP maintains flight control on last heading which could direct target over populated areas, depends on timer setting and distance from coast. Needs review. Alternatively EMI/EMC testing may decrease probability range for failure. EMI/EMC threats also exist pre-launch and during launch, against which launch clearance should be considered.
4.13	Operating	EMI/EMC Hazards flown into.	Possible LOC condition detected in transponder. DAP maintains flight control on last heading which could direct target over populated areas, depends on timer setting and distance from coast. Needs review. Alternatively EMI/EMC testing may decrease probability range for failure
4.15	Operating	Excessive G loads during controller-directed flight	Controller input limit is 6.25 G. The 7.7 G structural design limit is based on a wing failure during a flight test at Tyndall AFB, FL, resulting in a redesign and stiffening of the wing. The design limit for the stiffened wing has not been established.
4.17	Operating	Flutter/Divergence	Cites Proven MQM-107E performance, however no reports are referenced. In addition there are only performance curves for the clean Kalkara. No curves are available for the Kalkara with the payloads fitted. Aerodynamic performance of the Kalkara requires investigation and development, based on the AFQTs. Refer Annex A for analysis of the incidence margin to flow separation, and the inability of the DAP to control the aircraft to wings level, following rolling motions, due to flow separation, on launch. The aeroelastic properties, and hence flutter/divergence margins of the Kalkara aircraft, may be affected by in-service damage/wear - an example being the mechanical backlash introduced by wear on the elevator control torque tube, due to surface corrosion on the central universal joint, mating the left and right torque tube sub-assemblies. Due to the low inertia and low high speed drag, airspeed/mach build-up in a dive is likely to be quick. Lack of an overspeed warning system (such as a software-generated 'clacker'), this may present a risk of penetrating the flutter margin. The Type Record should record the Design Flight Envelope, including V_D and M_D, in order to assess the adequacy of speed/Mach margins, handling.
4.20	Operating	Ground test equipment failure to detect flight critical UAT defect.	Uncontrollable target with unplanned recovery. Severity category and probability range need to be reviewed to cover possible recovery over populated areas.
4.21	Operating	Hardware failure of Flight Control System	Uncontrollable target with unplanned recovery. Severity and probability range need to be reviewed to cover possible recovery over populated areas or pleasure craft. Known component failures during the AFQT such as DAP (3 failures), Engine Flight Control Box (5 failures), Magnetometer (8 Failures), Pressure Altitude Transducer (5 Failures), Servo assemblies (3 Failures) and probable failures or limited performance of the Vertical Gyro and Yaw rate Gyro (refer Annex A) should all be analysed for effects on controllability of the Target and the results presented in the log.

No	SYSTEM EVENT PHASE	HAZARD DESCRIPTION	COMMENT
4.24	Operating	Logic receiver fails h/w or s/w (Transponder)	A hardware and/or software failure of the Transponder would indicate a possible inability to initiate LOC recovery. In any case the DAP maintains flight control on last heading which could direct target over populated areas. Needs review.
4.26	Operating	Loss of RF carrier to target	DAP maintains flight control on last heading for up to 4.5 nautical miles which could direct target over populated areas, depends on timer setting and distance from coast. Needs review.
4.27	Operating	Loss of command during flight	DAP maintains flight control on last heading for up to 4.5 nautical miles which could direct target over populated areas, depends on timer setting and distance from coast. Needs review.
4.31	Operating	Loss of logic to target for long duration (many seconds or longer)	LOC auto recovery. DAP maintains flight control on last heading for up to 4.5 nautical miles which could direct target over populated areas, depends on timer setting and distance from coast. Needs review.
4.33	Operating	Loss of unlink or downlink control	LOC auto recovery. DAP maintains flight control on last heading for up to 4.5 nautical miles which could direct target over populated areas, depends on timer setting and distance from coast. Needs review.
4.38	Operating	Relay equipment failure, Command/Tm set (WAXA)	LOC auto recovery. DAP maintains flight control on last heading for up to 4.5 nautical miles which could direct target over populated areas, depends on timer setting and distance from coast. Needs review.
4.47	Operating	Target goes out of control at any time.	This appears to be a “catch all” event. Uncontrolled target could fly over populated areas before controller initiated recovery. This event is comprised of all the other events in this log and can only be analysed with reference to the probabilities of failures of the equipment.
4.49	Operating	Yaw departure caused by controller.	Controller has no direct control of rudder. Needs review.
4.50	Operating	Excessive Gs during automatic manoeuvre	See comment in 4.15
6.05	Recovery	Parachute deploys but fails to open.	Loss of target is indicated, however this may be dependent on land or water recovery; ie does this event, coupled with recovery in water, necessarily mean a loss of the target?
6.06	Recovery	Parachute release switch fails and closes before target impacts the ground	Loss of target is indicated, however this may be dependent on land or water recovery; ie does this event, coupled with recovery in water, necessarily mean a loss of the target?

11. CONCLUSIONS

11.1 The System Safety Hazard Analysis, Reference C, as presented, lacks sufficient rigour to be used as the System Safety basis for Type Certification for the Kalkara UAT. The AFTS critical review of the SSHA assessment has highlighted several areas of deficiency, including omissions of events, types of failure and multiple failures. The lack of rigour is particularly evident in the lack of justification, in the form of reference to reports, tests, past performance, etc., for Severity Category and Probability Range selected for each event. Considering that earlier variants of the equipment have been operational in the US for some time and there are commonalities between the variants, then data should be available to the manufacturer to justify the hazard events and their severity and probability.

11.2 The policy of basing Type Certification upon an acceptance of the MQM-107E Design plus an engineering audit of Kalkara Design differences, is fundamentally flawed, due to the environmental differences introduced by the normal Kalkara seawater recovery procedure, as opposed to the normal land recovery procedure for the MQM-107E. This operational difference is not reflected in the aircraft environmental specification, which flows down to the environmental specifications for aircraft system components.

11.3 In particular this specification should include a waterproofness specification for some parts of the aircraft structure, seawater immersion and driving-water specifications for some components and, possibly a driving water specification, for other components. Following the stipulation of specifications, environmental qualification test programmes can be instituted and conducted for components items.

11.4 Additionally, of particular importance, EMI/EMC detailed specifications and qualifications are not visible in the SSHA.

11.5 The SSHA does not cover the problems and anomalies that have been uncovered during the twenty Acceptance Flight Qualification Tests conducted in Australia. Aerodynamic analysis of flight data has indicated that peak incidence during the launch phase is of a magnitude such that wingtip asymmetric flow separation most probably occurred on several occasions, resulting in roll instability. Furthermore, following the occurrence of roll instability, the DAP has not controlled the aircraft to wings-level, the resultant roll-offset turning the aircraft from the launch direction. The roll-offset may be due to separated-flow hysteresis, or to a negative static lateral stability margin, which may be different from that for the MQM-107E. Full details are provided in Annex A.

11.6 The hazards associated with the proximity of populated areas and road traffic adjacent to the launch site, along with the probability of loss of control of the target during launch and operations, and the nature of the recovery system design, could result in an unacceptable risk. The nature of the loss of control during the launch phase, as seen over the twenty launches to date, is such that the probability of occurrence of this event alone is unacceptably high. A detailed analysis is provided at Annex A, based on the data collected from the twenty AFQTs to date.

11.7 The loss of command (LOC) failure of the target during operations over the mission area results in the DAP controlling the target on the last commanded heading. The delay between the transponder recognising a LOC and the initiation and activation of the recovery sequence can be such that the target can fly up to 4.5 nautical miles before parachute deployment. This can be controlled by the timer setting in the Transponder and the distance from shore that the target is operated, thereby ensuring there is no possibility of the target being recovered over populated areas. There is no evidence that this has been done, but should be included, as a risk mitigation for the hazards where LOC is the prime factor.

11.8 The allowable structural G levels have not been clearly established for the wing on the Kalkara. The 7.7G referred to in the SSHA appears to be based on an analysis of outboard wing failure during a test flight at Tyndall AFB, FL in May 1997. The System Specification for the MQM-107E (Reference F) requires the target aircraft to be capable of 6.25G manoeuvres; this, when combined with a 25 ft/sec gust load results in a normal load factor of 8.8G (Reference I). Due to the failure of the outboard wing, the manufacturer has conducted tests and has modified the Kalkara outboard wing by adding foam stiffening in the leading edge, revising the adhesive type and process and adding rivets. The summary report (Reference I) does provide a justification that the modified wing design limit is now at least 8.8G, however, this is conducted by factoring an analysis conducted by another organisation, which is not provided. Consequently there is no visibility of the veracity of this report, nor has the report been checked or approved.

11.9 Due to the damaging nature of the normal operational environment for Kalkara, structural damage tolerance and fatigue characteristics are of particular concern. Although it is intended that damage and fatigue effects are monitored by a visual inspection programme, as part of the refurbishment procedure, without manufacturer guidance and with due regard to the difficulty of visual inspection of some structural areas, there is no assurance that all significant damage shall be detected. Furthermore, there is evidence of a lack of structural design details, appropriate to seawater recoveries, such as the removal of residual seawater from some internal parts of the structure (for example, the elevator torque tubes) and a lack of corrosion proofing (for example, the universal joint, connecting the elevator torque tube halves). The freezing of residual water, during flight above the freezing level, should be considered in the SSHA.

11.10 As a matter of System Safety, the Type Design of the Controller Flight Display is non-compliant, in a number of areas, when considered against typical airworthiness requirements codes, appropriate to the size of aircraft - to the extent of having a highly detrimental effect upon human performance.

11.11 The Type Design of the Controller's Selector/Switch panel is non-compliant against airworthiness requirements, relating to the controls and selectors of manned aircraft, and is such as to markedly increase the difficulty of correct switch selection and activation, particularly emergency selections. As much of the SSHA justification relies upon the operation of the auto-recovery system, correct selection is a vital part of the probability chain.

12. RECOMMENDATIONS

12.1.1 The following recommendations are based on the critical review of the SSHA, first hand observation of AFQTs 18,19 and 20, and observation of the maintenance and reconditioning processes. The recommendations are not ranked and have been limited by the scope as well as the constrained timescale applied to this report.

a. Review of the aerodynamic design for the Kalkara wing to correct the roll instability, due to flow separation, and the subsequent roll-offset, resulting in the right turn anomaly during launch and to ensure that the target stays with in the launch corridor. Refer to Annex A for detailed conclusions and recommendations;

b. Revise the SSHA, taking into account the aerodynamic configuration changes, resultant from the above review/investigation, and determine the severity category and probability for divergence from the launch corridor;

c. Establish which events have the highest risk and obtain justifications from the manufacturer for the selected severity category and probability range;

d. Re-word the Accident Severity Category descriptions to be more relevant to Kalkara operations;

e. Establish performance curves for the Kalkara when fitted with each possible combination of payloads;

f. Review the watchdog timer settings and probable Target locations to ensure that the worst case auto recovery is initiated with sufficient margin to recover the target before it reaches the coast in situations of loss of control of the Target;

g. Establish detailed and complete environmental specifications and qualification tests for the airframe and system components, appropriate to the seawater recovery operation; in conjunction with suppliers, review re-design and test LRUs and electronics bay components; of particular concern are the EED panel, the Digital

Auto Pilot, the Engine Flight Control Box, Magnetometer, Static and Pilot Pressure Altitude Transducers, Servo assemblies, Vertical Gyro and Yaw rate Gyro, all of which are fundamental to the reliability of the flight control systems and the aircraft recovery system; in light of the detailed environmental specifications, review the airframe design, and revise as required, *e.g.* waterproofness, including fastening, drain holes and corrosion treatment;

h. Review the Electrical Sub-System Test procedure, for adequacy, in the detection of component unserviceabilities and latent unserviceabilities, in particular those that could be caused by residual internal seawater;

i. Incorporate within the Sub-System Engine Run Test Procedure, a thrust assurance measurement procedure (which need only be based upon static EGT, for RPM values);

j. Review severity category and probability range for the parachute failure-to-open event in light of the failure in Australia and reports of failures in the US; alternatively, establish the cause of the failure and rectify with documented procedures;

k. Obtain evidence from the manufacturer that the modified wing meets the normal inertia load requirements based on the System Specification for the MQM-107E target aircraft combined with the gust loading. Obtaining the referenced third party reports for review would allow a justification of Reference I based on original the wing loading estimates and analysis;

l. Review the risks associated with multiple failures and establish the risk acceptance class for critical events; this will need to include a definition for the combinations of probabilities as indicated in para 9.3.1;

m. Review the maintenance and re-conditioning procedures to ensure that water ingress, corrosion, broken parts and structural damage tolerance/fatigue effects aircraft are fully inspected for and corrected before further flight; the Record of Unserviceabilities and Component Changes (RUCC) system and current fault reporting appears satisfactory; however the follow up fault investigation by the manufacturer is time consuming and to date no re-designs have been conducted to resolve the problems; while replacement of units found faulty during the Sub System Electrical Test should prevent a faulty unit from flying, the fault may be dormant until the launch sequence, when it may become a failure due to high G loads or vibration;

n. Establish launch clearance procedures, incorporating road barrier gates on the road passing to the East of the Jervis Bay aerodrome; and

o. Finally, following the outcomes of the above work, review the separation criteria, from overflying any surface vessels, land structures/persons, and any aircraft.

12.1.2 The above actions should be considered as part of the due process of Type Certification. In particular, flight-path clearance and object/person separation criteria follow directly upon the details of the Type Design of the Kalkara system, as recommended for Type Certification.

ANNEX A to AFTS Report 629/11/14/RPRT-001

ANNEX A