CONCEPTUALISATION & AUTOMATIC GENERATION OF TEST & EVALUATION MASTER PLANS FOR DEFENCE ACQUISITION TEST PROGRAMS

Volume I

by

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“I dedicate this Thesis

to my Parents

Stamatios & Eleni Nissyrios

for their Love, Patience, and

above all, Spiritual Guidance”

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Table of Abbreviations & Acronyms

ACRONYM	MEANING
A&T	Acquisition and Technology
ACTE	Australian Centre for Test and Evaluation
ADE	Army Design Establishment
ADF	Australian Defence Force
ADI	Australian Defence Industries
ADM	Acquisition Decision Memorandum
AFB	Air Force Base
AFDTC	Air Force Development Test Centre
AFFTC	Air Force Flight Test Centre
AFMC	Air Force Materiel Command
AFOTEC	Air Force Operational Test & Evaluation Center
AHQAUST	Air Headquarters Australia
AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics
AIMS	ARDU Instrumentation Management System
AMASS	Auxiliary Minesweeping and Surveillance System
AMC	Army Materiel Command
AMRL	Aeronautical and Maritime Research Laboratory
ANSI	American National Interchange Standard
APB	Acquisition Program Baseline
APRA	Australian Postgraduate Research Award
ARC	Australian Research Council
ARDU	Aircraft Research and Development Unit
ASCII	American International Code InterchangeStandard
ATPS	The Automated Test Planning System
AU	Adelaide University - Barr Smith Library
AutoTEMP©	Automatic Test & Evaluation Master Plan Generator

Table of Abbreviations & Acronyms

BLRIP	Beyond Low-Rate Initial Production
C^3I	Command, Control, and Communication
CA	California
CALS	Continuous Acquisition and Life Cycle Support
CD-ROM	Compact Disk Read Only Memory
CDS	Congressional Data Sheets
CE	Concept Exploration and Definition
CEA	Cost Effectiveness Analysis
CEPMAN	Capital Equipment Procurement Manual
CFC	Chloro-fluorocarbon
CO	Commanding Officer
COEA	Cost and Operational Effective Analysis
COI	Critical Operational Issues
COTS	Commercial Off The Shelf
CSCI	Computer Software Configuration Item
CTN	Continuous Acquisition and Life Cycle Support Test Network
CUTL	Centre for University Teaching and Learning
DAB	Defence Acquisition Board
DAB	Defence Acquisition Board
DAE	Defence Acquisition Executive
DAE	Defence Acquisition Executive
DAO	Data Access Object
DAS	Data Acquisition System
DATP	Defence Acquisition Test Program
DCM	Data Cycle Map
DDE	Dynamic Data Exchange
DEM/VAL	Demonstration and Validation
DID	Data Item Description
DLL	Dynamic Link Library
DML	Data Manipulation Language
DoD	Department of Defence
DoDD	Department of Defence Directive
DoDI	Department of Defence Instruction

Table of Abbreviations & Acronyms

DOT&E	Director Operation Test & Evaluation
DSARC	Defence Systems Acquisition Review Council
DSMC	Defence Systems Management College
DSS	Decision Support Systems
DSTO	Defence Science and Technology Organisation
DT	Developmental Testing
DT&E	Developmental Test and Evaluation
DTE	Directorate of Trials and Evaluation
DTP	Directorate Trials and Planning
DTRIALS	Directorate of Trials
DTSE&E	Director, Test, Systems Engineering and Evaluation
DTSEE	Director, Test, Systems Engineering, and Evaluation
E&T	Education & Training
EMD	Engineering & Manufacturing Development
EOA	Early Operational Assessment
ESRL	Electronics and Surveillance Research Laboratory
EU	Engineering Unit
EW	Electronic Warfare
EXE	Executable
F/A	Fighter Aircraft
FCT	Foreign Comparative Testing
FDD	Floppy Disk Drive
FOC	Full Operational Capability
FOT&E	Follow on Test and Evaluation
FRS	Functional Requirement Specification
FT&E	Future Test & Evaluation
FTDMS	Flight Test Data Management System
FTE	Flight Test Engineer
FTIMS	Flight Test Information Management System
GB	Giga-Byte
GEA	General Accounting Office
GUI	Graphical User Interface
HCC	Human-Computer Collaboration

Table of Abbreviations & Acronyms

HCI	Human-Computer Interface
HP	Home Page
HQ Log Cmd	Headquarters Logistic Command
HQADF	Headquarters Australian Defence Force
HTML	Hyper Text Markup Language
HTS	Heuristic Transaction Shell
HTTP	Hyper Text Transfer Protocol
HWCI	Hardware Configuration Item
IBM	International Business Machines
IEEE	Institute of Electrical and Electronic Engineers
IFT	International Foundation for Telemetering
ILS	Integrated Logistic Support
ILSP	Integrated Logistic Support Plan
IOC	Initial Operational Capability
IOT&E	Integrated Operational Test & Evaluation
IOT&E	Initial Operational Test & Evaluation
IPS	Integrated Program Summary
IT	Information Technology
ITC	International Telemetering Conference
ITEA	International Test and Evaluation Association
ITP	Integrated Test Plan
IV&V	Independent Validation & Verification
JORN	Jindalee Over-The-Horizon Operational Radar Network
KBS	Knowledge Base System
KBSS	Knowledge Based Software System
KISS'EM	Keep it Simple, Small, Economical and Manageable
LADS	Laser Airborne Depth Sounder
LC	Levels Campus Library
LCC	Life Cycle Testing
LFT&E	Live Fire Test & Evaluation
LRIP	Low Rate Initial Production
LSA	Logistic Support Analysis
LSA	Logistic Support Analysis

Table of Abbreviations & Acronyms

M&I	Measurement and Instrumentation
MatDiv	Materiel Division
MCOTEA	Marine Corps Operational Test & Evaluation Activity
MCSC	Marine Corps System Command
MIL-STD	Military Standard
MNS	Mission Need Statement
MOD	Ministry of Defence
MOE'S	Measures of Effectiveness
MOP'S	Measures of Performance
MRTFB	Major Range and Test Facility Base
MS	Milestone
MS	Milestone
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
MUX	Multiplexor
NATO	North Atlantic Organisation
NT	North Terrace Campus Library
OA	Operational Assessment
OLE	Object Linking & Embedding
OOD	Object Orientated Design
OPEVAL	Operational Evaluation
OPTEC	Operational Test & Evaluation Command
OPTEVFOR	Operational Test & Evaluation Force
ORD	Operational Requirements Document
OS	Operations and Support
OSD	Office of the Secretary of Defence
OT	Operational Testing
OT&E	Operational Test and Evaluation
OTA	Operational Testing Agencies
OUSD	The Office of the Under Secretary of Defence
PAP	Phased Acquisition Process
PAT&E	Production Acceptance Test and Evaluation
PC	Personal Computer

PCI	Peripheral Control Interface
PCM	Pulse Code Modulation
PD	Production and Deployment
PDAS	Programmable Data Acquisition System
PhD	Doctor of Philosophy
PO	Program Officer
PRS	Production Representative System
QA	Quality Assurance
R&D	Research and Development
RAAF	Royal Australian Air Force
RAL	Rule-extended Arithmetic Language
RAM	Random Access Memory
RAN	Royal Australian Navy
RANAMFTU	Royal Australian Navy Aircraft Maintenance and Flight Trials Unit
RANRAU	Royal Australian Navy Ranges and Assessing Unit
RANTEG	Royal Australian Test & Evaluation Group
RDBMS	Relational Database Management System
RDT&E	Research, Development, Test and Evaluation
RE	Requirements Engineering
RTMF	Real Time Monitoring Facility
RWE	Real World Environment
S3	Safety and Suitability for Service
SACAE	South Australian College of Advanced Education
SAR	Selected Acquisition Report
SDD	Software Design Document
SDD	Segment Design Description
SDP	Software Development Plan
SE	Software Engineering
SEMP	Systems Engineering Management Plan
SEMP	Systems Engineering Management Plan
SOR	Statement of Requirement
SPP	System Performance Parameters
SQL	Structured Query Language

Table of Abbreviations & Acronyms

SQL	Structured Query Language
SR	Strategic Review
SRS	Software Requirement Specification
SSDD	Software Segment Design Document
SSEG	Sensor Science and Engineering Group
STD	Software Test Document
STR	Software Test Report
SUT	System Under Test
T&E	Test and Evaluation
TBD	To Be Determined
TECHEVAL	Technical Evaluation
TECNET	Test and Evaluation Community Network
TEMP	Test and Evaluation Master Plan
TEP	Test & Evaluation Plan
TM	Task Manager
TO	Typical Operators
TPP	Technical Performance Parameters
TQM	Total Quality Management
TTRF	Total Tape Relay Facility
US	United States
USD(A&T)	Under Secretary of Defence for Acquisition & Technology
USD(A)(T&E)	Under the Secretary of Defence for Acquisition, Test & Evaluation
USTEPAP	United States Test and Evaluation Phased Acquisition Process
V&V	Verification and Validation
VB	Visual Basic®
VBP	Visual Basic® Professional
WFWG	Windows® for Work Groups
WPA	Woomera Prohibited Area
WWW	World Wide Web

SUMMARY

This thesis investigates a method to support an important facet of the T&E process, in particular, the conceptualisation and consequent automation via the assistance of a computer, the manual generation of Test & Evaluation Master Plans, from the functional requirements specification of any defence acquisition test program, for the real-time test & evaluation (T&E) of complex systems, such as the highly instrumented fighter aircraft F/A-18 Hornet of the RAAF.

The origins of test & evaluation are described in Chapter 2, where the history, types of T&E, interests, reasons, importance, objectives and the need for conducting T&E are discussed. This Chapter hypothesises that T&E is essentially a process and synonymous to the systems engineering process, and as the phrase implies, a two part process, i.e., testing and evaluating.

Chapter 3 then outlines a brief genealogy of the discipline of this research, i.e., aircraft flight testing, giving a short introduction to flight test, flight test planning, test resources, and telemetry formats used in flight testing that could assist in the design of telemetry data formats. This Chapter reveals that T&E practitioners are taking more measurements than are required, and as a consequence increasing the cost of testing not to mention human resources required to carry out these tests, hence the importance of keeping tests simple, small, economical and manageable, i.e., adhering to the philosophy of parsimony.

Chapter 4 analyses and compares two most prominent T&E structures and processes, namely, that of the United States of America and Australia. It is determined that one of best documented T&E systems in the world, is that originating from to the United States of America and due to this fact, many non-US based countries have adopted its basic principles, terminology, and structure.

Chapter 5 gives a concise description on the research methodology utilised in the attempt to conceptualise and automate the Australian T&E process. The importance of adhering to and regularly updating a TEMP is emphasised as the most vital part of any defence acquisition test program, as it outlines very crucial elements that all such test should adhere to.

Chapter 6 describes the results of this research, namely, a software tool known as AutoTEMP© Beta 2.0, outlining descriptions of all three modules, namely, the US defence phased acquisition process tutorial, the TEMP generation module, and the automatic generation of the TEMP document. It was designed to comply to the Australian Defence Force Capital Equipment Procurement Manual, often referred to as the CEPMAN 1, instruction.

This research is considered important as it is the first time ever that this problem has been researched using an academic methodology, as opposed to picking up from something well known. The development of this project has provided a tool that can save the agencies involved in high volume testing, hundreds of millions of dollars, due to a reduction in time, cost, and effort taken to manually produce a TEMP, whilst offering more thorough and reliable testing, as well as increasing confidence in the safety and predictability of complex systems, such as the highly instrumented fighter aircraft, F/A-18 Hornet.

DECLARATION

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

John S Nissyrios

January 1997

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I would like to express my appreciation to all the staff and research colleagues of the Australian Centre for Test and Evaluation (ACTE), whom have also contributed to the successful completion of the research project through innovative ideas and constructive criticisms.

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CHAPTER 1

1. Introduction

1.1 Preface

This thesis details the work accomplished on the research *project "Conceptualisation and Automatic Generation of Test & Evaluation Master Plans for Defence Acquisition Test Programs"*. This work was conducted by John S. Nissyrios, one of four project postgraduate research students working under the guidance of Professor Peter Sydenham at the Australian Centre for Test & Evaluation (ACTE) and Mr Viv Crouch of the Aircraft Research & Development Unit (ARDU) of the Royal Australian Air Force (RAAF), on a full-time basis at the Salisbury Campus of the University of South Australia (UniSA), over 1994 to 1996 inclusive, whilst also employed as a casual tutor/practical supervisor in the School of Electronic Engineering.

The aim of the collaborative project, involving both the ACTE and the ARDU of the RAAF, was to conduct research which would "assist in the design of telemetry data formats and contribute to assuring end-to-end data traceability of test programs" (ARDU, 1993). Research has been conducted in four primary areas. These research areas and associated ACTE researchers are:

1. **An Analysis of Test and Evaluation in the Acquisition of Defence Systems**. This research project was conducted by Mr Mark Dvorak[1], *"is to investigate worldwide T&E policies and practices in an effort to increase understanding of the T&E process and to suggest areas of improvement"* (Dvorak, 1996).

[1] Mark Dvorak is the ARC Collaborative Project Leader, and has recently completed his research project leading towards a Masters Degree on, *"The Definition and Characteristics of Test and Evaluation in the Acquisition of Defence Systems"*.

2. **Computer Aided Synthesis of Measurement Schema's for Telemetry Applications**. Mr Peter Evdokiou is currently conducting research into the *"development of a methodology, and associated software based tool, that will allow a non-telemetry expert to specify test measurement schema's given a high level test requirements and a test measurand database"* (Evdokiou, 1996).

3. **Configuration of Flight Test Telemetry Formats**. Mrs Mouna Samaan is currently conducting research to improve the efficiency in the configuration of flight test data telemetry formats. *"Efficiencies sought are a reduced use of allocated telemetry bandwidth and increased data capabilities through an enhanced approach to the production of PCM telemetry data formats"* (Samaan and Cook, 1995).

The fourth research area and the subject of this thesis, is the automation or knowledge based computer-assistance in the manual generation of a Test & Evaluation Master Plan (TEMP), from functional requirements, along with the production of the TEMP document associated with the real-time Test & Evaluation (T&E) of complex systems, such as the highly instrumented fighter aircraft F/A-18 Hornet.

While the concepts are widely applicable, the project specifically targets, the large, multi-sensor and high speed systems such as those involved in aircraft testing and the telemetering of the data to land based stations (Sydenham, 1993a). However, the concepts and design methodology is not intended to be constrained entirely to aircraft, such as the F/A-18, but to a more general and diverse array of test recipients, from aircraft carriers, submarines, complex weapons systems, missiles, spacecraft, etc., to the likes of automobiles, computers, mobile phones, and even physical processes.

This work forms an integral part of the Heuristic Transaction Shell (HTS), at the Aircraft Research Development Unit (ARDU) of the Royal Australian Air Force (RAAF), which is to enhance the current ARDU Flight Test Information Management System (FTIMS) through improved test management, data traceability, and Data Cycle Map (DCM) synthesis (Dvorak, 1994), of which will be discussed further on.

The research is concerned with an approach to automating the primary stage of a Defence Acquisition Test Program (DATP), that being the preparation of the fundamental Test and Evaluation Master Plan (TEMP) document associated with the real-time T&E of a complex system, as mentioned previously. The TEMP is a high level document that is continually evaluated and updated, and finally verified and validated (V&V), over the duration of the test program.

1.2 Aim of the Research

The aim of the research was to produce an automated, or at least a computer-assisted method to aid in the manual generation of a TEMP, from the Functional Requirements Specification (FRS) of any DATP.

A further aim was to produce a TEMP document in a form that can be used for both technical, management, and contractual purposes, conforming to military standards, such as the Australian Defence Force (ADF) Capital Equipment Procurement Manual (CEPMAN 1) instruction.

1.3 Background

Test and Evaluation is practiced by many defence sectors around the world, such as the United States of America, United Kingdom, France, Israel, Germany, Republic of China and Australia. Whether they are testing F/A-18's for the RAAF or carrying out research on submarines at the Naval Postgraduate School in the States, there are T&E processes that these groups follow (Nissyrios, 1995b).

The Sensor Science and Engineering Group (SSEG) in conjunction with the Australian Centre for Test and Evaluation(ACTE) has won an ARC grant for a collaborative research project with the RAAF. The project, co-located at the Salisbury Campus of the University of South Australia and at ARDU, Salisbury, South Australia, is envisaged to ***improve computer-based means of handling the large quantities of data associated with the real-time Test and Evaluation (T&E) of complex systems*** *(Nissyrios, 1994b)***.**

The ARDU has developed a limited capability to manage test programs through the development of a prototype Flight Test Information Management System (FTIMS). This system is under continuous development at ARDU to meet new flight test task commands.

Traditional software development methods used to upgrade FTIMS have been proven to be skill intensive, whereby specialist contracted programmers are needed, and costly to maintain, i.e., beyond the skill level of organic staff to do other than minor amendments (ARDU, 1993).

The Australian Research Council (ARC) recognised the need for the development of improved methods for Test and Evaluation (T&E) management, planning and execution and granted funding for a collaborative research project with the ARDU of the RAAF and the Australian Centre for Test and Evaluation (ACTE) (Dvorak, 1995a) to conceptualise and bring into fruition a suitable Heuristic Transaction Shell (HTS) for the FTIMS that will encapsulate the ***"business rules"*** related to test management and design, bring discipline to data identification handling, quality monitoring and interpretation processes and have the capacity to build on future lessons learned, i.e., knowledge-based. The FTIMS HTS will be a by-product of that research with the specific aim of improving flight test operations at ARDU.

1.3.1 HTS Primary Mission

The mission of the HTS segment is to assist ARDU test personnel in the full range of flight test management. The HTS is intended to aid in the traceable formulation of quantitative test measurements derived from high level qualitative test requirements. It will then translate the required measurements into an optimised telemetry stream format through a computer-aided Data Cycle Map (DCM) synthesis procedure. The proposed system is intended to support ARDU task management through the entire process of planning execution and reporting (Dvorak, 1995a).

1.3.2 HTS Secondary Mission

The secondary mission of the HTS is to support test management externally to ARDU. Future growth should consider links with associated test facilities, laboratories and administrative offices (Dvorak, 1995a).

1.3.3 System Architecture

The overall system of which the HTS segment is a part is known as AIMS. AIMS resides on the ARDU Unix based network known as ARDUNET, which comprises several Sun Sparc Workstations and host computers. The HTS segment is purely software based and resides on the same host computer as AIMS and therefore does not contain internal Hardware Configuration Items (HWCIs) (Dvorak, 1995a).

1.3.4 AutoTEMP© Beta 2.0 CSCI

AutoTEMP© Beta version 2.0 is a by-product of this research, with the specific aim of automating the manual generation of the fundamental underlying document of any DATP, namely, the TEMP. The HTS segment incorporates the following Computer Software Configuration Items (CSCIs) depicted in Figure 1-1.

With reference to Figure 1-1, the CSCI AutoTEMP© comprises of the following CSCIs: T&E Information CSCI and Task Management CSCI.

1.3.4.1 T&E Management Module

This module assists the user by providing an interactive map of the T&E process with support for a logical flow of test planning documentation from the TEMP through detailed test plans for each phase of a given project. The module also supports evaluation report writing ensuring that results reported are linked to the originally defined test objectives (Dvorak, 1994). The direct benefits to ARDU from this module of the HTS are:

1. Disciplined, repeatable testing.
2. The ability to capture corporate knowledge in an expert flight test system instead of having that knowledge reside with a select number of experienced test engineers (expert). The captured knowledge will be clearly visible allowing simpler development, extension, and modifications, as requirements change.
3. The system will increase the efficiency of training new flight test personnel, as traditional methods have proven to exceed both budget and time scales.

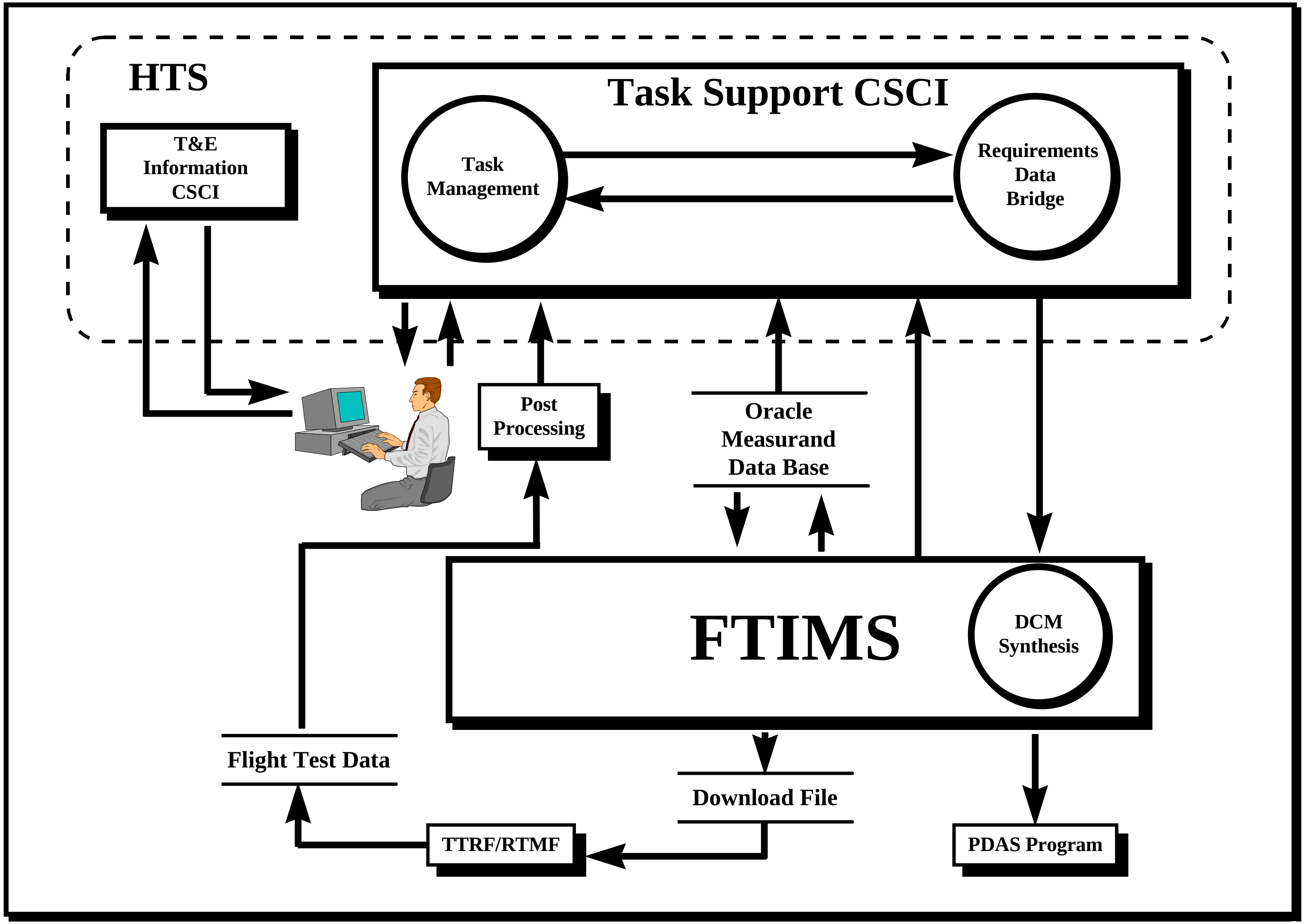


Figure 1-1 (Top Level Segment Architecture of HTS (Dvorak, 1995a))

1.4 Structure of the Thesis

This thesis is divided into two volumes. Volume I contains the main text, namely, seven chapters and references, whilst Volume II contains the appendices as is depicted in the table of contents. Chapter 1 introduces the topic of the research, the aim of the research, gives an overview of the background that gave rise to the research project, and it's contributions that it has made to Australia and world wide.

Chapter 2 discusses a review of the literature pertaining to T&E, and how these theories and practices have evolved into the automation of T&E processes & procedures. After a brief introduction to T&E, a description of the history of T&E is given, outlining the traditional scientific method and how T&E has evolved from systems engineering practices. The majority of the remainder of this chapter is devoted to defining T&E, describing the two types of T&E, and such things as the reason, need for conducting, and the importance of T&E.

Chapter 3 gives a genealogy of aircraft flight testing outlining its relation to T&E. An overview of the ARDU is presented describing the FTIMS project further, as well as a discussion on flight test planning and a brief description of major range and test facility bases in the United States of America as well as telemetry formats used in flight testing.

Chapter 4 analyses and compares T&E structures and processes pertaining to the most well documented T&E system developed in the United States and the present one in Australia, with a lean towards the RAAFs paradigm. This chapter presents a comprehensive description of the differences between the United States and Australian T&E perspectives and TEMP formats.

Chapter 5 examines the need for automating the T&E process, along with the requirements for the implementation via computer-aided methods. Against this background, a review of two other well authorised theses pertaining to the automation of a process, and a commercial piece of software developed by the Pentagon in the United States is discussed and analysed. This is followed by an outline of the requirements for generating a TEMP, namely, content of the TEMP, and the automation of the extraction process with respect to the Software Requirement Specification (SRS).

Chapter 6 describes AutoTEMP© Beta 2.0, the knowledge based software system that uses a computer to aid in the generation of a TEMP for any DATP, and embraces the ideas of chapter 5. This chapter discusses the selection of the development software, the selection of the host machine and hardware requirements. The remainder of this chapter is devoted to the three modules that make up AutoTEMP© Beta 2.0, namely, the Defence Phased Acquisition Process (PAP) tutorial, the TEMP Generator Module, and TEMP Document Generator. The chapter also gives a description of the lessons encountered from sample tests of the software, namely, developmental and operational software related bugs, and user related problems. This is followed by a discussion of the quality of the TEMP document automatically generated by AutoTEMP© Beta 2.0.

Chapter 7 concludes the thesis by summing up the achievements of all phases of the research project and the contribution it has made to knowledge. The chapter also presents a discussion on further research, in particular, the use of AutoTEMP© Beta 2.0 on the Information super highway known as the Internet. Finally a description of a research outline at the Doctorate level (PhD) is presented as a possible extension of the current research.

1.4.1 Thesis Editorial Format

This Thesis was prepared using Microsoft *Word* Version 7.0, on a Windows® 95 platform and the "Thesis1" template which comes with this version of Word. The structure of the Thesis abides by the *"Guidelines for the Preparation of Theses" - Section 5* of the Academic Procedures and guidelines for Masters Degrees by Research, located in the 1996 University of South Australia Research Degree Student Information Folder.

1.5 Contribution to Australia

The development of this project has provided a tool (AutoTEMP© Beta Version 2.0) of immediate benefit to ARDU, and a spin off value to other Australian agencies faced with test and evaluation problems on a similar scale. In particular, those agencies involved with aircraft, ships, submarines, large simulation and modeling tasks, command, control, and communication (C^3I) systems, air traffic control systems, and space related activities (Sydenham, 1993a).

The United States of America, Canada, France, and the United Kingdom have made investments in test & evaluation amounting to billions of dollars. The high volume of work required at some overseas agencies has resulted in their facilities being fully booked in advance for the next four years. It is not possible to make quantum leap changes to present test & evaluation technology without delaying the existing programs at huge expense. Australia does conduct high volume testing, and does not have large investments in past programs. The opportunity exists to make radical changes to uneconomic and obsolescent processes using new generation technologies, which could then be marketed in other countries. *An integrated KBS based test and evaluation system, namely, AutoTEMP© Beta 2.0, for the computer-aided generation of TEMPs, can save the agencies involved in high volume testing hundreds of millions of dollars, due to a reduction in time, cost, and effort taken to manually produce a TEMP*, whilst offering more thorough and reliable testing, and increasing confidence in the safety and predictability of complex systems, such as the highly instrumented fighter aircraft, F/A-18 Hornet.

Test and evaluation program management in the United States alone represents a $3Billion annual turnover in technology and services. The potential for attracting US investment in proving the economy of test and evaluation is high with a prospective world market that at present impacts on a $70Billion capital investment.

CHAPTER 2

2. The Genesis of Test & Evaluation

2.1 Introduction to Test & Evaluation

We now live in a world where it is well recognised that rapid technological advances are fast outstripping mankind's ability to provide adequate test surveillance using conventional wisdom, tools and techniques. As a result of this shortfall, new measurement tools and techniques are now being urgently developed, and this thrust is being matched by aggressive research, post-graduate education programs, and both national and international test resource development on a very large scale. This has spawned a professional discipline and a multi-billion dollar industry known simply as Test and Evaluation (Crouch, 1992). Test & Evaluation (T&E) is a process for technical and programmatic control of systems acquisition. As the phrase implies T&E is a two part process. The test involves the planning and execution of an experiment in an effort to collect data. Evaluation is the assessment of the collected data, against a known standard, in order to obtain knowledge regarding the quality or goodness of the subject under test (Miller and Sears, 1993), (Dvorak, 1995). At it's most fundamental level T&E is normally conducted to influence some type of a decision. It imparts a known level of confidence (Miller and Sears, 1993) regarding the utility of the subject under test (Dvorak, 1995). T&E consists of structured processes. Mostly these processes involve collection of data describing aspects of the operation of a system which is then compared against criteria, the process of evaluation (Dvorak and Equid, 1994).

2.1.1 What is Test and Evaluation (T&E)

Having briefly introduced test and evaluation and why it is a very necessary part of a two fold process, it is only appropriate to define the two phrases formally. The Concise Oxford Dictionary (Allen, 1992) defines the two phrases as follows:

> *"**Test**. A critical examination or trial of a person's or thing's capabilities; The means of so examining; A standard for comparison or trial."*

> *"**Evaluate**. Assess, appraise; Find or state the number or amount of; Find a numerical expression for."*

Simply stated, T&E is a means of obtaining knowledge about something. To obtain that knowledge we use a two part process integrating (Crouch, 1992):

1. **Testing.** In which we gather data about the thing we are endeavoring to learn more about.
2. **Evaluating**. The analysis and interpretation of the data which enables a conclusion to be made regarding the relative merit of the thing we just tested.

From this two part process we now "know" something about the object, or product under investigation.

A concise definition for T&E is as hard to come by as a concise definition for Research & Development (R&D). The following definitions look at both the Australian and American perspectives.

> ***"Australian*** *T&E is defined as a structured investigation designed to obtain or verify data on which to base an objective assessment (Crouch, 1992)."*

> ***"American I*** *T&E is the measurement of the performance of a system, and the assessment of the results for one or more specific purposes (Reynolds, 1994)."*

> ***"American II*** *T&E may be defined as all physical testing, modeling, simulation, experimentation and related analyses performed during research, development, introduction and employment of a weapon or subsystem (Defence Systems Management College, 1995)."*

In evaluation of the above three definitions it is evident that (Crouch, 1992) defines T&E as a *structured investigation,* and the *verification of data,* as opposed to (Reynolds, 1994) who sees it as a *measure of a performance (MOP)* of a system, whilst the (Defence Systems Management College, 1995) defines it *as all the aspects of testing and employment of a weapon system,* towards a very military sighted view.

T&E is usually conducted to assist in making engineering, programmatic or process decisions, and to reduce the risks associated with the outcome of those decisions. Following from the above definitions, T&E is seen to be a universal tool that is equally applicable to monitoring R&D efforts as well as monitoring the operational health of systems that have been introduced into the service. Arguably (Crouch, 1992) then, "*the need for rigorous testing should be driven by a passion for success rather than a fear of failure*".

2.1.2 How is T&E used on a Day to Day Basis

Possibly the first thing that comes to mind is a team of skilled engineers crowded around complex high tech. machinery. If you stop to think about it T&E is part of almost everything we do. The following section gives a layman's perspective using two children that have made slingshots, inspired by a similar example in (Dvorak, 1995).

2.1.2.1 Children Making Slingshots

For this example I have chosen two bright young elasto-projectile test engineers Roy Rogers & Steve Stevens. The two boys have challenged each other to an afternoon slingshot challenge down at the riverside valley park, using home made targets. Both boys have done extensive T&E to prepare for their shooting challenge. Both Roy and Steve had identical slingshots made out of wood and rubber bands, with a small leather pouch to hold their ammo. Both Roy and Steve conducted initial testing to perfect their accuracy:

- They picked up stones, tried them out, these seemed to fall short of the target and thus had no choice but to redesign their slingshots.
- They picked smaller rounded stones, which seemed to work better and fly longer, thus were more accurate.
- They used an old tyre tube instead of rubber bands as the sling, tried this out, and managed to hit the target 7 out of 10 times, thus concluded that tyre tubes were - more powerful and happened to work even better.
- After an iterative designing test process the boys came up with the ultimate design, taking into account, projectile type, size, shape, weight, type of sling, type of wood, type of ammo pouch, employment technique, distance, trajectory, etc.

Roy stopped testing when he felt that he had achieved the best design, which was:

- An oak wood slingshot.
- Truck tyre tube as the sling.
- Light small leather ammo pouch and

- Uniform small spherical stones.

Roy was positive that this configuration was sure to reach the target accurately and swiftly every time. That afternoon the boys went down to Riverside Valley Park, set up their targets and began. Roy was shooting down every target with one shot, which was a perfect triumph for his test program. However, Steve was only shooting down every 1 out 3 targets with one shot.

Roy had extended his testing to include the operational environment, that is, he shot at rocks first and noticed the following:

- That they wouldn't fall when hit at the edges
- Changed his targets to potatoes which was a lot better
- Only shot when there was less or no wind
- Prepared a plan

From our example we can see that:

♦ **T&E is a process**, that is:
  - ⇒ Design - Test - Analyse - Fix -Test
  - ⇒ Needed to shoot a number of projectiles to get a significant sample size
  - ⇒ Wood type (material)
  - ⇒ Construction (manufacturing)
  - ⇒ Shooting (employment)
  - ⇒ Logistics

- It involves the collection of data.
- The data relates to aspects of the system operation.
- The data is compared against criteria in a process of *evaluation*.
- Does this type of stone work as well as the last:
  - ⇒ Towards a rock,
  - ⇒ Towards a potato

♦ **An extension of the scientific method, whereby we**

⇒ Identify the problem.
⇒ Hypothesis.
⇒ Experiment.
⇒ Verify Hypothesis.

It is therefore necessary to understand the ***“T&E process***”:

- The question often put forth is *“What information is required, not what data can be made available” (Scheikhard, 1991).*
- More targeted testing requirements.
- Better use of test results.
- More effective use of test facilities.

All this leads to research and establishes the profile and the characteristics of the T&E process. The T&E process is a system of documentation coupled to engineering design and project management. Two important facets of the T&E process are:

1. To identify features of the process and how you can improve on the already available documentation, practices, and techniques.
2. How to make all the documentation and further information available in a dynamic manner.

The next paragraph is a view expressed by the Defense System Management College on the T&E process.

> *"**The test and evaluation (T&E) process** is an integral part of the systems engineering process which identifies levels of performance and assists the developer in correcting deficiencies. It is also becoming a significant element in the decision-making process, providing data supportive of trade-off analysis, risk reduction and requirements refinement. Programmatic decisions on system performance maturity and readiness to advance to the next phase of development are becoming more dependent on demonstrated performance. The ultimate customer, the Service-member user, is concerned about neither unit cost nor production schedule. The issue of paramount importance is system performance, i.e., will it fulfill the mission. The test and evaluation process provides data to tell the user how well the system is performing during development and if it is ready for fielding. The program manager must balance the unit of cost, schedule and performance to keep the program on track to production and fielding. The responsibility of decision-making authorities centers on assessing risk trade-offs."*

Hence, test and evaluation is streamlining the process of putting test data into a form that users can analyse quickly and efficiently. Software eliminates the preprocessing phase and allows users to directly access and analyse raw telemetry data streams written in arbitrary and complex formats. Their philosophy *is "record it all and sort it all out later" (Moss, 1993).* Streamlining also results in increased productivity, reduced time for data preparation, access and analysis, and greatly reduced costs when evaluating the total test and evaluation solution.

2.1.3 History of Test & Evaluation

It is said that "One test is worth a thousand expert opinions" (Reynolds, and Damman, 1994). The concept of test and evaluation to determine whether a new device is useful and whether it can accomplish a task that it has been assigned is old as that of invention itself (Stevens, 1986). As inventions and new systems become more complex, this gives rise to a development and testing methodology, hence T&E has evolved and manifested itself into almost everything we do.

2.1.3.1 Prolegomena

The study of test and evaluation has been isolated almost entirely to defence and defence related agencies, namely, the Army, the Navy, and the Air Force. Because of this dilemma very few academic textbooks have been written on this subject, and are not as readily available as textbooks for more traditional research topics. The notable few that the author has discovered so far have been (Stevens, 1986) regarding OT&E and (Rodriguez, 1992) which discusses OT&E suitability related issues, and The Defence Systems Management College textbook, Test and Evaluation Management Guide (1993). These textbooks are oriented toward non-academic applications in defence acquisition (Dvorak, 1995). Thus, due to the scarcity of academic textbooks pertaining to T&E, a majority of the relevant research in this field is in the form of defence related journals or conference papers as well as military standards and instructions as shown in Table 2-1.

DoD ACQUISITION DOCUMENTS	
∗ **DoD DIRECTIVE 5000.1**	Defence Acquisition
∗ **DoD INSTRUCTION 5000.2** ∗ **[Change 1 - February 26, 1993]**	Defence Acquisition Management Policies and Procedures
∗ **DoD 5000.2 MANUAL** ∗ **[Change 1 - February 26, 1993]**	Defence Acquisition Management Documentation and Reports

Table 2-1 (DoD Acquisition Documentation (Damaan, 1993))

The DoD Policy for Acquisition is such that it (Damaan, 1993) *"Establishes a disciplined management approach for acquiring systems and materiel that satisfy the operational user's needs"*. This is applies to all major as well as non-major defence acquisition programs.

2.1.3.2 Test and Evaluation & the Scientific Method

The Test and Evaluation process dates back to scientific principles and foundations. The scientific method (Dvorak and Equid, 1994) is based on a combination of logical reasoning or philosophical assertions with methods for acquiring knowledge. The scientific method can be defined as *"an objective, logical and systematic method (process) of analysis of phenomena for accumulation of reliable knowledge"* (Miller and Sears, 1993).

The Encyclopaedia Britannica (Benton and Benton, 1980a) defines the words science and scientific method in the following manner:

> ***"Science,*** *philosophy of, a discipline in which the elements involved in scientific inquiry - observational procedures, patterns of argument, methods of representation and calculation, and metaphysical presuppositions are analysed and discussed; and the grounds of their validity are* ***evaluated*** *from the points of view of formal logic, practical methodology, and metaphysics".*

> *"**Scientific Method**, once considered to be a rigorous procedure that included the study of scientific hypotheses, induction, theories, laws, and methods of exploration; now regarded as a family of methods each of which differs according to the subject matter involved. The core of the scientific method, however it is defined, is related to measurement of phenomena and experimentation or repeated observations."*

The measurement of this so called phenomena, repeated observations is conducted in a series of seven steps. These seven steps are defined by Lastrucci (1963) and Fiebleman (1972) which are defined and compared in Table 2-2 below.

THE SCIENTIFIC METHOD SEVEN STEP PROCESS	
LASTRUCCI (1963)	**FIEBLEMAN (1972)**
1. Formulation of the problem (hypothesis)	1. Observation
2. Literature survey	2. Induction
3. Research design	3. Hypothesis
4. Determine "universe" encompassed	4. Experiment
5. Collect data, process for use	5. Calculate (verification)
6. Interpretation of data	6. Prediction (verification)
7. Verification of results	7. Control (verification)

Table 2-2 (The Scientific Method Seven Step Process (based on Miller & Sears, 1993))

A generalised structure of the scientific method compared to the T&E process is presented in the following table (Fiebleman, 1972):

GENERALISED SCIENTIFIC METHOD	TEST & EVALUATION PROCESS
I. DEVELOP HYPOTHESIS	**I. DEVELOP HYPOTHESIS**
1. Identify Question/Problem	1. Develop Test Objectives
2. Formulate Hypothesis	2. Estimate Performance
II. EXPERIMENT	**II. EXPERIMENT**
3. Plan the experiment	3. Develop Method of Test
4. Conduct the Experiment	4. Collect Test Data
5. Analyse the Results	5. Calculate Measures of Performance
III. VERIFY HYPOTHESIS	**III. VERIFY HYPOTHESIS**
6. Check the Hypothesis	6. Compare Results to Thresholds
7. Refine the Hypothesis	7. Retest or Extrapolate

Table 2-3 (Relationship of the Scientific Method vs Test and Evaluation Process (Fiebleman, 1972))

2.1.3.3 Test and Evaluation & Systems Engineering

2.1.3.3.1 Introduction

The discipline of Systems Engineering (Przemieniecki, 1993) first came into being in the late1950s with the advent of the Intercontinental Ballistic Missile program in the United States. The concept of the Intercontinental Ballistic Missile pushed the state of the art in a number of technical areas, resulting in the need to develop engineering specialties to concentrate on these advances. It was important that these engineering specialties worked together in a final product, and the need to balance these specialties created the concept of Systems Engineering. According to MIL-STD-499B (1992), Systems Engineering is defined as follows:

> ***Systems Engineering*** *is an interdisciplinary approach to evolve and verify an integrated and life cycle balanced set of systems product and process solutions that satisfy customer needs. Systems engineering: (a) encompasses the scientific and engineering efforts related to the development, manufacturing, verification, deployment, operations, support, and disposal of system products and processes, (b) develops needed user training equipment, procedures, and data, (c) establishes and maintains configuration management of the system, (d) develops work breakdown structures and statements of work, and (e) provides information for management decision making.*

Systems engineering integrates the total engineering effort to meet cost, schedule, and technical performance objectives (Lacy, 1994), and is both a technical process and a management process.

2.1.3.3.2 Systems Engineering Process

Many definitions of a system have been offered, but, in the broadest sense, "*any two or more objects interacting cooperatively to achieve some goal or purpose constitute a system*" *(Grady, 1993).* According to MIL-STD-499B (1992), the system engineering process is defined as follows:

> ***System Engineering Process*** *is a comprehensive, iterative problem solving process that is used to: (a) transform validated customer needs and requirements into a life cycle balanced solution set of system product and process designs, (b) generate information for decision makers, and (c) provide information for the next acquisition phase. The problem and success criteria are defined through requirements analysis, functional analysis/allocation, and systems analysis and control. Alternative solutions, evaluation of those alternatives, selection of the best cycle balanced solution, and the description of the solution through the design package are accomplished through synthesis and systems and analysis and control.*

A more complete description as depicted by Brook and Arnold (1996) of the system engineering process can be illustrated by the use of system levels, as shown in Figure 2-1. System engineers at the top level define the overall architecture of the complete system in terms of the next components at the next level down. Those at lower levels receive a package of requirements about the architectural element (or group of elements) they are to design, as well as defining any new requirements which appear at that level.

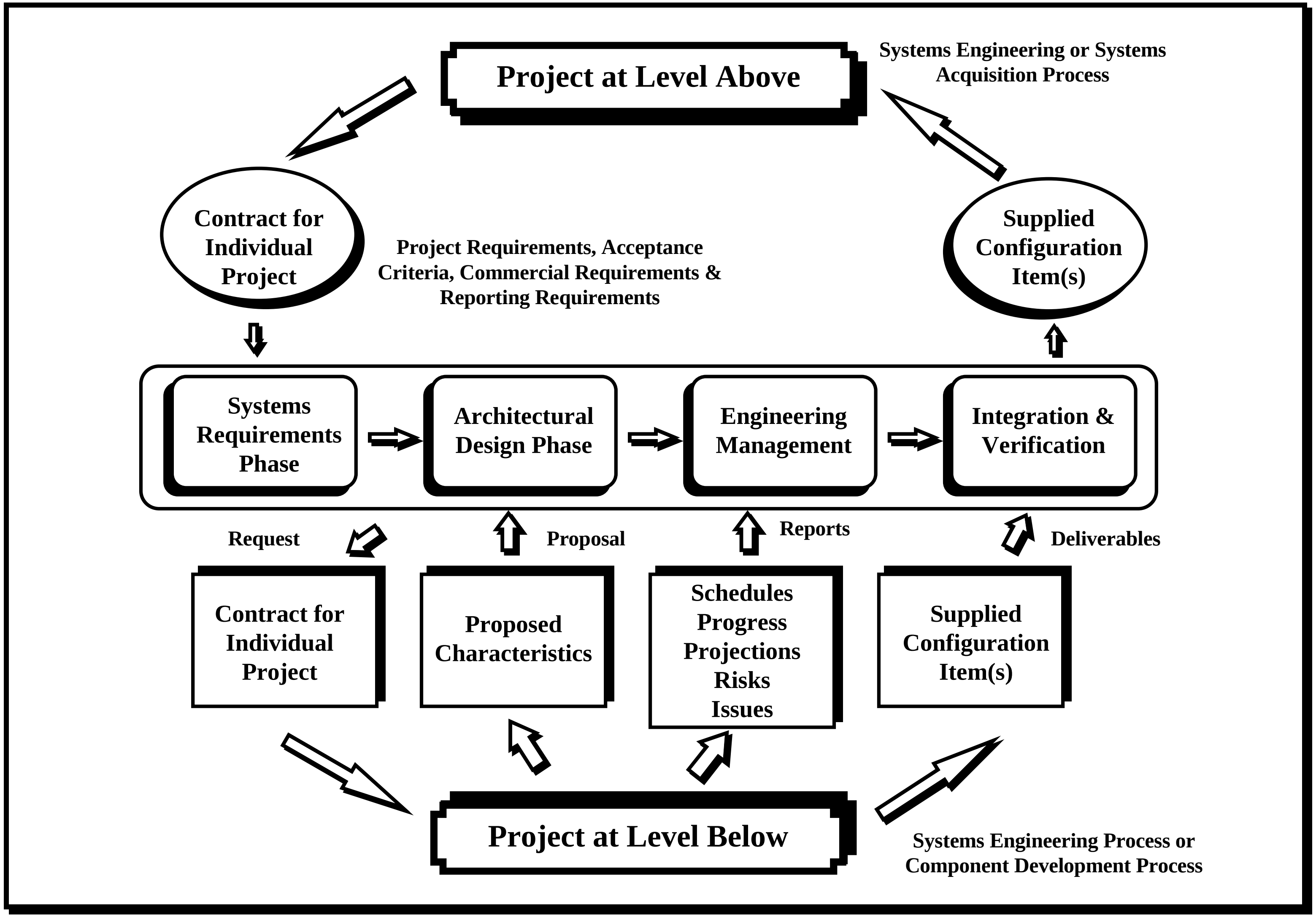


Figure 2-1 (Systems Engineering Process (based on Brook & Arnold, 1996))

It follows then from the decomposition process (Brook and Arnold, 1996) that only the highest systems engineering level responds directly to user requirements and all other levels receive systems requirements from the level above, and then only the subset which is relevant for that level.

Successful OT&E is a systems engineering process in which the system and its testing are approached from an overall systems point of view, and the complete philosophy of the systems approach is brought to bear (Stevens, 1986).

2.1.3.3.3 Test and Evaluation in Systems Engineering

The United States Department of Defence (DoD) Military Standard (MIL-STD) 499B on Systems Engineering depicts T&E as an essential element of the Systems Engineering "engine" (Przemieniecki, 1993). Test and Evaluation must be integrated with the rest of the system engineering effort. The testing program in the Test and Evaluation Master Plan (TEMP) must be consistent with the System Engineering Master Plan (SEMP) (Lacy, 1994). The SEMP is a concise, top-level management plan for integrating all of the system activities. The major objective of the SEMP are to (Lacy, 1994):

- Facilitate communications.
- Integrate all engineering disciplines.
- Ensure the product meets the requirements.
- Establish streamlined checks and controls.
- Define the system engineering process.

The SEMP defines the type of degree of system engineering management, the system engineering process, and the integration of engineering efforts. The plan identifies (Lacy, 1994):

- Organisational responsibilities.
- Authority for system engineering management.
- Levels of control for performance and design requirements.
- Control methods to be used.
- Technical program assurance methods.
- Control procedures to ensure integration of requirements and constraints.

- Schedules for design and technical program reviews.
- A detailed description of the system engineering process to be used.
- Specific tailoring to requirements of the system in-house documentation.
- Trade-off study methodology.
- Types of mathematical and simulation models to be used for system and cost-effectiveness evaluations.

A SEMP is created to structure engineering planning, processes, and outputs. Engineering Management for the DoD is described in MIL-STD-499A. DoD MIL-STD-499A divides systems engineering management into three types of activities (Lacy, 1994):

1. Technical program planning and control
2. System engineering process.
3. Engineering specialty integration.

The structure of MIL-STD-499A activities are shown in Table 2-4 (Lacy, 1994).

SYSTEM ENGINEERING MANAGEMENT PLAN		
TECHNICAL PROGRAM PLANNING AND CONTROL	**SYSTEM ENGINEERING PROCESS**	**ENGINEERING SPECIALTY INTEGRATION**
⇒ Work breakdown structure and specification tree	⇒ Mission requirements analysis	⇒ Reliability
⇒ System test planning	⇒ Functional analysis	⇒ Maintainability
⇒ Decision and control process	⇒ Allocation	⇒ Logistics engineering
⇒ Technical performance parameters (TPP's)	⇒ Synthesis	⇒ Human engineering
⇒ Technical reviews	⇒ Logistic engineering	⇒ Safety
⇒ Vendor reviews	⇒ Life cycle cost analysis	⇒ Value engineering
⇒ Work authorization	⇒ Optimization	⇒ Standardisation
⇒ Documentation controls	⇒ Production-engineering analysis	⇒ Transportability
	⇒ Generation of specifications	

Table 2-4 (The Structure of MIL-STD-499A Activities (Lacy, 1994))

A typical SEMP has a similar format to that of a TEMP (which is addressed in the proceeding chapters) and should contain the information listed in the sample format of Figure 2-2.

Introduction
Part 1 Technical Program Planning and Control
- 1.0 Responsibilities and Authority
- 1.1 Standards, Procedures, and Training
- 1.2 Program Risk Analysis
- 1.3 Work Breakdown Structure
- 1.4 Program Reviews
- 1.5 Technical Reviews

1.6 Technical Performance Measurements
1.7 Change Control Procedures
1.8 Engineering Program Integration
1.9 Interface Control
1.10 Milestones/Schedules
1.11 Other Plans and Controls

Part 2 System Engineering Process
2.0 Mission and Requirements Analysis
2.1 Functional Analysis
2.2 Requirements Allocation
2.3 Trade Studies
2.4 Design Optimization/Effectiveness Compatibility
2.5 Synthesis
2.6 Technical Interface Compatibility
2.7 Logistic Support Analysis
2.8 Producibility Analysis
2.9 Specification Tree/Specificationa
2.10 Documentation
2.11 Systems Engineering Tools

Part 3 Engineering Specialty/Integration Requirements
3.1 Integration Design/Plans
3.1.1 Reliability
3.1.2 Maintainability
3.1.3 Human Engineering
3.1.4 Safety
3.1.5 Standardisation
3.1.6 Survivability/Vulnerability
3.1.7 Electromagnetic Compatibility/Interference
3.1.8 Electromagnetic Pulse Hardening
3.1.9 Integrated Logistics Support
3.1.10 Computer Resources Life Cycle Management Plan
3.1.11 Producibility
3.1.12 Other Engineering Specialty Requirements/Plans
3.2 Integration System Test Plans
3.3 Compatibility with Supporting Activities
3.3.1 System Cost Effectiveness
3.3.2 Value Engineering
3.3.3 TQM/Quality Assurance
3.3.4 Materials and Processes

Figure 2-2 (Typical SEMP Format (based on DSMC, 1990))

2.1.4 Types of Test & Evaluation

In a system T&E requires knowledge of both development activity, which is usually driven by requirements and specifications, as well as the operational environment the system will reside in. This leads to two distinct branches of T&E, namely, Developmental Test & Evaluation (DT&E) and Operational Test and Evaluation (OT&E). DT&E is that T&E that supports the development of a system or process, whilst OT&E is that T&E which assesses (Dvorak, 1995) the effectiveness and suitability for service of a system. The proper scope, structure, and timing of these two types of T&E has yet to be established, a number of T&E practitioners are still in an intense world-wide debate on these issues, namely (Parker, 1993), (Sanders, 1994), (Seglie, 1993a), (Seglie, 1994), (Griffin, 1994), and (Joseph, 1992).

2.1.4.1 Development T&E

The primary focus of DT&E is the identification and verification of system performance specifications. Unfortunately, due to the difficulty in perfectly allocating requirements into systems functionality, a system can often meet all of it's engineering specifications yet still fail to adequately perform its mission (Stevens, 1986). The US Department of Defence Directive 5000.3 defines Developmental Test and Evaluation as follows:

> ***"Development Test and Evaluation** is test and evaluation conducted throughout various phases of the acquisition process to ensure the acquisition and fielding of an effective and supportable system by assisting in the engineering design and development and verifying attainment of technical performance specifications, objectives and supportability."*

Whilst (Joseph, 1992) defines Developmental Test and Evaluation as:

> ***"Development Test and Evaluation** is conducted to assist, the engineering design and development process, and to verify attainment to technical performance specifications and objectives."*

DT&E also includes T&E of components, subsystems, hardware/software, as well as qualification and production acceptance testing. T&E compatibility and interoperability with existing or planned equipment and systems is also emphasised, as well as system effects due to natural and induced environmental conditions. It encompasses the use of models, simulations, and test beds, as well as prototype of full-scale engineering development models of the system (Defence Systems Management College, 1995). According to DoDI 5000.2, the overall DT&E objectives encompass the following:

1. Identify potential operational and technological limitations of the alternative concepts and design options being pursued.
2. Support the identification of cost-performance trace-offs.
3. Support the identification and description of design risks.
4. Substantiate that contract technical performance and manufacturing process requirements have been achieved, and
5. Support the decision to certify the system ready for operational test and evaluation.

2.1.4.2 Production Acceptance Test and Evaluation (PAT&E)

PAT&E is conducted on production items, to ensure systems meet technical specifications and requirements, and is a type of DT&E (Joseph, 1992). It is conducted to assure that production items meet specifications and performance requirements (Defence Systems Management College, 1995).

PAT&E assures that production items demonstrate the fulfillment (Przemieniecki, 1993) of the requirements and specifications of the procuring contract or agreement. The testing also ensures the system being produced demonstrates the same performance as the pre-production models and operates in accordance with the specifications.

2.1.4.3 Contractor Based T&E

In addition to the governmental agencies, the contractor plays a key role in DT&E (Przemieniecki, 1993), especially in the early part of the test program. A contractual system test plan is developed jointly by the Program Officer (PO) and the contractor and it identifies the roles of each participant. The contractor is involved in a range of testing, namely, sub-system testing, operational mock-up testing, and a number of other tests leading up to the first live launch of a rocket or the first test flight of an aircraft.

The Defence Systems Management College (1995) summarises the contractor's role in testing as follows:

- Deliver Integrated Test Plan (ITP) for approval
- Test Sufficiently before delivery to Government
- Provide Technical support to Government testing
- Correct Problems

- Increase Test and evaluation efficiency

2.1.4.4 Operational T&E

OT&E is conducted to determine a systems operational effectiveness and operational suitability, identify system deficiencies and the need for potential modifications to meet established OT thresholds, and develop tactics (Joseph, 1992).

OT&E has three major distinguishing characteristics:

⇒ It is ***conducted*** in an operationally representative environment.

⇒ It is ***conducted*** on production representative equipment using fleet personnel for operation and maintenance.

⇒ It is ***conducted*** against a threat - representative simulated enemy carrying out threat tactics per the latest threat assessment.

The Defence Systems Management College (1995) defines OT&E as follows:

> ***"Operational Test & Evaluation*** *is the field test, under realistic conditions, of any item of (or key component of) weapons, equipment, or munitions for the purpose of determining the operational effectiveness and suitability of the weapons, equipment, or munitions for use in combat by typical military users; and the evaluation of the results of such tests"*

The primary focus of OT&E is to ensure that only systems that are operationally effective and suitable will be delivered to the operating forces. The results of OT&E are provided to the appropriate decision makers for decisions on system production and fielding. Therefore, OT&E should be structured to provide inputs at each decision point, including major systems (Defence Systems Management College, 1995).

In general the final evaluation should determine operational effectiveness and suitability. The US Department of Defence (DoD) provides clear definitions of these terms (Seglie, 1993b) (Rodriguez, 1992):

> ***"Operational Effectiveness*** *is the overall degree of mission accomplishment of a system when used by representative personnel in the environment planned or expected (e.g., natural, electronic, threat) for operational employment of the system considering organisation, doctrine, tactics, survivability, vulnerability, and threat (including countermeasures, initial weapons effects, nuclear, biological and chemical threats)."*

> *“**Operational Suitability** is the degree to which a system can be placed satisfactorily in field use with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower supportability, logistics supportability, natural environmental effects and impacts, documentation and training requirements.”*

Operational suitability applies to each level of support. Table 2-5 presents some examples of the levels of support that may be applied, for various weapon systems.

<table>
<tr><th rowspan="2">LEVEL</th><th rowspan="2">TYPE OF SUPPORT</th><th colspan="3">EXAMPLE</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><td rowspan="2">1st</td><td rowspan="2">Owner or User</td><td rowspan="2">Organisational</td><td>Crew</td><td>Crew</td></tr>
<tr><td>Unit</td><td>Unit</td></tr>
<tr><td rowspan="2">2nd</td><td rowspan="2">Supporting Unit(s) with More Capability</td><td rowspan="2">Intermediate</td><td rowspan="2">Direct Support</td><td>Direct Support</td></tr>
<tr><td>General Support</td></tr>
<tr><td>3rd</td><td>Highest Level of Capability</td><td>Depot</td><td>Depot</td><td>Depot</td></tr>
</table>

Table 2-5 (Variance in the Definitions of Support Levels (Rodriguez, 1992))

In each of these services, operational testing is conducted under the auspices of an organisation that is dependent of the development agency, in as operationally realistic environments as possible, with hostile forces representative of the anticipated threat and with typical users operating and maintaining the system (Defence Systems Management College, 1995). Often the specific criteria against which to judge the operational effectiveness and suitability are not clearly identified and often gives rise to mandated tests (Seglie, 1993b). In such cases, the objective is implied by the mandate.

2.1.4.5 Differences Between DT&E and OT&E

Development testing is focused on meeting detailed technical specifications, the operational test focuses on the actual functioning of the equipment in a realistic combat environment in which the equipment must interact with humans and peripheral equipment. Where DT&E and OT&E are separate activities and are conducted by different test communities, the communities must interact frequently and are generally complementary. The DT&E provides a view of the potential to reach technical objectives, and OT&E provides an assessment of the system's potential to satisfy user requirements (DSMC, 1995). The key differences are outlined in Table 2-6.

DEVELOPMENT TESTING	OPERATIONAL TESTING
CONDUCT OF TESTS	
Technical, Controlled Environment, Specification Tested, Technical Personnel, “Tweaked System”.	Realistic Environment, Fleet Operators and Maintenance, Simulated Enemy Engagements (No Contractors).
SCOPE OF TESTS	
“Black Box”, Single Weapon, Generally Only Part of the Complete System.	Total Weapons System Including Operators and Logistics Support.
EVALUATION CRITERIA	
Technical Criteria, Measurable Parameters (Signal Strength, Specifications).	Probability of Mission Accomplishment, P_{det}[2], P_{hit}[3], P_{kill}[4].
MEASUREMENTS & FREQUENCY	
Specific Parameters (Launch Velocity, Load Factor Time To Climb). Test Must be Repeatable.	Generally Specific Measurements Not Tested. Create Combat Conditions and Observe Results. Test Not Repeatable, Interactions Usually Unique.

Table 2-6 (Differences Between DT&E and OT&E (Hoivik, 1995))

In some instances OT&E and DT&E are combined. The following points adhere to carrying out this action (Hoivik, 1995):

- Usually conducted to obtain significant cost and time benefits.

[2] Probability of detection.

[3] Probability of a hit.

- Must provide necessary resources, test conditions, and test data is required by both development agency and operational testing agency.
- Data collected must be sufficient and credible for OT&E agency requirements.
- Separate and independent evaluation of test results are required.

2.1.5 Interest in T&E

It is evident that both the public and the government want credible T&E programs (Reynolds and Damman, 1994), hence their full attention, due to the underlining reasons:

- Consumer concerns about commercial products.
- Government concerns about commercial products.
- Government concerns about governmental products.

There is pressure from consumer groups in areas such as safety in automobile designs and children's toys, which have alerted considerable interest in the last two decades on the method in which industry tests it's products. It is not unusual to see impressive, graphic crash tests as part of the marketing material used by new car manufacturers. Fisher-Price has placed lot's of emphasis on the safety of their toys for kids of different age categories, and has become known as the industry leader in that arena.

Oversight of commercial products by government regulatory agencies has also increased attention to T&E. Take the T&E effects of cigarette smoking on humans for example, this has been a long-term evolving task. Moreover, testing to determine the effects that household aerosol sprays have on the ozone layer, due to the emission of chloro-fluorocarbons, or CFC's, has been under serious investigation for almost two decades. Another good example is the testing to determine the effects that chopping down trees and gradually wiping-out forests has on the environment. Trees help clean the air by removing poisonous gases and participates such as dust and pollen. Through photosynthesis, trees reduce atmospheric levels of carbon dioxide and release vital oxygen. In addition, well placed trees reduce the need to burn fossil fuels to generate energy for air conditioning. The solution to all these problems and perhaps gradual demise of the planet is rigorous T&E, and verification and validation (V&V) of these test is needed.

[4] Probability of a kill.

2.1.5.1 T&E Education & Training

2.1.5.1.1 In the United States

In the United States alone, both under-graduate and postgraduate T&E studies are available. T&E engineering specialty topics are taught at a variety of civil Universities and tertiary institutes in Georgia, New Mexico and Texas. T&E management is also taught as a disciplined process at Army, Navy, Air Force and Defence colleges; and at the Federal Aviation Academy (Crouch, 1992).

2.1.5.1.2 In Australia - Formation of ACTE as a Support Base for Advancing T&E

In July 1993 interests in large multi-sensor measurement systems engineering and how they are used to obtain effectiveness measures from sensed data were combined with pragrammatic needs at the nearby Aircraft Research Establishment RAAF to form the Australian Centre for Test and Evaluation (ACTE). After two years the T&E research program is becoming more focused from its longer standing Measurement and Instrumentation (M&I) thrust (Sydenham, 1995).

The aim of ACTE is to develop the professionalism and skill level of T&E practitioners by high-level education and training; technology transfer; research and development; consulting and project management. It also provides a resource support for the International Test and Evaluation Association, ITEA (Harris, 1995).

2.1.6 Reasons for Conducting T&E

There are numerous reasons for conducting T&E with the most important objective of T&E being reduction of the risk of doing something. Testing is conducted for many of the following reasons (Dvorak and Equid, 1994):

a) To prove a concept
b) To ensure safety.
c) To ensure adequate human factors.
d) To ensure user requirements are met.
e) To avoid failures in service.
f) To check contract compliance.
g) To support acquisition decisions.
h) To provide feedback to designers.
i) To verify Supportability.

j) To validate models and simulations.

The purpose of test & evaluation as seen by the Defence Systems Management College (1993) is as follows:

> *"**The fundamental purpose of test and evaluation** in a defence system's development and acquisition program is to identify the areas of risk to be reduced or eliminated. During the early phases of development, T&E is conducted to demonstrate the feasibility of conceptual approaches, evaluate design risk, identify design alternatives, compare and analyze trade-offs, and estimate satisfaction of operational requirements. As a system undergoes design and development, the emphasis in testing moves gradually from development test and evaluation (DT&E), which is considered chiefly with attainment of engineering design goals, to operational test and evaluation (OT&E), which focuses on questions of operational effectiveness, suitability and Supportability. Although there are usually separate development and operational test events, DT&E and OT&E are not necessarily serial phases in the evolution of a weapon system. Combined and concurrent development and operational testing is encouraged when appropriate."*

Hence the reduction of risk or complete elimination of these risks in any defence acquisition program can only be accomplished by thorough T&E, and consequently verification and validation of these tests to a well known standard. As implied by the defence systems management college, testing does not stop after the initial developmental phase, simply because the engineering design goals have been achieved and the procurement process has adhered to specifications as set out in the statement of requirement (SOR), but continues right through the operational phase. Even when the desired product is sitting on the shelf ready for sale there is quality control inventory processes that all products having attained a "saleable rank" must adhere to, via random testing and evaluation. This system large volume quality control testing is a mandatory procedure for most (if not all) "commercial of the shelf (COTS)" products.

2.1.7 Importance of Test & Evaluation

Several important features of T&E are (Dvorak and Equid, 1994):

1. T&E is a process,
2. It involves the collection of data,
3. The data relates to aspects of the systems operation, and
4. The data is compared against criteria in a process of evaluation.

In the acquisition of defence systems the importance of T&E as dictated by the United States Government Accounting Office Report, August 7, 1972 was as follows (Reynolds, 1993):

- Establishment of test objectives adequate.
- Most system test plans not adequate.
- T&E in most programs not timely and effective.
- Test results were adequate, but their value was diminished.
- Complete test data not available to decision makers prior to key decision points.

2.1.8 Objectives of T&E

The principal objectives of T&E are to (Crouch, 1992):

- Reduce technical risk
- Find problems while they are cheap to fix
- Give confidence to the decision makers that the:
  - ⇒ Promises of emerging technology are being realised,
  - ⇒ Simulations and models are faithful,
  - ⇒ Systems meet their specifications and that
  - ⇒ Systems behave safely and as predicted over their useful life.

Objectivity enters during test planning, evaluation, and reporting. It has three aspects (Seglie, 1993b):

1. The test should present a balanced spectrum of missions to the system.
2. The evaluation should weigh the pluses and minuses of the system openly and carefully.
3. The report should describe what actually happened in the test and explain the reasons for the judgments that are made.

2.1.9 Need for Conducting T&E

T&E Principles can be applied to a wide range of products. The Defence Department uses disciplined T&E for a range of reasons as follows (Dvorak and Equid, 1994):

1. Systems in procurements/use can be very complex.

2. System usage can be in a dangerous environment or an environment that is not easily simulated for test purposes, and
3. Development and acquisition programs can be phenomenally expensive and T&E is applied to lower technical or program risks.

2.1.10 Foreign Comparative Testing

Foreign Comparative Testing, otherwise known as FCT is a program supported by the United States as a national policy for encouraging international armaments cooperation and helps reduce overall DoD acquisition costs by facilitating the procurement of non-developmental items (NDI). Biskey (1994) defines FCT as follows:

> ***"Foreign Comparative Testing** involves the T&E of selected items of defence equipment developed by US allies, and other nations considered friendly toward the US, to determine whether such equipment can effectively satisfy DoD requirements or correct mission area shortcomings, as cost-effective alternatives to new, and perhaps unnecessary, developmental efforts."*

By identifying foreign alternatives, Biskey states that FCT stimulates competition from US manufacturers; however, safeguards are in place to ensure that US manufacturers are not placed at any disadvantage and that US industrial base issues are considered.

The underlying document for carrying out any FCT program, outlining procedures and formats is the DoD 5000.3-M-2 (1994), instigated by The Under Secretary of Defence (Acquisition & Technology). This standard states that the subsequent acquisition of foreign technology and/or deployment of selected foreign systems evaluated under the auspices of the FCT program results in significant resource savings by avoiding unnecessary duplication of R&D, achieves more timely fielding, and provides viable alternative solutions to component requirements, promoting healthy competition and resultant procurement savings.

Further more, the FCT program directly supports the DoD policy that equipment procured for use by personnel of the Armed Forces of the US stationed in Europe, under the terms of the North Atlantic Treaty, by standardised or interoperable with equipment from other North Atlantic Organisation (NATO) nations.

In the Australian arena, a number of locally grown products are being evaluated under the US FCT program with good prospects for follow-on procurements by the US Services. Walls

(1995) states that these products have successfully competed against international competition before entry into the FCT program. At present, Australian products being tested by the US Navy are as follows:

- Vision System's Laser Airborne Depth Sounder (LADS)
- Ryan Marine's PROPSCAN computerised propeller measurement equipment
- Australian Defence Industries (ADI) Dyad decoy project which relates to the Auxiliary Minesweeping and Surveillance System (AMASS)

An earlier program led to the purchase of Australian transportable recompression chambers from Crown Engineering. Funding for the FCT program has averaged about $US27 million over the last six years. Generally, projects approved for T&E through the FCT program are funded for no more than a two-year effort. However, on an exception basis, funding for T&E of complex systems (such as F/A-18 fighter aircraft) may be provided for a longer period.

2.2 Conclusion

This chapter has reviewed test and evaluation, flight test, past and present. It was found through the comprehensive literature review that, test and evaluation is a process, and merely an extension of the scientific method, that is: design - test - analyses - fix - test. This was substantiated with a layman's example of children making slingshots.

Over the duration of the literature search it was determined that very few academic textbooks had been written on this subject, due to the fact that the subject of this research has been primarily concerned with defence, and in particular the United States Department of Defence.

An outline on the connection between systems engineering and test & evaluation was discussed, and the different types of test & evaluation, namely, developmental test & evaluation and operational test & evaluation. A description on the interests, education and training, reasons for conducting, importance, objectives and the need for conducting test and evaluation was made.

In conclusion, test and evaluation is a very new field of research and open to a vast multitude of exploration in a rapidly maturing environment. The next chapter will look at the genealogy of aircraft flight test and how it is directly interpolated with the role of test and evaluation.

CHAPTER 3

3. The Genealogy of Aircraft Flight Testing

3.1 Introduction to Flight Test

The first flight tests took place over two hundred years ago in a balloon in France. Credit for the invention of the balloon goes to *the Montgolfier Brothers, Joseph and Jacques,* who were sons of a wealthy paper bag manufacturer. They developed the technology for both hot air and hydrogen systems but they were not the intrepid pilots. The test crew for the first full scale test was a cock, a duck and a sheep. The operational role of each in the test mission is unknown but they obviously did not know enough about flying because it was immediately proposed to have a human crew for the next flight. Two prisoners were proposed by *King Louis XVI over the protests by Jean Francois Pilatre de Rozier who believed this to be an honor* and not a sentence. In the end he prevailed and was given the nod for being the first test pilot of the first manned flight (Schweikhard, 1991).

The "testability" (of say an aircraft) is defined by the Encyclopaedia Britannica (Benton and Benton, 1980b) as follows:

> ***"Testability****, in the philosophy of science, the capability of a scientific hypothesis to be tested by comparing the predictions that it formulates with observational or experimental data that are capable of either indicating the falsity of the hypothesis or of corroborating, though not necessarily proving, its validity"*.

The increasing complexity and volume of the information needed to support test missions has led to a need to expand the capability of current test data management systems. While the abilities currently exist to collect and manage calibration and telemetry information in an automated fashion, new requirements have emerged to link this data with other systems and to expand the functions and devices supported (Hoaglund and Gardner, 1993). As a result, a large volume of data is generated for each test conducted. This is not only computationally expensive, making data processing very time consuming, and stretches the telemetry bandwidth to it's limit in the case of air and space-ground telemetry, bus also hinders the design of test and evaluation programs to accurately validate the function of the systems (Teng et al, 1994).

The thrust of this research is based on the highly instrumented fighter aircraft F/A-18 Hornet, however the research is not intended to be constrained entirely to the test and evaluation of FA/18's, but to a more general and diverse array of test recipients (Nissyrios, 1994a).

The process of testing an aircraft such as the highly instrumented fighter aircraft F/A-18 Hornet, equipped with over 500 onboard sensors and 6000 measurements available from the internal MIL-STD-1553[5] (Chavez and Sutherland, 1990) avionics bus for both onboard tape recording and telemetering, is very complicated because of a number of resource limiting factors such as (Nissyrios, 1994b):

1. Telemetry bandwidth considerations, as for each half-hour flight test, there is approximately 1.2GigaBytes (GB) of measurement data generated with the serial Pulse Code Modulated (PCM) streams produced at a rate on the order of 100kbits per second.
2. Wish to know numerous amounts of information (very large numbers) in a very short span of time.
3. Speed at which the test takes place is sometimes in the vicinity of twice the speed of sound[6].
4. Further exacerbated with missile testing as the entire process is completed within a few minutes, hence is only carried out once a year as it requires $US1Million dollars for each test.
5. Severe space problems, because of the clutter of sensors onboard the aircraft which are also constrained to very strict safety regulations.

The complexity, size, and the number of people involved cause the user to lose contact with what happens to and hence otherwise affects his/her data. Pressures on the cost of testing,

[5] Note that MIL-STD-1553 multiplex data buses are commonly used to link complex software-controlled systems in modern aircraft (Fletcher, 1992) such as the Hornet F/A-18.

[6] Example: Flying at Mach 2 (twice the speed of sound) and moving a wing on the aircraft whilst simultaneously recording and telemetering numerous measurements.

that is, want more effective systems for less cost and in less time. However every variable of any significance is under threat, and thus T&E is seen as one of the main ways of reaching those goals

3.1.1 Flight Test Defined

Flight Test is a very important and very expensive portion of the Test and Evaluation activities that support the acquisition of new aircraft capabilities. The data gathered during flight or ground test forms the foundation for major acquisition decisions, and the accuracy and efficiency of the testing process is vital to the entire acquisition effort (Hoaglund and Gardner, 1993). Of all the research papers that the author has come across on flight test, the most prominent one would have to be *"Flight Test - Past Present and Future"* by Schweikhard (1991). Schweikhard defines flight test as follows:

> ***"Flight test** is a process by which quantitative and qualitative results are obtained on an air vehicle."*

> ***"Evaluation** of flight test results is a process by which cognitive or knowledge-based conclusions of the flight test process are arrived at."*

No matter what type of aircraft or type of testing is being done, or whether we are recording the data by hand or we are using the most sophisticated of data acquisition systems, there are certain elements that remain the same. They are (Schweikhard, 1991):

1. Planning and coordination
2. Instrumentation and calibration
3. Flight test operations
4. Data acquisition
5. Data processing
6. Data analysis and interpretation
7. Reporting of results

Flight test is a *"process"* whereby we (Schweikhard, 1991):

1. Evaluate an air vehicle (aircraft).
2. Prove or disprove new concepts or designs.

3. Identify design problems or deficiencies.
4. Prove or certify the airworthiness of an aircraft.

Two very important questions that one needs to ask continually are (Schweikhard, 1991) "*How much do we really need to measure ?" and two is "How much money for manpower and equipment is it worth ?"*.

As stated previously a number of parameters can cause the user to lose contact with what happens to and hence otherwise affects their data. So we need to ask ourselves the questions, "Who is looking at the data and evaluating it ?" and "Do we really need it all ?" (Schweikhard, 1991). Off course we appropriately archive the data and almost always never go back to look at it again. A paraphrased variation of Parkinson's Law for instrumentation says that *"The number of parameters requested will grow to fill the capacity of the data acquisition system"* !. We become like kids in the toy department and want everything insight. "Top-down" flight test planning results in the recording of too many parameters. Hence need to (Schweikhard, 1991):

- Keep it ***S****imple*
- Keep it ***S****mall*
- Keep it ***E****conomical*
- Keep it ***M****anageable*

KISS'EM

The more sophisticated weapons become, the more information required for thorough system test and evaluation. With the increasing capability in instrumentation technology, more data is being generated, and this is turn is stressing the amount of telemetry bandwidth available (Hoefner, 1992). A constant question thus put forth is *"What information is required not what data can be made available"*, and that, *"It is not enough to just do things right, first, we must be doing the right things" (Schweikhard, 1991).*

3.1.2 Aircraft Research & Development Unit

The Aircraft Research Development Unit (ARDU) is the flight test authority for the Royal Australian Air Force (RAAF). ARDU was born out of a requirement to handle the testing of developmental aircraft and weapons during Word War II. Its nucleus was established in 1941 and one of its first tasks was to evaluate qualities and performance of captured aircraft (Slezak and Crouch, 1992). The ARDU is the prime Australian Defence Force (ADF) agency for the collection and analysis of flight test data for military aircraft, airborne systems and weapons. As directed by the Royal Australian Air Force (RAAF), ARDU (ARDU, 1989):

1. Executes Research, Development, Test and Evaluation (RDT&E) tasks and trials.
2. Provides flight test data that is essential to monitor the effectiveness of other ADF and Defence Science and Technology Organisation (DSTO) Research Development Test & Evaluation (RDT&E), modelling and software verification and validation (V&V).

The ARDU performs flight testing on Royal Australian Navy (RAN) aircraft. There are fifty or more flight test tasks of varying complexity at any one time. Flight test missions in ARDU inventory currently include (Slezak and Crouch, 1992):

- Test and Evaluation requirements for flight loads measurement.
- Software verification and validation.
- Flying qualities measurement.
- Weapons clearance and release.
- Validation of simulations and models.
- Tactical testing.

Amongst the numerous amounts of issues that the ARDU must take into consideration when undergoing flight testing to ensure that all avenues for mishap have been looked at, the most prominent issues that must always be considered are:

1. Time to deliver the interpretation of the results of any one test.
2. Quality of performance that applying T&E will bring along.
3. Cost of carrying out a test.

At present, the most important of the ARDU's tasks include participation in international Hornet F/A-18 (Fighter Aircraft) test programs with the Canadian Forces (International Follow on Structural Test Program) and with the United States Navy (Software Verification and Validation). A diagram of the Hornet Integrated Flight Test Data Acquisition and Analysis System is shown in Figure 3-1. Figure 3-2 illustrates some of the parameters as shown on the screen in the control room, illustrating such things as altitude, roll rate, torque, elevation, fuel in both left and right wing compartments, rudder position, etc. Note however, the parameters shown are those depicted at that instant in flight and are continuously being updated during the test.

In fulfilling its role the ARDU mandatory tasks are classified into seven categories, as follows (Ward, 1995):

1. Conduct, DT&E for the RAAF and Australian Army on aircraft, aircraft weapons and associated systems.
2. Process Electronic Warfare (EW) data collected by RAAF resources.
3. Conduct software support of RAAF EW systems.
4. Conduct specialised EW training.
5. Develop and maintain appropriate capabilities, facilities, equipment, expertise and techniques required for the real-time qualitative and quantitative flight test activities in DT&E and EW.
6. Maintain and operate all aircraft, aircraft weapons and associated systems permanently allocated to ARDU.
7. Maintain an EW reference library.

ARDU's main product is therefore intellectual property (outcomes of the tasks), and is used by customers to make informed decisions.

3.1.3 Flight Test Information Management System (FTIMS)

3.1.3.1 Overview

The FTIMS as mentioned in Chapter 1, performs those transactions needed to manage the flow of information related to quantitative flight testing. This will involve management of information associated with flight test planning, data acquisition and reduction, configuration management of test aircraft and ground systems, inventory control of flight test systems, identification of type records, and data traceability and validation.

3.1.3.2 FTIMS Operation

The ARDU of the RAAF has developed a prototype FTIMS (as illustrated in Figure 3-1). FTIMS provides a limited capability to manage flight test related data, specifically for the support of the Hornet F/A-18 flight testing effort. The FTIMS allows the definition and acquisition of flight test related data (ARDU, 1994b).

From an identified task, a test flight or series of test flight may be initiated. Flight test Engineers or Task Managers (TM) (as they are sometimes referred to) from Flight Test Squadron define information that they wish to acquire and retain from a test flight. Engineering squadron then determines the specific measurands to be captured, and the configuration required, in order to satisfy the request.

There are two types of measurands that are directly accessible on a test article, Mux-bus measurands and Non-Mux-bus measurands. The availability and characteristics of the Mux-bus measurands are dependent on the specific hardware and software configuration of the bus-interactive systems fitted to the test article. The availability and characteristics of all non-mux-bus measurands (both residual and non-residual) are defined by the ARDU.

Flight test requirements are defined including the measurands required and the desired sample rate. Calibration is defined for the Total Tape Relay Facility (TTRF)/Real Time Monitoring Facility (RTMF) to process the test data received and the PCM details are also defined.

A Data Cycle Map (DCM) is then produced that is used to program the Programmable Data Acquisition System (PDAS). Also produced are Download files for the TTRF/RTMF and PDAS calibration system amongst others. This file is used to automatically program the TTRF/RTMF with the measurand information, de-commutation rules and measurand calibration particulars.

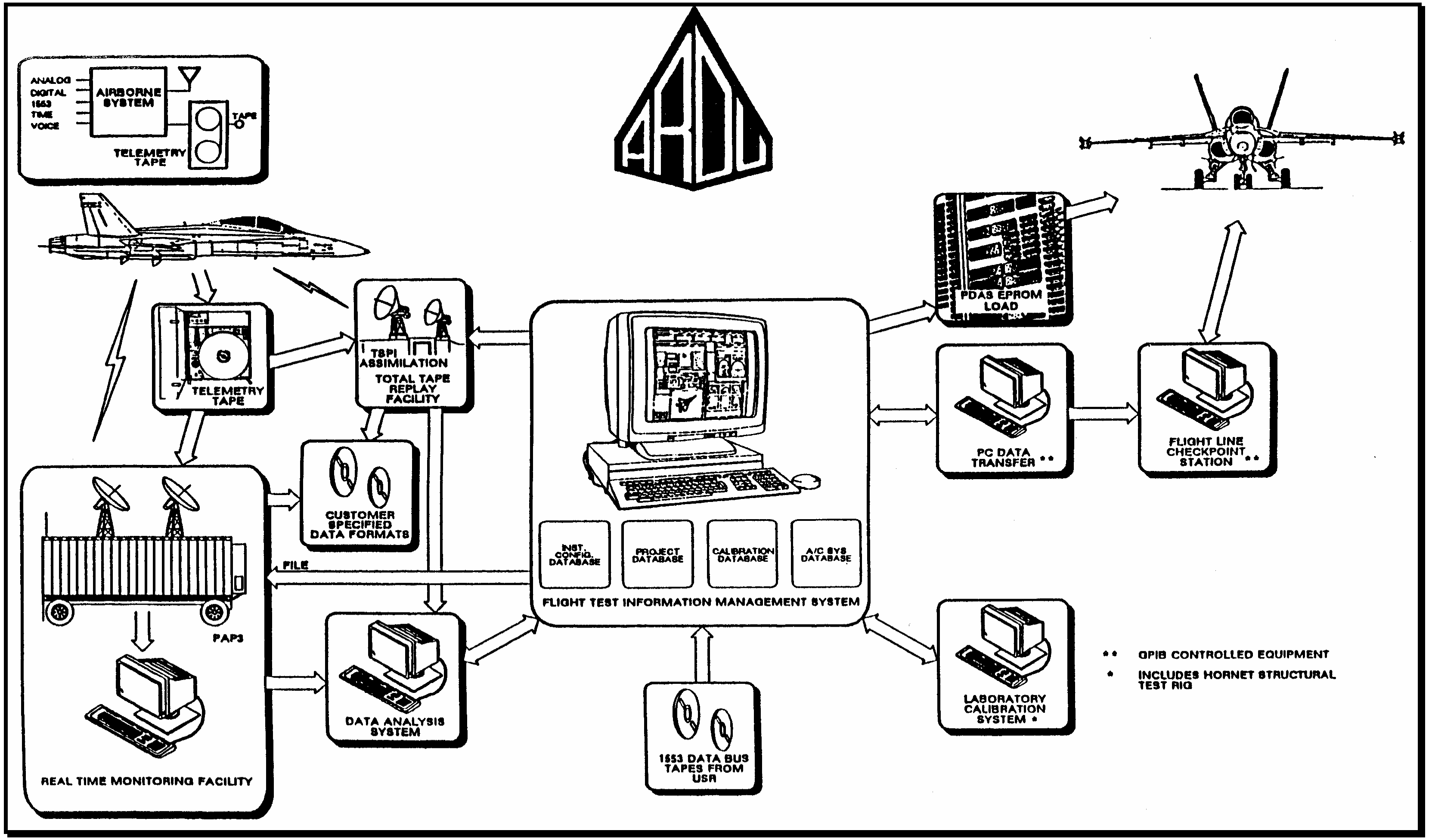


Figure 3-1 (Hornet Integrated Flight Test Data Acquisition and Analysis System)

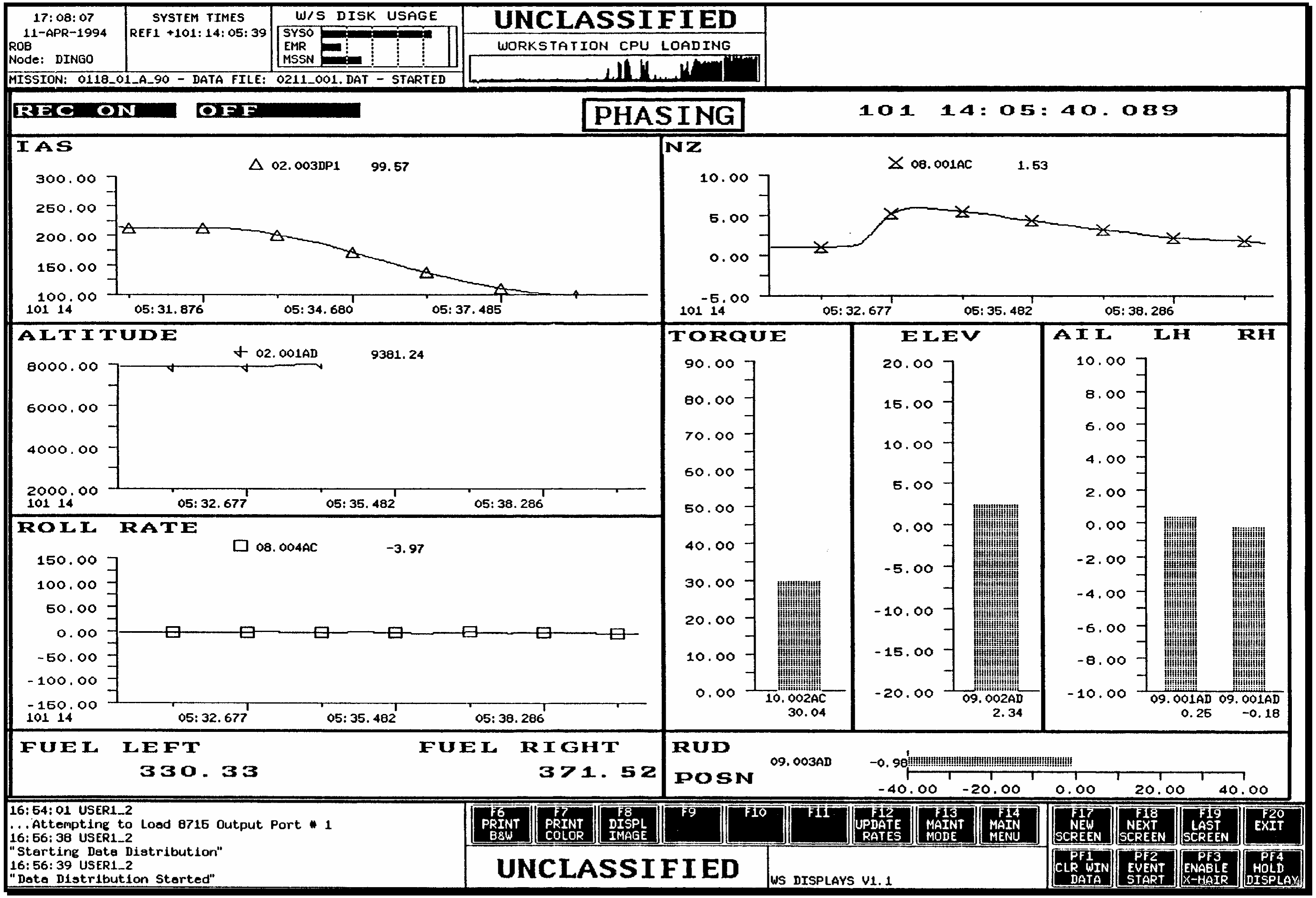


Figure 3-2 (Telemetry Flight Test - Outputs that can be achieved with Flight Test Data Acquisition Systems)

3.1.3.3 Data Cycle Map

Once all the data to be acquired on a test flight is known, along with the selected frequency of acquisition and preferred spacing, a transaction shell has been written for the data base as an aid to designing a suitable data format for the telemetering and/or on-board recording.

Once linked to the data attribute records in the data base, this enables the Data Acquisition System (DAS) on a test aircraft to be automatically programmed, the decommutation rules of Engineering Unit (EU) conversion rules to be commonly down loaded to the RTMF and TTRF, and the test aircraft configuration to be fixed.

3.1.4 Flight Test Planning

Flight test planning is a multi disciplinary endeavor which defines *test* and *test support requirements*. *Test requirements* include defining the *test objectives, the test procedures, and test evaluation criteria. Test support requirements* include scheduling test range assets, configuring the test article and its data collection system, and defining data products. The process must consider (Bender et al, 1993):

- Flight safety.
- Aircraft limitations.
- Test constraints.
- Range support requirements.
- Instrumentation requirements.
- Aircraft configuration.
- Data output requirements.

Miller and Sears (1993) states that “failing to plan is planning to fail”, which in reality is a very realistic statement to make especially when your talking about the procurement of a multi-million dollar project. Test evaluation criteria describes how the data collected during test are to be evaluated and how to determine the success of the data. Test support planning includes scheduling range airspace, control room and data acquisition, processing, display systems, frequency allocation, chase aircraft, vehicle tracking, fire truck and medical coverage. It also includes defining instrumentation system measurands to collect telemetry transmission format and frequency, general aircraft configuration (i.e., fuel, load, weight, balance, etc.), aircraft specific system hardware, software, and firmware configuration (Bender et al, 1993).

Single test planning systems will probably not be useful for all test programs. Having all the test points accessible to the test mission planning system and by marking them with status indicators like *"planned", "flown", and "complete" (Bender et al, 1993),* a simple database query will provide the desired reports instantly. The application of an Knowledge-based system (KBS) can validate a planners ideas and provide an environment for exploring alternate plans. In conclusion, software saves *Flight Test Engineers* (FTE) time, ultimately reduces data processing costs for the whole test program.

One should avoid ad hoc testing. There should always be a *written test plan*. Writing it down helps communicate to those who must approve the plan, what your intentions are, as well as the ability to communicate (Seglie, 1993b) what must be the necessary preparations to those who must support the plan. The task of writing down our plans is far from new, and can be traced back to biblical times, as is written in The Holy Bible (Nelson, Deutronomy, 5:22, 1983):

> *"These words the Lord spoke to all your assembly, in the mountain from the midst of the fire, the cloud, and the thick darkness, with a loud voice; and He added no more. And He* ***wrote them*** *on two tablets of stone and gave them to me."*

3.1.4.1 The Test Plan

It is impossible to meaningfully consider a "cookbook" approach to test planing. For it to be effective and affordable, the test plan must be tailored to both the type of system and to the risks (technical, schedule, and cost risks) inherent in the particular program. Nevertheless, we have the intelligence to use some sort of test plan writing guidelines, based on the more common problems from test plans written in the past that could have been reduced with better test planning. The following is a fifteen point summary of test planning rules compiled by Reynolds and Damaan (1994) and also applies to T&E defence acquisition programs:

1. Plan early and thoroughly.
2. Integrate the test program.
3. Focus on the operational.
4. Pick the right measures.
5. Make the T&E events complement each other.
6. Design for testability.
7. Test reliability throughout development.
8. Use models and simulations, wisely.
9. Establish a failure reporting system early.
10. Ensure disciplined computer software testing.
11. Tailor design-limit testing.
12. Conduct life-testing during engineering and manufacturing development phase.
13. Ensure the whole system is ready for OT&E.
14. Determine test resources needs early.
15. Collect and use initial field feedback.

Figure 3-3 (Flight Test Planning Rules (adopted from Reynolds and Damaan, 1994))

3.1.4.2 Analysing Test Data

In a flight test, the analyst of the final data should always witness trials, as there is no other way to visualise the context in which the data takes on meaning, and hence save time. Trying to recreate the test procedure or trial from the gigabytes of data collected during a one hour flight test is worse than blind men trying to describe an elephant. The following suggestions depicted by Seglie (1993b) will have the capacity to speed up the analysis by focusing in on the drivers for mission success, the most important aspect of the evaluation.

1. Keep all the data for analysis.
2. Determine if the trial lead to a mission success.
3. Assign a probable cause for each mission failure.
4. Determine if there are any order effects or apparent learning during the test.
5. Search for other confounding effects.
6. Find out why things happened the way they did.

Figure 3-4 (The Flight Test Data Analysis Rule Set (based on Reynolds, and Damaan, 1994))

3.1.4.3 Evaluation of Flight Test Data

The evaluator will experience many pressures from individuals who have a stake in the answer (Seglie, 1993b), who may want the answer to come out one way or another. The following suggestions aim to make the evaluator’s difficult task as unstressful as possible by: playing by announced rules, not winking at faults in the test or the system under test, and by being complete in the evaluation.

1. Evaluation criteria should be available before test planning starts.
2. Evaluate against all stated evaluation criteria.
3. Don’t put blinders on during the evaluation.
4. Keep the evaluation objective.
5. Evaluate the test as well as the system under test (SUT).

Figure 3-5 (Evaluation of Flight Test Data Rule Set (based on Reynolds, and Damaan, 1994))

From Figure 3-5, it is evident that the evaluator must carefully consider all the “surprises” to determine if the test as executed is adequate for the decision makers purposes. Often the test is evaluated in terms of it’s “limitations” rather than conventional rules.

3.1.5 Test Resources

According to DoD 5000.2-M (1993), the term “test resources” is a collective term that encompasses elements necessary to plan, conduct, collect and analyse data from a flight test event or program. These elements include (DSMC, 1993):

- Funding (to develop new resources or use existing ones)

- Manpower for test conduct and support
- Test articles
- Models
- Simulations
- Threat simulators
- Surrogates
- Replicas
- Test-beds
- Special instrumentation
- Test sites
- Targets
- Tracking and data acquisition instrumentation
- Equipment[7]
- Frequency management and control
- Base/facility support services

Part eight, of the DoD Instruction 5000.2 (1993), states that the following about testing with reference to the Test and Evaluation Master Plan:

> *"**Testing** shall be planned and conducted to take full advantage of existing investment in DoD ranges, facilities, and other resources, whenever practical, unless otherwise justified in the **Test and Evaluation Master Plan.**"*

3.1.5.1 Major Range and Test Facility Base in the United States

All services operate ranges and test facility for test, evaluation and training purpooses. Twenty one of these activities constitute the DoD Major Range and Test Facility Base (MRTFB). The United States Department of Defence has a number of Major Range and Test Facilities Bases located all over the country for carrying out test and collating flight test data, as depicted in Figure 3-6. One of the more prominent ones is the Air Force Flight Test Centre or AFFTC, at Edwards Air Force Base (AFB) California, USA. The AFFTC handles a large

[7] For data reduction, communications, meteorology, utilities, photography, calibration, security, recovery, maintenance and repair.

number of highly diverse flight test programs on a continuing basis (Gardner, 1992). Goals of the AFFTC mission planning effort are to (Bender et al, 1993):

1. Reduce the cost of T&E testing.
2. Enhance flight safety.
3. Capture corporate test knowledge.
4. Standardise and automate common test support functions where it makes sense.
5. Provide a standard architecture to meet test data management needs of future complex projects.
6. Increase management oversight.

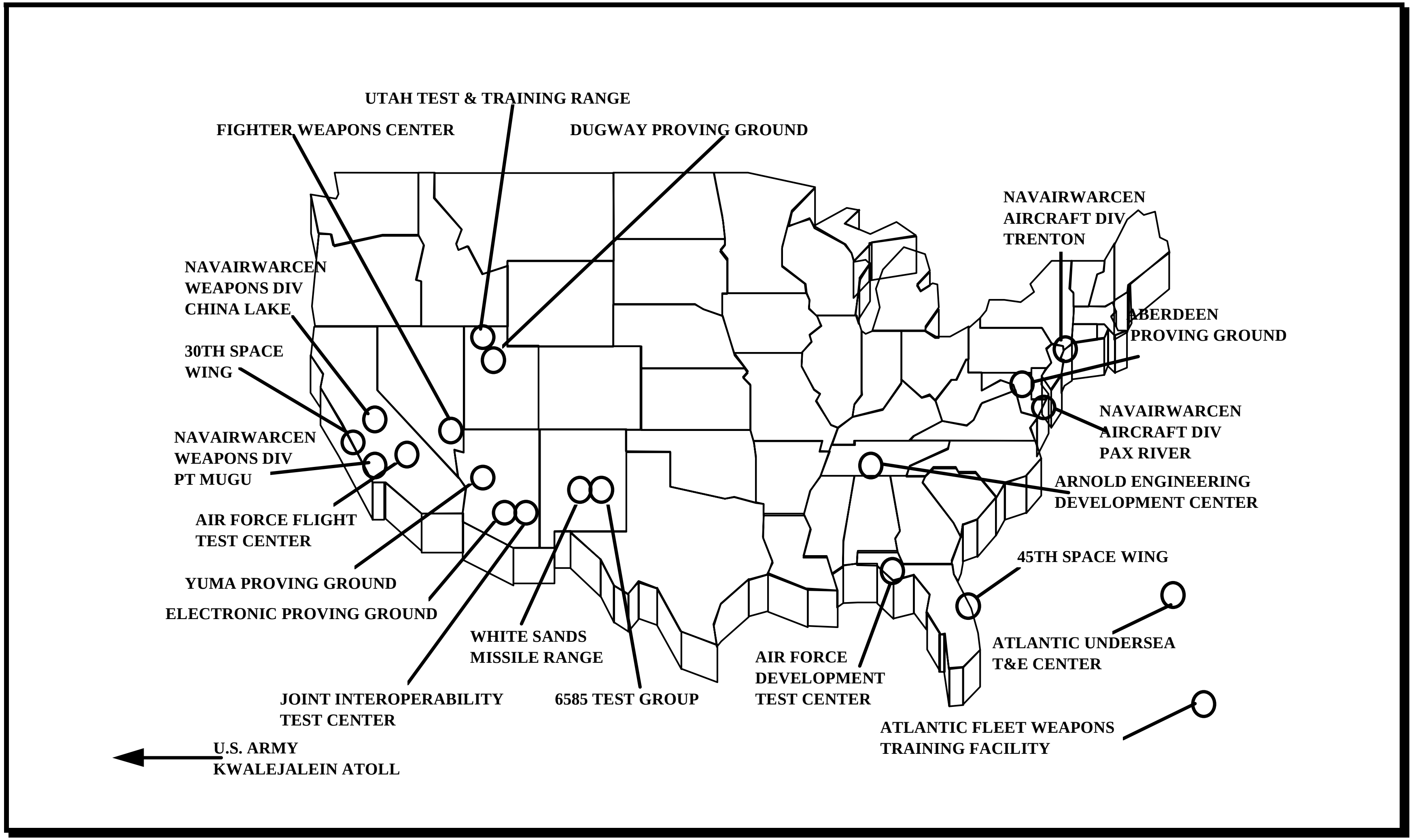


Figure 3-6 (Major Range Test Facility Bases (MRTFB) (based on DSMC, 1995))

Another prominent centre is the Air Force development Test Centre or AFDTC, of the Air Force Materiel Command, located at Eglin AFB, Florida, in the United States. In short, major tests on or above AFDTC's ranges involve all types equipment, including (Nissyrios, 1994c):

- Aircraft systems
- Subsystems
- Missiles
- Guns
- Bombs
- Rockets
- Targets and drones
- High powered radar's
- Airborne electronic countermeasures equipment

The AFDTC, is now in the process of "reinventing" test and evaluation (Cranston, 1995), focusing on better testing through better planning, better business practices, and better teaming.

3.1.5.2 TEMP Requirements

The program manager must state all key test resource requirements in the TEMP and must include items such as unique instrumentation, threat simulators, surrogates, targets, and test articles. Included in the TEMP (DSMC, 1993) are a critical analysis of anticipated resource shortfalls, their effect on systems T&E and plans to correct resource deficiencies.

3.1.5.3 Australian Defence Ranges Suitable for T&E Activities

All Defence ranges within Australia come under the control of one of the three Services, i.e., Army, Navy or Air Force. Some ranges have a specfic function or specialisation but most are general training ranges.

Wallace (1995) states that the Air Force ranges are controlled by either Air Headquarters Australia (AHQAUST) or Headquarters Training Command and are administered by the nearest RAAF Base. The major Air Force ranges are:

- Evans Head, New South Wales;

- Woomera Instrumented Ranges, South Australia;
- Delamere, Northern Territory;
- Learmonth, Western Australia;
- Halifax Bay, Queensland;
- Saumarez Reef, Queensland;
- Saltash, New South Wales;
- Dutson, Victoria; and
- Muchea, Western Australia.

The Woomera Prohibited Area (WPA) is not a dedicated range, and encapsulates approximately 130,000 square kilometres (about the size of England) located in the north west part of South Australia which under the Defence Act can be declared a prohibited area for the testing of military weapons.

3.1.6 Telemetry Formats used in Flight Testing

3.1.6.1 What is Telemetry

The ARDU (1993d) states that telemetry is the process of measuring quantities at a data source (such as an aircraft or missile), transmitting the results to a distant station, and thereby displaying, recording, and analysing the quantities measured.

Further more, in today's high volume telemetry applications, it would be costly and impractical to use separate transmission channels for each measured quantity. Therefore, the telemetry process involves grouping the measurements (such as pressure, speed, and temperature) into a format that can be transmitted as a single data stream. Once received, the data stream is separated into the original measurement components for analysis.

3.1.6.2 Why Use Telemetry

Telemetry gives one the option of staying in a quite safe and convenient location in order to monitor what is happening in an unsafe or inconvenient location. Aircraft development for example, is a major application for telemetry systems. During initial flight testing, an aircraft performs test maneuvers and undergoes certain aerobatic trials. In this instance, the critical flight data from a particular maneuver is transmitted to Flight Test Engineers (FTE's) at what is known as a ground station and thereby analysed within minutes of that maneuver prior to the next one taking place. After real-time analysis, the maneuver can be repeated, and perhaps the next maneuver performed, or the test pilot can be instructed by the ground station and two-way radio, that the test mission has been successfully accomplished and that it is now safe to return to base.

3.1.6.3 Telemetry System Configuration

Telemetry systems are usually configured differently to meet the needs of each user and in which are unique to that user, however, they all have some common elements, as is shown in Figure 3-7. These are (ARDU, 1993d):

- Electrical data starts at sensors. Some sensors measure electrical quantities (like gain, voltage, and current) directly. Others (such as thermocouples, resistance-temperature devices, bridges, and potentiometers) convert physical conditions like temperature, pressure, and acceleration into a proportional amount of electrical voltage.
- A multiplexor combines these electrical voltages and timing data (frame synchronisation and subframe synchronisation) into a single data stream.
- The transmitting device (radio transmitter, coaxial cable, telephone line, tape recorder, etc) then passes the data stream to the distant receiver.
- A decommutator (also called a demultiplexor),like the DS 100, accepts the data stream from the receiver and separates it into its original measurements.
- The original measurements are then selected, processed, and displayed in accordance with the specific test plan. In many telemetry systems, this select, process, and display action is done by independent general purpose digital processor: however, the ADS 100 is designed with these capabilities built in.

All the data is transmitted from the transmitter to the receiver at the ground station using Pulse Code Modulation or PCM, which is a serial bit stream of binary-coded time-division multiplexed words, as defined by the ARDU (1993c).

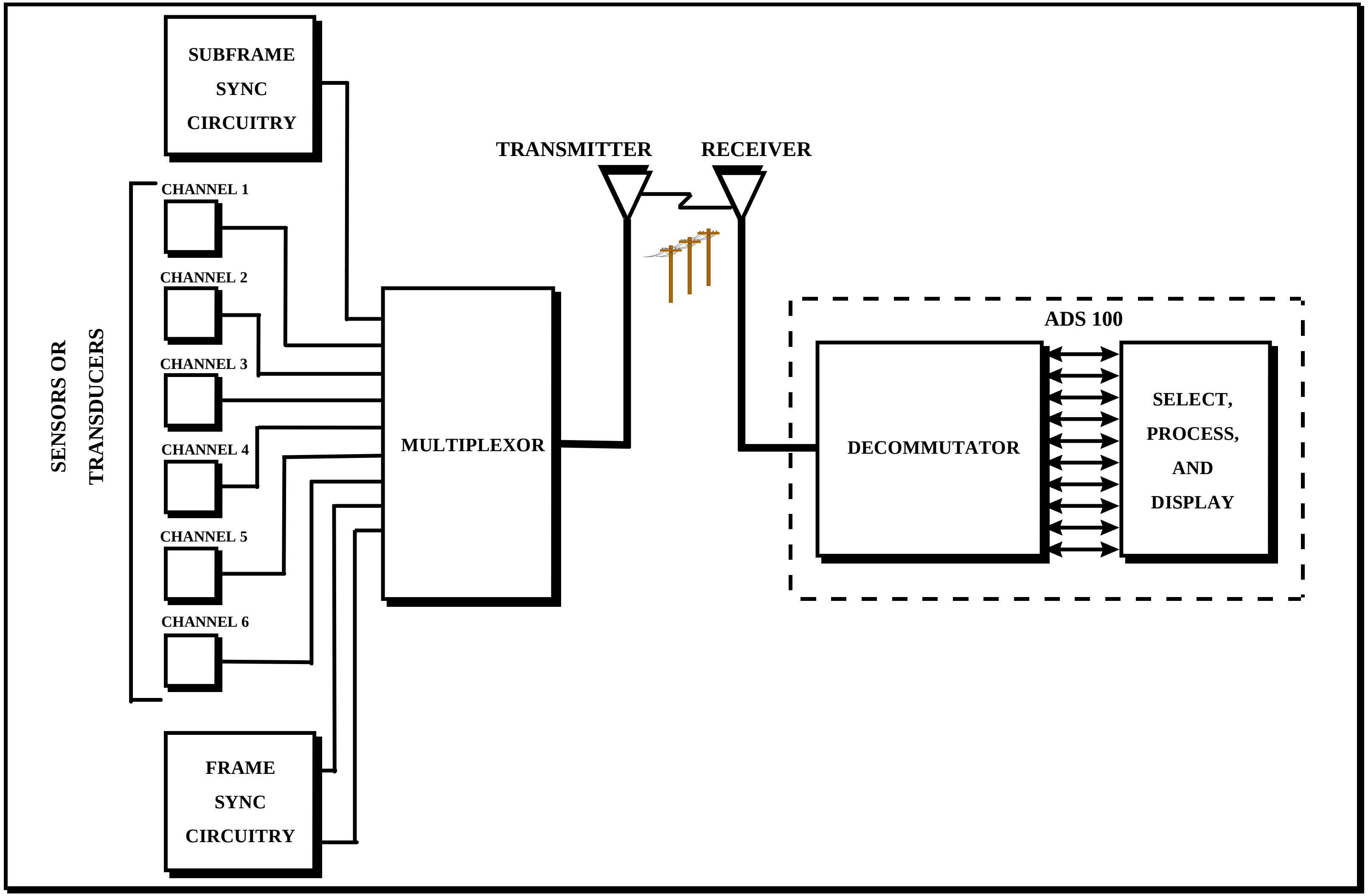


Figure 3-7 (Simplified Telemetry System Configuration (based on ARDU, 1993d))

3.1.6.4 Flight Test Data Management Systems

The telemetry format is a key piece of information utilized by both the flight segment and the ground segment of a mission. The conventional Relational Data Base Management Systems (RDBMS) do not work well with telemetry formats because of the multi-dimensional nature of most telemetry formats (Li, 1990). A Flight Test Data Management System (FTDMS) is currently being developed at the ACTE, as outlined in (Samaan and Cook, 1994b) as part of a Masters Degree research program, that is envisaged to reduce to complexity, size, and cost of managing dynamic telemetry formats, as part of the ARDU collaborative program. (Li, 1990) however, utilises object-oriented concepts in managing the creation, evolution, and the utilisation of telemetry formats. There are three key Object Orientated Design (OOD) concepts, namely, Abstraction, Encapsulation, & Inheritance. These are defined as follows (Li, 1990):

> *"**Abstraction** is the ability to specify generic attributes and necessary operations required for modeling a class of objects with respect to a problem domain. A model defined by a set of representing attributes and operations is often called an abstract data type."*

> *"**Encapsulation** is the ability to hide non-essential and implementation dependent information from the user of abstract data types."*

> *"**Inheritance** is the ability to defining subtypes by inheriting type specifications i.e., attributes and operations, from a parent type. This feature allows one to build new data types upon existing ones."*

The advantage that these OOD concepts encapsulate are as follows (Li, 1990): Abstraction allows one to ***THINK*** at a higher level; Encapsulation allows one to ***WORK*** at a higher level; Inheritance allows one to ***EVOLVE*** at a higher level.

Managing the huge volume of telemetry information required to support flight test at the AFFTC requires new paradigms and system development strategies (Gardner, Hoaglund, and Painter, 1992). The collection of decommutation and calibration information from contractors present significant challenges to any system proposing to manage that information (Gardner, 1992). Calibration and decommutation can be defined as follows (Gardner, Hoaglund, and Painter, 1992):

> ***"Calibration*** *is the translation process in which a raw measurement from the aircraft is turned into a meaningful data value."*

> ***"Decommutation*** *is the process by which the incoming telemetry data are broken into tag/data pairs. The initial decoding of the signal."*

Any system that truly manages decommutation and calibration information must (Gardner, 1992):

1. Have a flexible input processor to accommodate information from many different instrumentation groups.
2. Maintain an efficient historical record of all changes in the instrumentation throughput in a project.
3. Have a flexible output processor to provide various set-up files required by ground analysis systems.
4. Be capable of rapid transfer of information via high speed networks and/or magnetic tape.
5. Process the information quickly and accurately to keep pace with the set-up speed of airborne systems.

3.2 Conclusion

This chapter gave a brief introduction and history of flight test, outlining the relevance between flight test and the thrust of the research topic, being the highly instrumented fighter aircraft F/A-18 Hornet. Much like test and evaluation it was determined that flight test is another process whereby quantitative and qualitative results are obtained on an aircraft. A description of the Aircraft Research Development Unit and its affiliation with the Royal Australian Air Force and research collaboration was given, outlining the Flight Test Information Management System as being the main thrust of their work with the Canadian forces and United States Navy. Finally, a discussion on flight test planning, flight test centres in the USA and telemetry formats used in flight test was presented.

The next chapter will look at the comparison and analysis of the United States and Australian test and evaluation processes, their individual defense acquisition structure and Test &

Evaluation Master Plan formats, according to their respective military standard and respective nature.

CHAPTER 4

4. Analysis & Comparison of T&E Structures and Processes

4.1 Introduction

As an addendum to the previous chapters, test and evaluation can be thought of as a cyclic process (Defence Systems Management College, 1995), that is based on the scientific method of observation and analysis. It takes issues from the acquisition process and inputs analysis and evaluations to decision makers. A summary of a typical test sequence is depicted in Figure 4-1. The fundamental purpose of test and evaluation in a defence system's development and acquisition program is to identify the areas of risk to be reduced or eliminated (DSMC, 1993). This process is depicted in Figure 4-2.

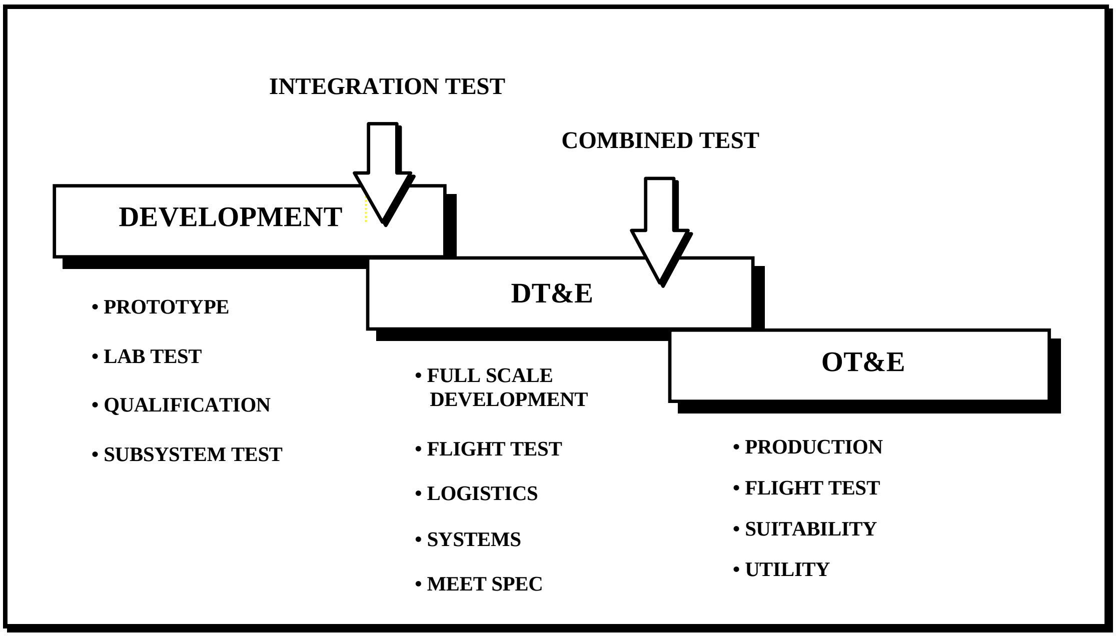


Figure 4-1 (Typical Test Sequence (based on DSMC, 1995))

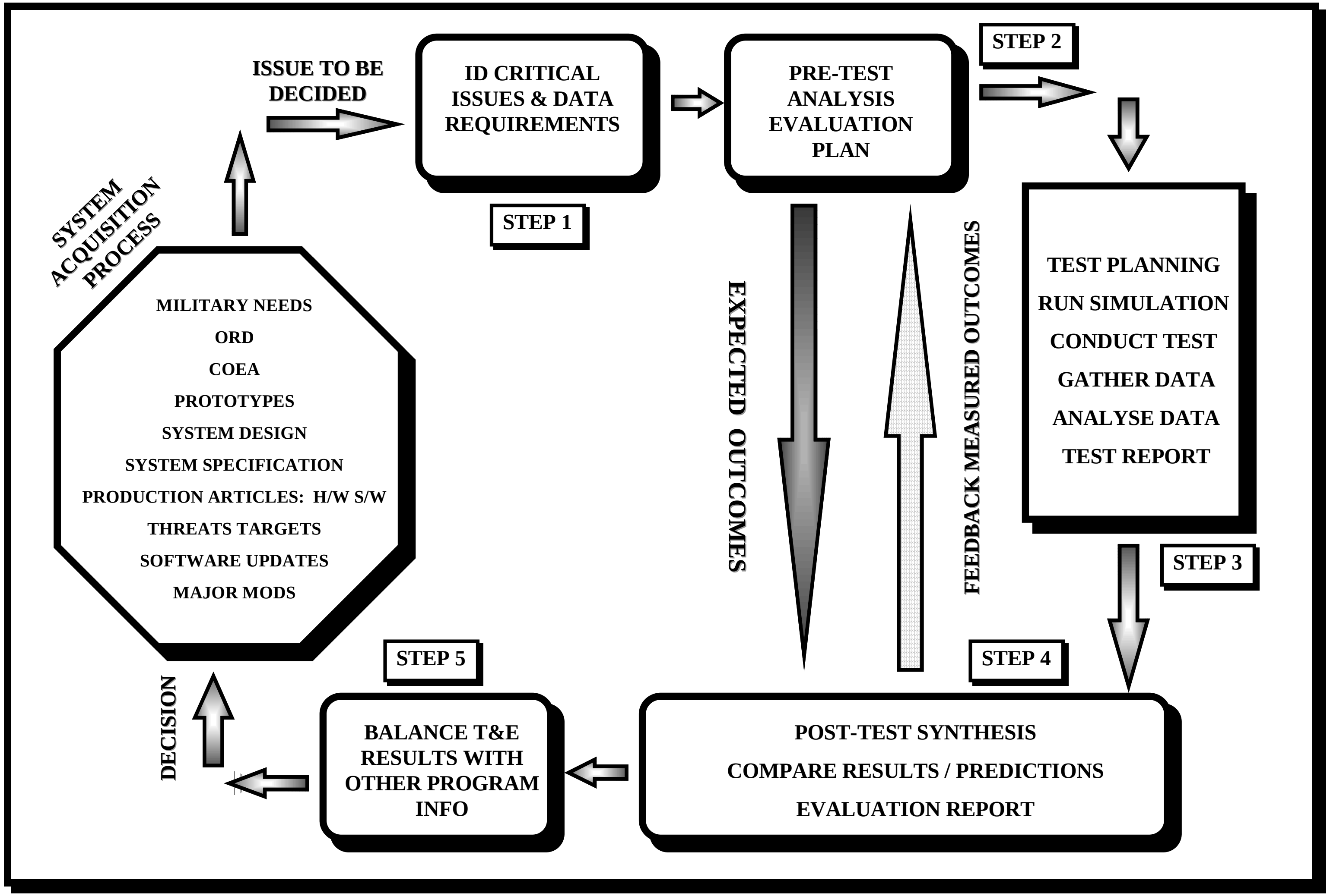


Figure 4-2 (Test and Evaluation Process (Defence Systems Management College, 1995))

4.1.1 Why Australia and the United States of America

As stated in chapter 2, the most well documented test and evaluation system is that of the United States Department of Defence. Because the United States is relatively well documented, many test and evaluation programs that are not US based have the tendency of adopting its basic principles, terminology, as well as its structure. Hence, the author has chosen to analyse and compare the United States and Australian test and evaluation processes. The following sections discuss the United States and Australian test and evaluation programs based on information obtained by the author to date.

4.2 The United States

4.2.1 A Brief History of US Defence T&E and Acquisition

In the early 1970s the Department of Defence issued the first documents that described the role T&E should play in each system acquisition program. Toward the end of the 1960s, Congress and the Defence Department started paying much attention to the way systems are acquired (Reynolds and Damaan, 1994). In 1970 the Department of Defence set up a Blue Ribbon Panel to examine the entire Department of Defence. The staff of this panel looked closely at the problem of T&E and in July 1970 issued a report to the Secretary of Defence and the President (Stevens, 1986).

The President's Blue Ribbon Panel as of July 1970 states (Reynolds and Damaan, 1993):

> *"**Functional Testing** (often called engineering testing) is done to determine how well various systems markets and material meet design and performance contractual specifications - in other words, whether they meet technical requirements. By and large, functional testing in and for the Department of Defence appears to be fully understood and faithfully executed. Serious policy deficiencies are not apparent, and such failures in functional testing as occur can be primarily attributed to lack of technical competence, oversight, or procedural breakdowns. Functional testing is not considered to be a major problem area."*

> *"It would be extremely useful to replace or support critical assumptions with quantitative data obtained from realistic and relevant operational testing. Significant changes are essential if operational test and evaluation is to realise its potential for contributing to important decisions, particularly where the tests and decisions must cross Service lines. There is no assignment of overall responsibility for deciding what operational testing should be done … or insuring that results reach those who need them. The most glaring deficiency of operational testing is the lack of any higher-than-Service organisation responsible for overseeing defence operational testing as a whole."*

As a result of the report of the Blue Ribbon Panel (Stevens, 1986), the Defense Department developed a new set of guidelines to improve the quality of operational test and evaluation. The new policy was promulgated on July 13, 1971, in Department of Defence Directive Number 5000.1, the key passage of which reads as follows (Stevens, 1986):

> *"**Test and evaluation** shall commence as early as possible. A determination of operational suitability, including logistic support requirements, will be made prior to large-scale production commitments, making use of the most realistic test environment possible and the best representation of the future operational system available. The results of this operational testing will be evaluated and presented to the DSARC[8] at the time of the production decision."*

On January 19, 1973, the Defence Department (Reynolds and Damaan, 1993) issued DoD Directive Number 5000.3 on T&E. This Directive accompanies Directive 5000.1 on system acquisition policies and DoD Instruction 5000.2 on the procedures to implement those acquisition policies. DoD Directive 5000.3 was updated several times to accommodate organisational changes and amplify procedural requirements. The basic policies have remained the same and are highlighted in Figure 4-3.

⇒ T&E shall verify the attainment of technical performance objectives and shall verify that systems are operationally effective and suitable for the intended use.

⇒ Successful T&E results will be a key requirement for milestone decisions.

⇒ Each service will have one major independent OT&E agency.

⇒ Planning for each T&E program will be documented in a TEMP.

Figure 4-3 (Defence Department T&E Policies , DoDD 5000.1 & DoDI 5000.2 (Reynolds and Damaan, 1993))

Currently they are embodied in Part 8 of DoD Instruction 5000.2 of February 23, 1991, entitled Defence Acquisition Management Polices and Procedures (Reynolds and Damaan, 1993). These acquisition documents marked the transformation of the US procurement system into what is now world re-known as "Milestone Procurement". Table 4-1 summarises the primary T&E documents.

[8] Defence Systems Acquisition Review Council

DoD T&E DOCUMENTS	
* **DoDD 5000.1**	Defence Acquisition
* **DoDI 5000.2, PART 8**	Test and Evaluation
* **DoD 5000.2-M, PART 7**	Test and Evaluation Master Plan
* **DoD 5000.3-M-2**	DoD Foreign Comparative Testing (FCT) Program
* **DoD 5003-M-4**	Joint T&E Procedures
* **Live Fire Test and Evaluation (LFT&E) Guidelines (January 1994)**	

Table 4-1 (Summary of Primary DoD T&E Documents (DSMC, 1995))

4.2.2 The US Defence T&E Structure

This section provides an overview of the policy and structure that govern the conduct of T&E activities within the DoD and is primarily based on the DSMC (1993) and DSMC (1995). The DoD is required to provide to the Congress the following reports on T&E (DSMC, 1993):

- Congressional Data Sheets (CDS)
- Selected Acquisition Report (SAR)
- Annual System Operational Test Report
- Beyond Low-Rate Initial Production (BLRIP) Report
- Live Fire Test & Evaluation (LFT&E) Report

The US DoD T&E structure is illustrated in Figure 4-4. In the OSD, T&E oversight is performed by two primary offices (DSMC, 1995): the Director, Test, Systems Engineering, and Evaluation (DTSEE) and the Director Operational Test & Evaluation (DOT&E). The management of acquisition programs in OSD is performed by the Defence Acquisition Executive (DAE), who uses the Defence Acquisition Board (DAB) and subcommittees to process information for decisions. The Under Secretary of Defence for Acquisition & Technology (USD(A&T)) uses the DAB and its committees to provide the senior-level decision process for the acquisition of weapon systems.

4.2.2.1 Director Test, Systems Engineering and Evaluation (DTSEE)

According to the DSMC (1995) the DTSEE serves as the principal staff assistant and advisor to the USD(A&T) for T&E matters. The DTSEE has the authority and responsibility for all

DT&E conducted on designated major programs. During the testing and designated weapon systems, the DTSEE and Services interaction includes the following reporting requirements:

- A TEMP (either initial or updated, as appropriate) must be provided for consideration and approval before each milestone review, starting with Milestone I.
- Prior to a milestone decision or the final decision to proceed beyond LRIP, T&E results with conclusion and recommendations must be submitted to the DTSEE.

4.2.2.2 Director Operational Test and Evaluation (DOT&E)

The DSMC states that the director reports directly to the Secretary of Defence (SECDEF) and has special reporting requirements to the Congress. The DOT&E's responsibility to the Congress is to provide an unbiased window of insight into the operational effectiveness and suitability of new weapon systems. For DoD and DOT&E-designated acquisition programs, the Services provides the DOT&E the following:

- A draft copy of the Operational Test Plan for review.
- The final Initial Operational Test & Evaluation (IOT&E) Test Plan for approval.
- Significant Test Plan changes.
- The final Service IOT&E report is submitted to the DOT&E before the DAB Milestone III review.

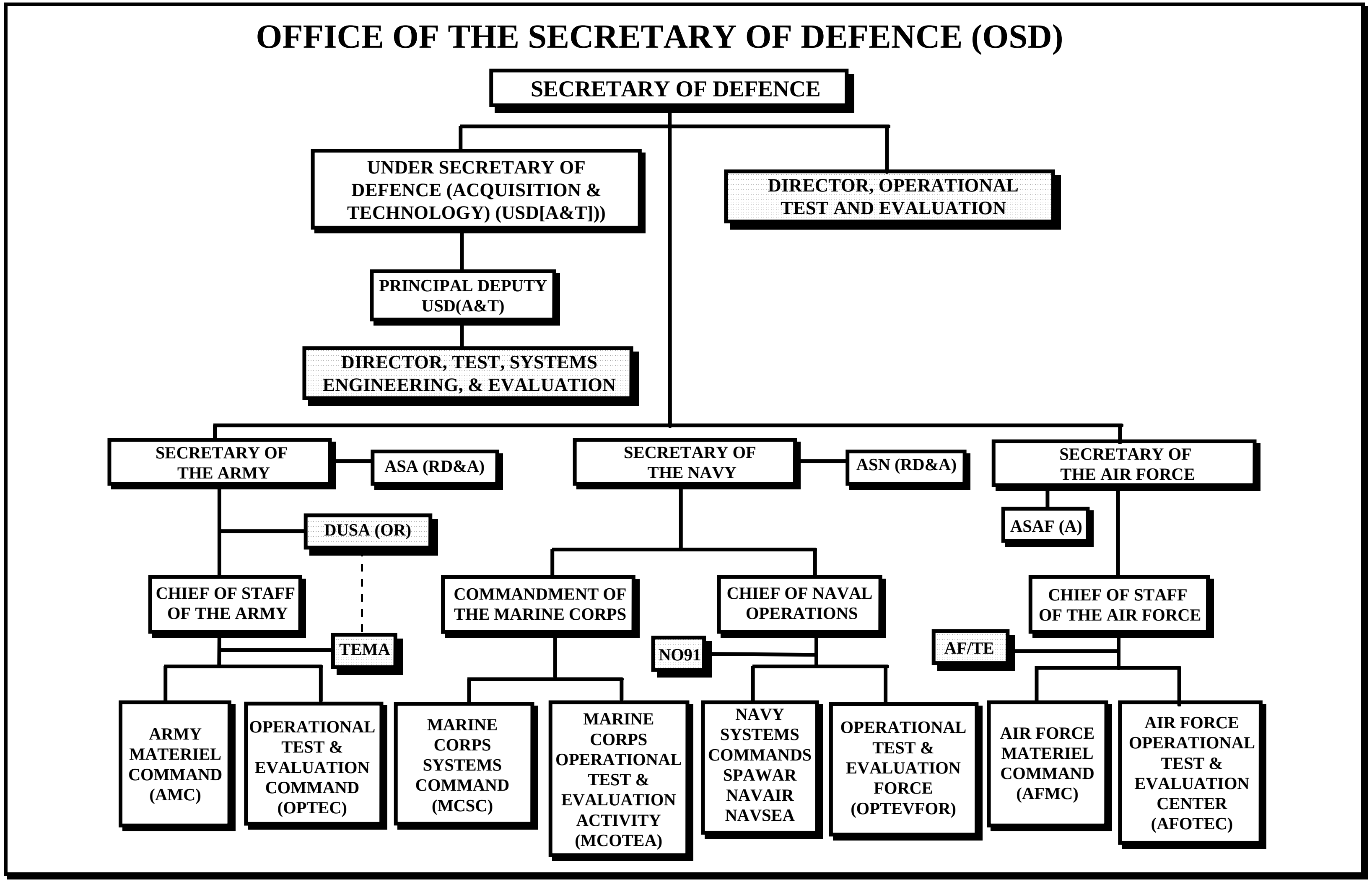


Figure 4-4 (US Defence T&E Structure (adopted from DSMC, 1995))

4.2.3 US Defence T&E Phased Acquisition Process

The defence system acquisition process was revised in 1991 to make it less costly, less time consuming and more responsive to the needs of the operational test and evaluation community. As it is now structured, the defense system life cycle consists of the following five phases as depicted in Figure 4-5 (DSMC, 1993):

1. Concept Exploration and Definition (CE)
2. Demonstration and Validation (DEM/VAL)
3. Engineering and Manufacturing Development (EMD)
4. Production and Deployment (PD)
5. Operations and Support (OS)

As is shown in Figure 4-5 these phases are separated by key decision points when a milestone (MS) decision authority reviews a program and authorises advancement to the next stage in the cycle. Thus T&E planning as mentioned in chapter 3, plays a vital role in the milestone review process.

An extremely comprehensive description of each milestone, phase and decision point of this milestone procurement process, known as the United States Test and Evaluation Phased Acquisition Process (USTEPAP) is detailed in the author's software AutoTEMP©, beta version 2.0, in the form of a hypertext interactive software tutorial. This tutorial is the first of three software modules that make up AutoTEMP© and its hypertextability and human-computer interactivity as well as a detailed description is dealt with in more detail in chapter 6. Please refer to the Table of Abbreviations at the beginning of this thesis for a description of any terminology in the form of acronyms used in Figure 4-5, that may not be defined explicitly in the main text, but are defined by AutoTEMP©.

As an addition to the description in AutoTEMP©, an extension of certain terms are described in the next few paragraphs, the perspectives of which have been obtained from both Hoivik (1995) and DSMC (1993).

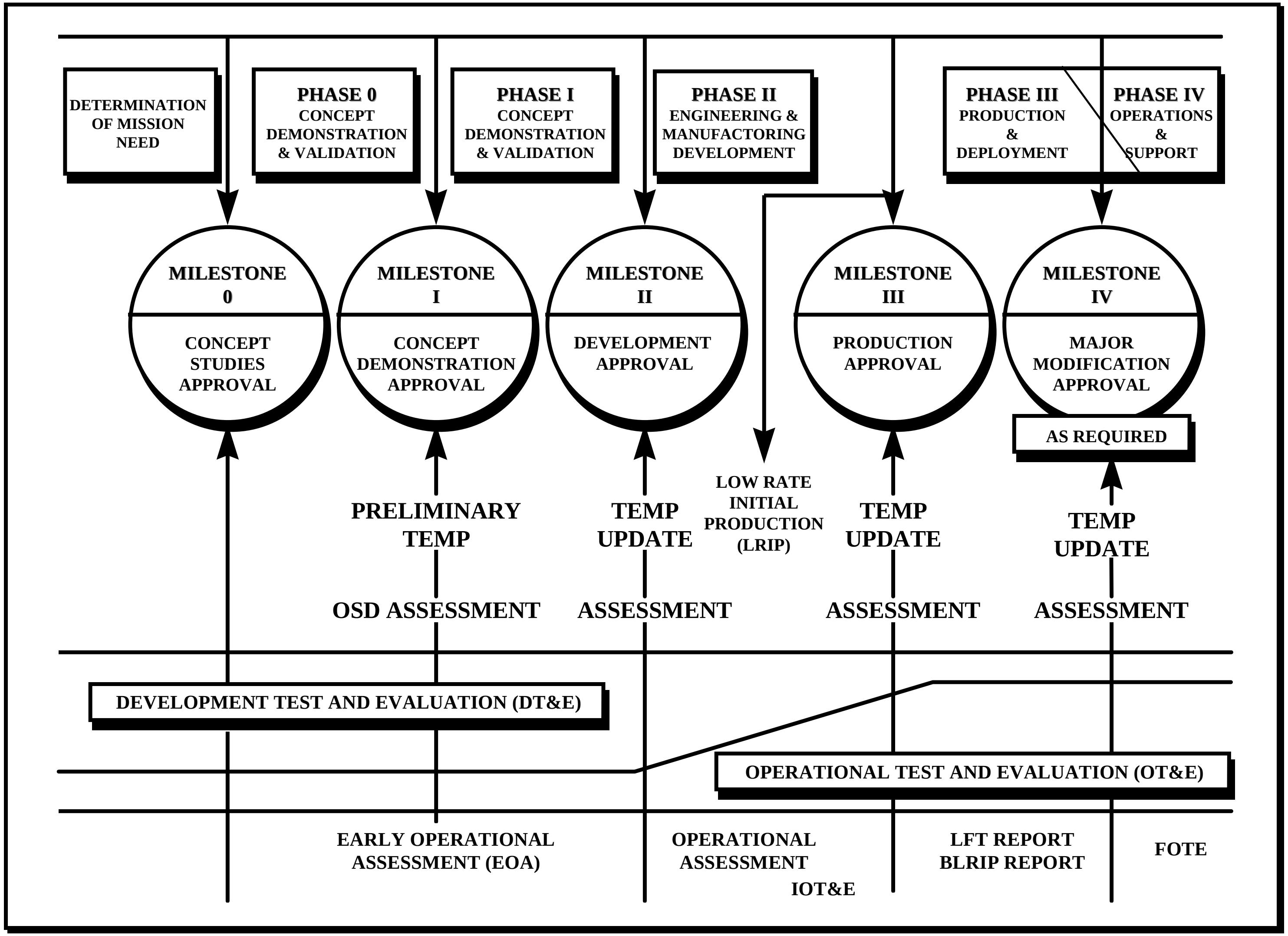


Figure 4-5 (US Test & Evaluation Phased Acquisition Process (DSMC, 1993))

With reference to Figure 4-5 Early Operational Assessment or EOA is an Operational Assessment (OA) which is conducted prior to, or in support of, a full scale development decision in the EMD phase. It's purpose is to provide operational input (a mission) to decision makers at early milestones, and also encompasses the following:

⇒ Forces early consideration by the Service Operational Testing Agencies (OTA's) of OT&E issues.
⇒ Provides the Program Manager (PM) with insight into future OT&E issues.
⇒ Helps OTA budget/plan for resources early in the piece.

EOA does not however evaluate technology, evaluate acquisition strategies, or look at DT&E funding. Operational Evaluation (OPEVAL) encapsulates:

- Operational Assessment (OA)
- Initial Operational Test & Evaluation (IOT&E)
- Live Fire Testing (LFT)
- Beyond Low Rate Initial Production (BLRIP)
- Follow on Test & Evaluation (FOT&E)

OPEVAL is the "Separate and Dedicated Phase" of OT&E in support of production of procurment decision. After the development command is certified the system is then ready for OPEVAL. OTA will conduct enough OT&E to evaluate the system's operational effectiveness and suitability and then reports these results to the decision authority, i.e., it is a *Production Representative System (PRS), with Typical Operators (TO), in "Real World Environment (RWE)"*.

Risk management is the means by which the program areas of vulnerability and concern are identified and managed (DSMC, 1993). Test and evaluation is the discipline that helps to illuminate those areas of vulnerability. The importance of T&E in the PAP is summarised well in a report produced in December 1986 by the General Accounting Office (GEA) of The Office of the Secretary of Defence (OSD):

> *"**OT&E** is the primary means of assessing weapon system performance. OT&E results are important in making key decisions in the acquisition process, especially the decision to proceed from development to production. OT&E results provide an indication of how well new systems will work and can be invaluable in identifying ineffective or unreliable systems before they are produced."*

Starting production before adequate OT&E is completed has some risks. If adequate OT&E is not done and the weapon system does not perform satisfactorily in the field, significant changes may be required. Moreover, the changes will not be limited to a few developmental models, but may also be applied to items already produced and deployed. In extreme situations, the DoD also risks (DSMC, 1993):

1. Deploying systems which cannot adequately perform significant portions of their missions, thus degrading their deterrent/defensive capabilities and
2. Endangering the safety of military personnel who operate and maintain the systems.

4.3 Australia

4.3.1 Introduction

The Australian Defence Force (ADF) is the equivalent of the US DoD and has been in the T&E business for sometime. T&E in one form or another is used in the ADF during the acquisition of weapon systems, as a decision mechanism during development and to test equipment after modification. The importance of T&E in the Australian Department of Defence dictates the need for good management to guarantee the proper selection of materiel and the tactical use of equipment (Griffin, 1994).

Australia has modest but well equipped Armed Forces. As a result, the number of major systems that are being designed and developed, and the number of existing systems requiring major modification at any one time are quite small in number. Past projects which commanded the attention of the Australian T&E community include the new ANZAC frigate project, the Collins-class submarine project and the Jindalee Over-The-Horizon Operational Radar Network (JORN) project, major aircraft modification programs such as the P3C Orion mid-life and the F-111C avionics upgrade projects (Crouch and Sydenham, 1993).

T&E conducted by the Australian Department of Defence is part of a rolling program to equip and maintain maritime, land, air, and sea forces that are capable of meeting the Defence Mission which is (Wallace, 1995): ***"To promote the security of Australia and protect its people and interests"***. The process of defining the equipment that is required by the ADF to fulfill mission starts with the strategic guidance provided by Government. Current strategic guidance is published in two principal documents (Wallace, 1995):

- **Strategic Review - 1993 (SR-93)** looks at Australia's political and economic position in South East Asia and the World and provides a strategic overview for the next five years.
- **Defending Australia - 1994 (DA-94)** defines how the ADF will develop over the next 15 years to meet both the perceived short term requirements of SR-93 and the longer term commitment to stability in our region and world peace.

4.3.2 A Brief History of Australian Defence T&E

The ADF encapsulates three military services, namely, the Australian Army, Royal Australian Navy (RAN), and the Royal Australian Air Force (RAAF). Griffin (1994) states that these three forces were conceived separately as the need arose to meet Australian defence requirements. Many of the practices and traditions were consequently "borrowed" from the relevant British Services, otherwise known today as the British Ministry of Defence (MOD). The ability to provide the services of these three forces (who work and cooperate as one in reality), serves a purpose as it generates Single-Service pride, and a willingness to function as a team, especially when the going gets tough, in peace time as well as war time. As with many other activities in the ADF, T&E has been developed from a Single-Service perspective.

Past requirements have dictated that the bulk of T&E associated with ships, land weapons, and aircraft is performed by the RAN, RAAF, and Army, respectively, in a fashion mirroring their different beginnings. The control of T&E is an individual service responsibility, and policy, practice, and procedure are well developed in the services. Each service has a major unit that performs T&E, collectively employing over 1,000 ADF and defence civilians. There are also some 66 defence establishments (e.g., proof and test ranges) where T&E is performed subsidiary to major roles. The majority of these establishments belong to the Defence Science and Technology Organisation (DSTO) (Griffin, 1995).

Griffin (1995) states that the Directorate of Trials (DOT) is a small section in the DSTO, separate from the services, which offers a coordination and advisory service, should the services seek help outside their own T&E capabilities. The DOT is sometimes involved with major and lengthy projects, but its contribution to the overall management of T&E is relatively small as the services are largely self-supporting.

4.3.3 Australian Defence T&E Structure

Documentation on any Australian Defence is somewhat fragmented as mentioned previously, a discussion of Australian Defence T&E structure is perhaps best accomplished by focusing primarily upon T&E within the DSTO and the three Services, namely, the Army, the RAAF, and the RAN, or land, air, and sea defence forces respectively.

4.3.3.1 DSTO Trials Directorate

Wallace (1993) states that the origin of the DSTO Trials Directorate can be traced to 1952 when the Army's Technical Services Establishment agreed to conduct Centurion Tank tropical trials on behalf of the UK Ministry of Defence (MOD). Over the years the Technical Services Establishment became the Army Design Establishment (ADE) and which conducted major trials and equipment evaluations for the Department of the Army. A Directorate of Trials and Evaluation (DTE) was established in 1972 as part of the Army reorganisation recommended by the Hassett Report. The Directorate's task was the management and coordination of Army trials using the facilities of the ADE.

In 1973, the Tange Report noted that the Service Laboratories and some Supply Laboratories conduct similar functions, but in a fragmented and uncoordinated manner. In order to overcome this problem, the report proposed the establishment of a Trials and Evaluation Division within the newly created DSTO.

In January 1975 the Service Laboratories absorbed the DTE and became the Directorate of Trials Planning (DTP) and was augmented by the addition of Navy, and Air Force and civilian officers, thus becoming a tri-service organisation. The division was renamed the Directorate of Trials Planning. Later in 1975 the office title was shortened to Directorate of Trials (DTRIALS). The current organisational structure of DTRIALS is shown in Figure 4-6.

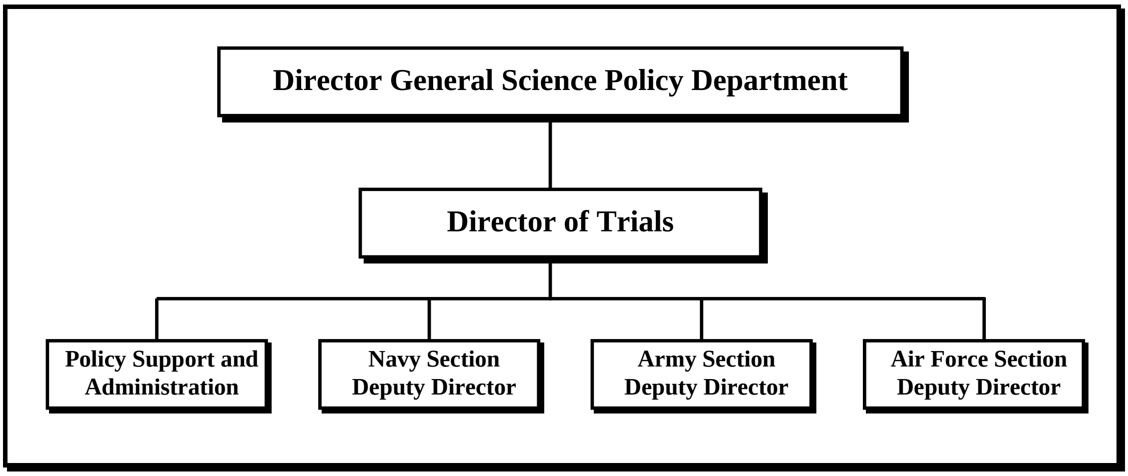


Figure 4-6 (DSTO Trials Directorate Structure (based on Wallace, 1993))

According to Wallace (1993) the mission of DTRIALS is to provide the Defence Organisation with an autonomous bureau service to efficiently and effectively manage and report on defence trials, to coordinate Service support for DSTO laboratories, and to coordinate scientific support and analysis for joint exercises. The objectives of DTRIALS are to:

- Ensure that the aims, objectives and methodologies of Defence Trials are valid and compatible with ADF objectives;
- Coordinate support requirements for and manage the conduct of Defence Trials;
- Ensure the timely production of Defence Trials Reports;
- Advise on the capabilities of DSTO Laboratory Divisions;
- Coordinate the allocation of ADF assets in support of DSTO activities;
- Coordinate the participation of Scientific Agencies in Joint Exercies; and
- Assist in the Scientific Adviser function by providing a direct liason link between the DSTO Laboratory Divisions and Headquarters ADF (HQADF), Defence Central and the Service Offices.

4.3.3.2 Defence T&E Facilities

To undertake T&E, the DoD has a number of integral facilities. DSTO is principally a research and development (R&D) organisation but it undertakes T&E in support of its own R&D and in support of the Army, Navy, and Air Force. DSTO has two laboratories (Wallace, 1995):

- Aeronautical and Maritime Research Laboratory (AMRL) with five divisions:

⇒ Airframes and Engines

⇒ Air Operations

⇒ Ship Structures and Materials

⇒ Weapon Systems, and

⇒ Maritime Operations

- Electronics and Surveillance Research Laboratory (ESRL) with six divisions:

⇒ Land Space and Optoelectronics

⇒ High Frequency Radar

⇒ Microwave Radar

⇒ Information Technology

⇒ Electronic Warfare, and

⇒ Communications

The **Navy** has three major T&E organisations, RAN Test & Evaluation Group (RANTEG), RAN Ranges and Assessing Unit (RANRAU) and the RAN Aircraft Maintenance and Flight Trials Unit (RANAMFTU).

The **Army** has two major T&E organisations belonging to Materiel Division (Mat Div) and a number of smaller T&E centres belonging to Headquarters Logistic Command (HQ Log Comd) (Wallace, 1995):

- **The Mat Div T&E organisations are:**

⇒ The Army Technology and Engineering Agency concerned with the engineering assessment of new equipment and DT&E for the product improvement of in-service equipment, and

⇒ The Maintenance Engineering Agency, concerned with the OT&E for the whole of life support of military equipment.

- **HQ Log Comd has:**

⇒ Static and mobile calibration facilities in major logistic units to service Army's calibration requirements Australia wide.

⇒ Cells in major logistic units to provide specialist maintenance DT&E support for specific equipment such aircraft, tanks, and combat radios, and

⇒ The Packaging Development Centre which undertakes R&D into packaging for the storage and transportation of stores and munitions.

The **Air Force** has two major T&E organisations and a number of specialist T&E centres belonging to Air Headquarters Australia (AHQAUST) but located in operational units to provide dedicated equipment support (Wallace, 1995):

- Aircraft Research Development Unit (Figure 4-7) concerned with the DT&E for air safety of in service equipment.
- Air Movements Training and Development Unit concerned with DT&E for aerial delivery equipment.
- AHQAUST specialist T&E centres are:

⇒ The Integrated Aircraft Software Support Facility which provides software development support to FA-18 aircraft.

⇒ The Weapons System Support Facility, that provides systems development support to F-111 aircraft, and

⇒ The Non-Destructive Inspection Laboratory, that provides general support for the development of aircraft non-destructive inspection methods.

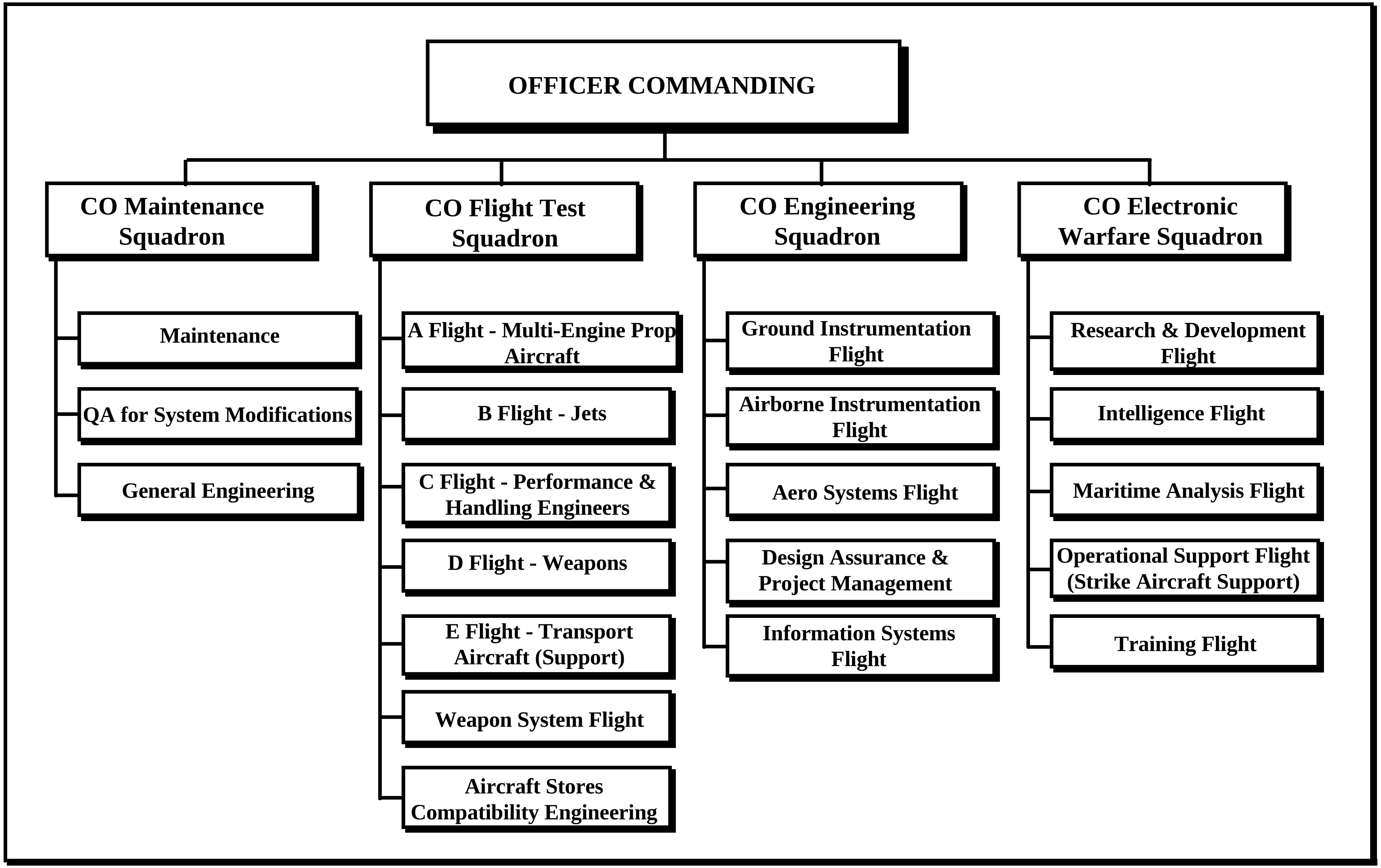


Figure 4-7 (The ARDU Organisational Structure (Dvorak, 1996))

4.3.4 The Australian Defence T&E Acquisition Process

The Australian defence T&E acquisition process is based on the well known United States paradigm described previously with a few minor variations. The Australian defence T&E acquisition process can be best described by an example that the author has conceptualised (based on an experimental model developed by Professor Sydenham), disciplined to aircraft flight test, and is depicted in Figure 4-8. The next section will describe this model in more detail and why it has evolved in the manner that it has, keeping in mind that to this day, there is no formal textbook on the Australian acquisition process, and hence documentation of a model is non existent to the author's knowledge. Therefore this is a major part of the author's contribution to knowledge and Australia.

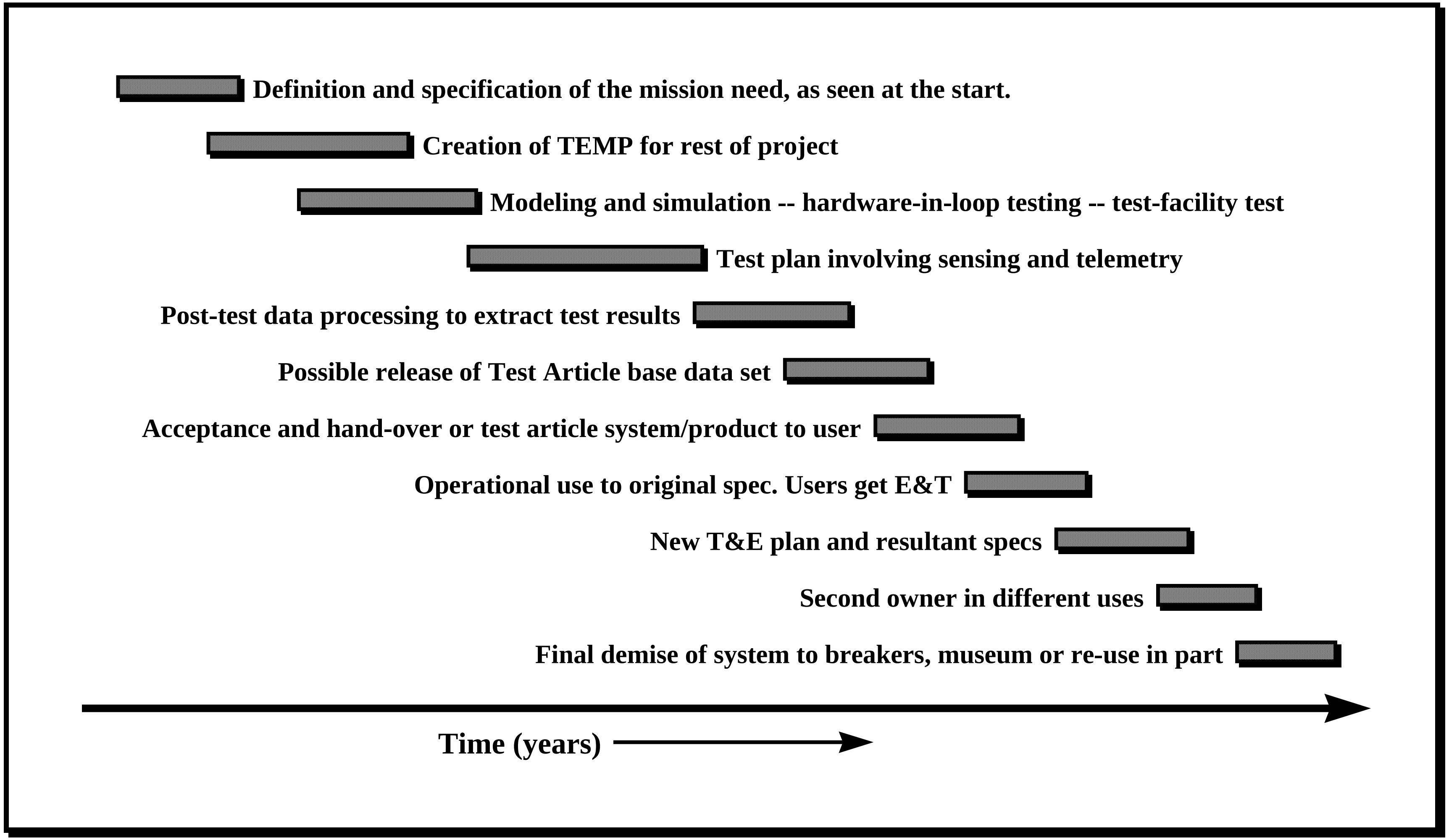


Figure 4-8 (Australian T&E Acquisition Process (adopted from Nissyrios, 1994c))

4.3.4.1 T&E Process Model - Generic Description

The above model can be described by referencing the annotated points along the model as follows:

a) Definition and specification of the mission need, as seen at the start of any prototype. From this comes the decision to acquire.
b) Creation of the Test and Evaluation Master Plans for the rest of the project. Definition of all tests are carried later in the process, however must be specified at this stage.
c) Modeling and Simulation is carried out using an ensemble of modeling software packages. Using techniques such as hardware-in-loop testing, whereby one develops as they model, test a little, then redesign, and so forth and so on, much like concurrent engineering and waterfall models which are out of the realm of this research.
d) Test plan is then constructed from the TEMP and SOR involving sensing and telemetering information needed and to test facilities such as instrument plans, data cycle map, etc.
e) There is now post-test data processing to extract the results of the test carried out on System Under Test (SUT). This action is actually an ongoing process, and not exactly unique to this step.
f) At this final DT&E phase there is possible release of test article base data set. This is where Verification and Validation (V&V) occurs by independent persons, as well as calibration but usually incomplete and with many errors yet unknown. This phase is the completion of all DT&E issues, which in turn gives rise to the instigation of OT&E.
g) At the beginning of this OT&E phase PAT&E occurs, whereby there is acceptance of the test article and hand over of the system/product to the user.
h) In this phase operational use of the system/product is carried out according to its original specification, part (a). After the completion of this the users will need some Education and Training (E&T) as they are not expected to be experts or knowledgeable users. Use of the system/product out in the field, its operational environment establishes its shortcomings, which are then documented.
i) As an occurrence of this document there is a new T&E plan made along with resultant specifications which are usually needed as the use of the system/product changes due to modification or altered mission needs, i.e., FOT&E is carried out still in the hands of the first user. This completes all DT&E and OT&E requirements.

j) This phase is merely where a second owner could possibly take possession of the system/product after many years in service and possibly by a different country even with different methodologies and practices or variation in mission needs.
k) Finally, the system/product has been over ridden with a later version, an upgrade many years down the track and the owners consider the demise of the system to applicable breakers, a museum or re-use of the system/product in parts as appropriate.

4.3.4.2 Relationship Between T&E and M&I Process

The above model gives birth to a relationship between T&E and Measurement and Instrumentation (M&I), in the form of measures, as illustrated in Figure 4-9. Crouch & Sydenham (1994) claim that the relationship has it's apex of demand in performance evaluation and its roots of supply in capability to traceable test artifacts to get physical data. Furthermore, neither the military or the civil strategists think in terms of performance measures that can be directly measured - but rather, they think in terms of complex relationships that stand on the things that can be directly measured. As an example of this theory, they state that the M&I world thinks in system behavioral terms such as how high? Or how fast? And how do you measure that with an ascribed error budget?. Whereas the T&E world usually thinks in terms of how do you measure that with known confidence?.

As a corollary to the above argument, Nicholas & White (1995) state that because measurement is often seen as a purely objective technical process there is a tendency to ignore or omit its conceptual foundation. Purpose implies some level of subjectivity, which is usually considered undesirable and therefore ignored rather than treated. Thus in the view of Nicholas & White, many measurements become virtually purposeless, with any purpose being sought after the event rather than before. Purposeless measurements of say flight test data, typically result in:

- Difficulties in the interpretation of the data
- Failure to collect important data
- Collection of data that later proves to be unimportant

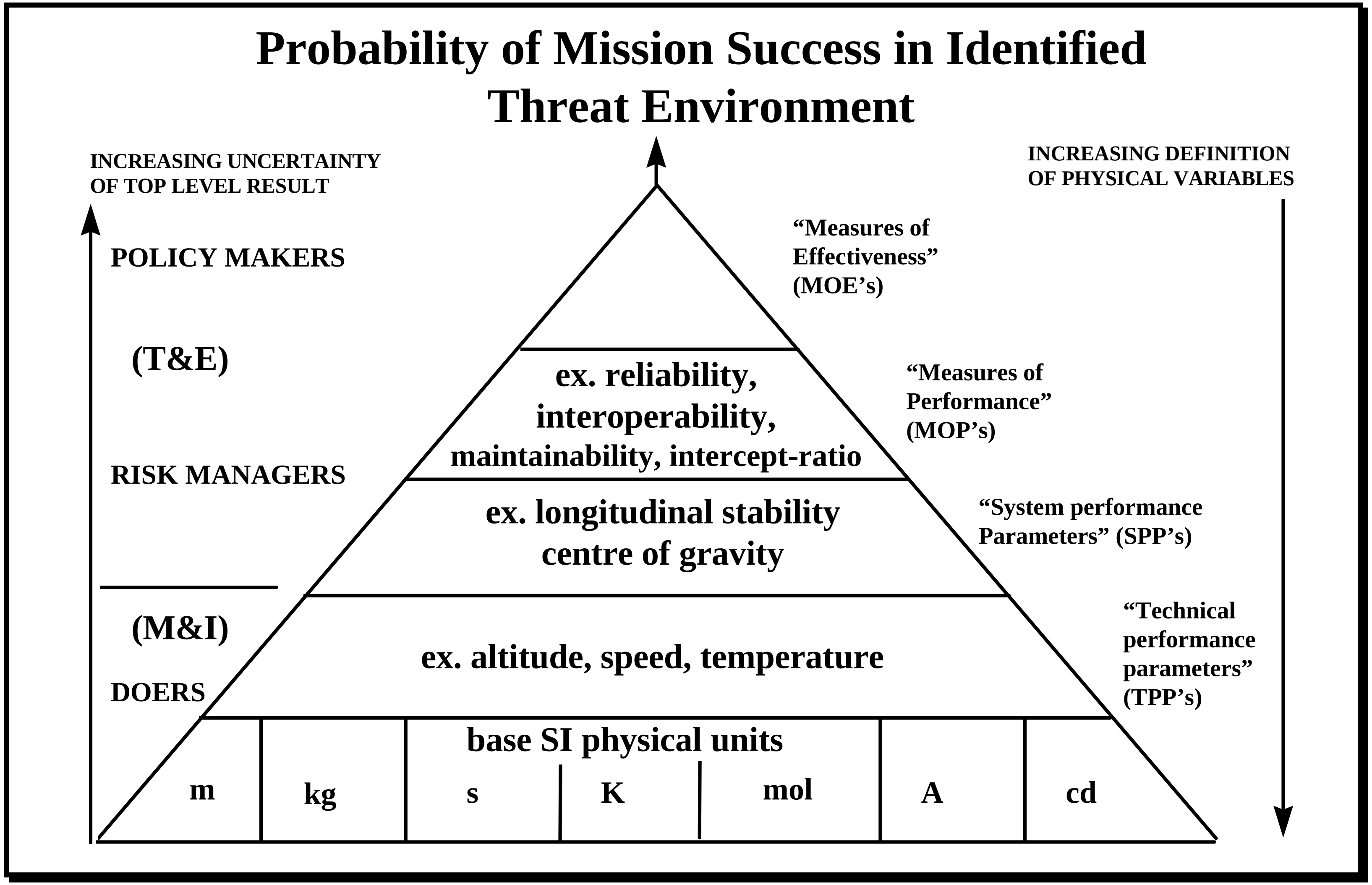


Figure 4-9 (Layered Pyramid of T&E and M&I Disciplines (Crouch & Sydenham, 1994))

The DSMC (1995) states that a *"measure is a numeric relation or element that describes the operation or efficiency of a system"*. The DSMC define Measures of Effectiveness (MOE's) as operational capabilities stated in terms of engagement or battlefield outcomes. In the modeling process, they are also tools that assist in discriminating among a number of alternatives. They show how the alternatives compare in meeting functional objectives and mission needs. MOE's should be selected which relate directly to a System's Performance Parameters (SPP's) and to mission accomplishment. Decision makers need to know the contribution of the system to the outcome of battle, and not just how far it can shoot or how fast it can fly.

Whereas, MOP's are technical data elements supporting a MOE. Cost and Operational Effective Analysis (COEA) must assess how each alternative performs the functional objectives. As mentioned previously models and simulations (M&S) are normally used to predict performance and outcomes. Models are merely a representation of an actual or conceptual system that involves mathematics, logical, or computer simulations, which are known as Technical Performance Parameters (TPP's). Intuitively these four measures can be described in Table 4-2.

MEASURE	DESCRIPTION
MOE	What do you want to know? (effectiveness)
MOP	How will you know you have got it? (performance)
SPP	How well does the system have to work?
TPP	How well do the components of the system have to work?

Table 4-2 (An Intuitive Comparision of MOE's, MOP's, SPP's and TPP's)

Kass (1995) states that a good measure is one that conveys the essential information without ambiguity or excess baggage. He goes on to say that ambiguity and excess wording of measures detract from the ability to clearly understand the data required from the T&E. Examples of measure expressions that are used frequently are (Kass, 1995):

1. Criterion measures
2. Mean measures

3. Data requirement measures
4. Technical measures
5. Question measures
6. Caveat measures
7. Double measures
8. Scope measures
9. Paragraph measures

A measure is phrased as a question and constructed with two components - a measure and a threshold, for example: "the system must detect 90 percent of the targets", or "time to set up cannot exceed 2 hours", or "mean time to repair should not exceed 1.5 hours".

4.4 Analysis and Conclusion

This chapter has presented and compared the United States and Australian T&E structures and their respective processes. It was found that the United States Armed forces have been more rigorous in their methods, considering their strong foundations, and formalities. Their defence is by far probably one of the most strongest in the world, due to their well documented approach, leadership, and impeccable efforts in thorough T&E, via their well renown phased acquisition process, depicted in Figure 4-5.

For the above reasons, their Australian counterparts, and respective DoD, have based their methods on that of the United States of America. Due to this well known fact, the author feels that Australia has been using the T&E acquisition process captured in Figure 4-8, the foundations of which emanated through M&I (as depicted in Figure 4-9) and Systems Engineering as outlined in chapter 2, for many years without realising that in actual fact they took part in all types of T&E, namely, DT&E and OT&E, PAT&E, FOT&E, and so forth.

The next few paragraphs compares US and Australian budgets for capital equipment, and comparing it to the ratio of people in their respective T&E communities, as seen by Wallace (1995).

Looking at the annual US DoD budget for capital equipment (Wallace, 1995), approximately $US63,200M, and comparing it to Australia's $A2,300M, the ratios of people engaged in integral T&E activities per $M expended on capital equipment and the relative percentage costs are shown in Table 4-3.

T&E COST	**COUNTRY**	
	UNITED STATES	**AUSTRALIA**
PEOPLE/$M	0.8	1.4
% OF CAP EQUIP	13.1	13.3

Table 4-3 (Comparison of T&E Costs US/AUS (Wallace, 1995))

Wallace states that the ratios for Australia of people engaged in integral T&E per $M expended on integral T&E and per $M expended on capital equipment are probably distorted a little by including the DSTO enabling technology activities; however, they do indicate that the Australian Department of Defence conducts more in-house T&E then the United States DoD.

The next chapter will look at the need for automating the generation of TEMP's, as required, and in doing so thus contributing to the automation of the T&E process, and gives a comprehensive description of the conceptualisation of the TEMP format that was used to carry out this action.

CHAPTER 5

5. Automating the Test & Evaluation Process

5.1 Introduction

The automation of a process in general can be viewed as a formal method as described by Minkowitz (1993), which has been exploited successfully for computer systems development. Their use in the formulation of abstract and precise models of complex systems such as an F/A-18 aircraft, makes them ideally suited to system specification and design.

The use of formal methods as argued by Vadera & Meziane (1994) in the development of software has been advocated as a way of improving the reliability of software. A formal development life-cycle begins with a formal specification. Design steps such as those discussed in this chapter can then be proved with respect to their specification.

In actual fact the first step in the design process (Elliot, 1993) in which the broad route for all of the detailed work that follows is mapped out is merely a systems engineering progression. This means that it must take into account every aspect of the problem and every component of the solution and must consider their interactions, and not just their individual properties.

In search for a methodology to automate the T&E process, the author carried out a comprehensive literature search, as well as sending electronic mail and attending appropriate seminars and conferences, to determine whether this task had been tackled in the past, looking primarily at Australia and the United States. The outcome of this action is documented in the following section.

5.2 Previous Automation Efforts in Australia and the USA

As mentioned previously in chapter 2, research in the area of Test and Evaluation has been confined to defence related agencies, and influenced by the United States of America Department of Defence. According to the author's knowledge, until now there has been no authentic published research related to the automation of Test and Evaluation Master Plans for defence acquisition test programs, except for that of a tool developed by the Science Applications International Corporation, more commonly addressed as SAIC, and funded by the Office of the Under Secretary of Defence for Acquisition and Technology/Director, Test, Systems Engineering & Evaluation (OUSD(A&T)/DTSE&E), as described by Roth (1995), in the United States of America, known as The Automated Test Planning System.

5.2.1 Automated Test Planning System

The Automated Test Planning System (ATPS) is a set of expert-system-based tools designed to aid in the test and evaluation oversight process. The tools are particularly well suited to staff members in the OUSD(A&T)/DT&E, and in the Department of Defence military service components. The current ATPS concept envisions four modules (Roth, 1995):

- Test and Evaluation Master Plan Review,
- Test and Evaluation Program Risk Assessment (TEPRAM),
- TEMP Build, and
- Test and Evaluation Program Design.

ATPS has been developed in close cooperation with the Test and Evaluation Community Network (TECNET). TECNET is a means of electronically exchanging unclassified information between Test and Evaluation practitioners since 1983 (Hurlburt, 1992). TECNET as well as ATPS release 4.5 for Windows® can be accessed and downloaded respectively, from the World-Wide Web (WWW) via the following Internet address; ***http[9]://atps.saic.com***. Phase I of the development process resulted in a systems-of-systems architecture as is shown in Figure 5-1, and a detailed system description.

[9] http stands for Hypertext Transfer Protocol (an Internet protocol)

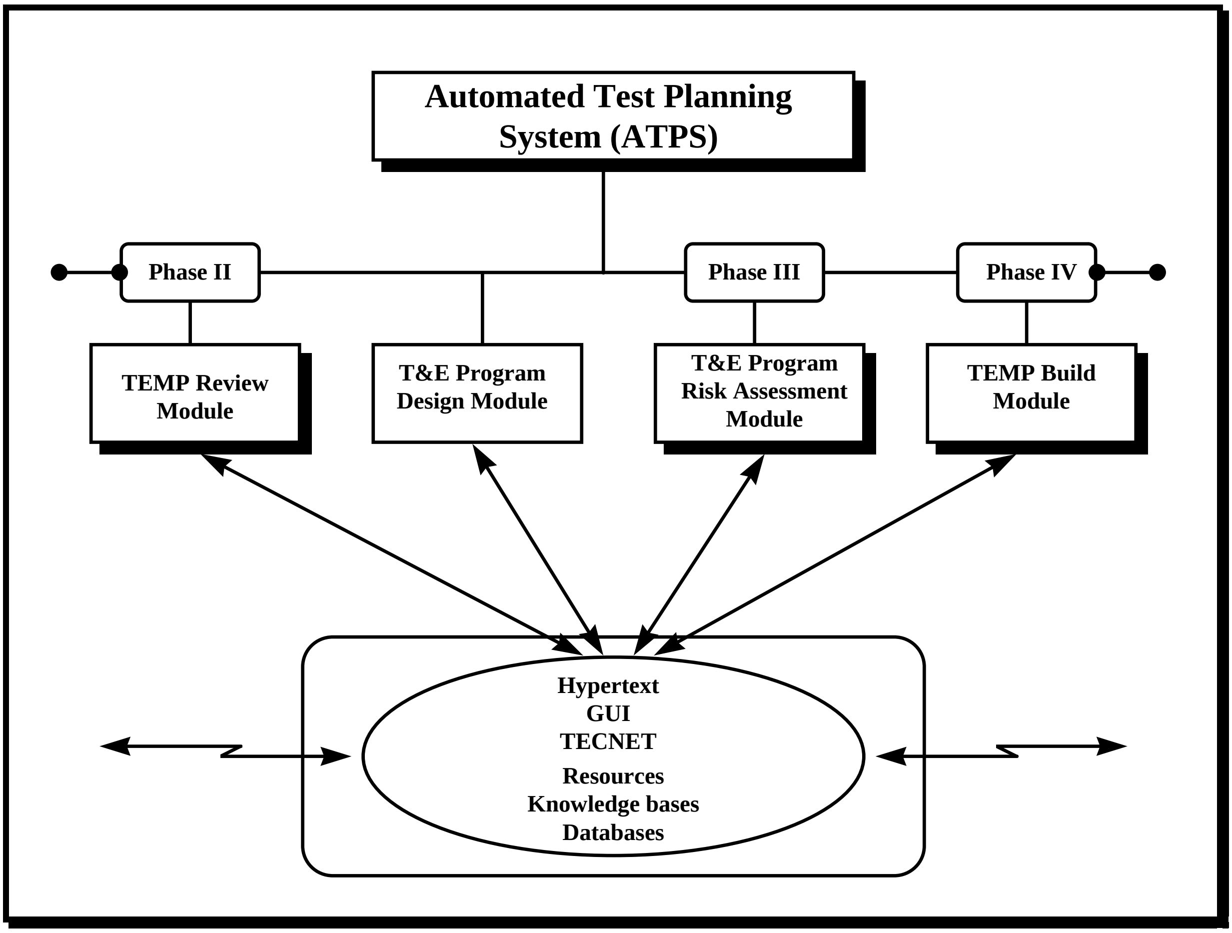


Figure 5-1 (A system-of-systems architecture of the Automated Test Planning System (Roth,1995))

The PC-based ATPS demonstrates the generation of an intelligent checklist for TEMP review. The body of knowledge was developed from representatives of United States DoD testing organisations, existing paper checklists (Okagaki and Helmuth, 1993). The software is based on the US DoD 500-series directives and instructions. In addition, the software accepts input by the user (TEMP review comments) and transfers those comments to an ASCII file, which can be read by a word processor for editing into a final report.

ATPS provides the user with a familiar Windows® (or Macintosh®) interface of buttons and menus to interact with its specialised rule bases, hypertext, advisor, editor, and file services (Roth, 1995). ATPS is a rule-based expert system (Okagaki and Ledesma, 1995) developed in Rule-extended Algorithmic Language (RAL), an extension of the C programming language, and encapsulates knowledge engineering and acquisition techniques, which are defined by Okagaki and Helmuth (1993) as follows:

> ***"Knowledge engineering*** *is based on conceptualising the portion of an experts knowledge that a computer program must emulate."*

> ***"Knowledge Acquisition****; The expert system consists of a knowledge base and a inference engine. The knowledge base contains a set of highly independent rules that link information concerning a problem to draw a conclusion. The inference engine controls the reasoning strategy of the system and suggests the action to be taken. The knowledge that is developed into rules is derived from facts and from information gained through experience or observation."*

ATPS is an analysis tool, designed to aid the human analyst, not to replace technical thought. It provides a standard baseline for TEMP development, risk assessment, and evaluation (Okagaki and Ledesma, 1995).

5.2.2 Review of Specriter 3© and AutoSpec©

Other more recent attempts to automate the generation of a process such as a plan, complying to military standards or specifications, using a computer aided approach have been the work of Cook (1991) and Evdokiou (1994), and the development of two software tools known as Specriter 3© and AutoSpec© respectively.

Cook (1991) developed a computer tool to assist in the production of measuring instrument specifications as part of his PhD entitled *"A Knowledge-Based System for Computer-Aided Generation of Measuring Instrument Specifications"*. The aim of this research was to produce a computer-assisted method of generating a measuring instrument requirements specification from a requirements analysis. Specriter 3© is a computer aided engineering package (Evdokiou, 1992) developed in Borland Prolog version 2.0, that employs knowledge representation techniques (Cook, 1990) to produce a specification for a measuring instrument, complying to US DoD MIL-STD-490A.

Evdokiou (1994) carried on the work by Cook (1991) with the development of a computer design tool to assist in the cognitive aspect of extracting requirement specifications for electronic systems, as part of his Masters Degree entitled *"Computer Aided Generation of Electronic Systems Requirements Specifications"*. The aim of this research was to conceptualise and develop a generic form of an electronic system such that descriptions of function, behaviour and structure are used in the formulation of a requirement specification template, and used as the basis for the subsequent automatic production of the initial requirements specifications documents (Evdokiou, 1994). AutoSpec© utilises Borland ObjectVision 2.1 for Windows® for extraction and storage of the requirements requested from the user, and Macros written in a document using Word 2.0 for Windows®, to automatically link the databases containing the requirements of the customer (Evdokiou, 1994) and generate a requirements specification document, complying to a type B1 USA MIL-STD-490A.

5.2.3 Review of T&E Plan Builder

The United States Army Operational Test & Evaluation Command (OPTEC), along with the University of Michigan has developed a similar type of automation software shell known as the Test & Evaluation Plan (TEP) Builder.

The TEP (Wyatt & Ward, 1996) is a prototype automated system developed to assist members of the Army T&E community in the key aspects of test planning such as the development of evaluation strategies, data requirements, and test designs. The TEP Builder is currently under construction and is being created to make OT&E both effective and affordable by producing consistently high-quality planning documents in less time.

Wyatt & Ward also state that the actual time required to produce test plans can be greatly reduced by eliminating redundant efforts. High-quality documents can be achieved by promoting document consistency, implement training, and managing quality.

5.3 The Need for Automation

In the past, in the Australian DoD, plans would be generated and products manufactured, systems developed, using the concepts, theories, and practices of T&E, and it has only been the last few years, more so since the birth of the Australian Centre for Test & Evaluation, that the Australian DoD and respective T&E community realised the importance of this process, and the importance to adhere to a master plan, a Test and Evaluation Master Plan (TEMP).

By regularly updating the TEMP from the genesis to the demise of a particular product/system, it would prove to be the most vital part of any defence acquisition test program, since it outlines strict critical issues, measures, and thresholds that all such test programs should adhere to. Only in this fashion can the efficiency be increased, and the cost and time of conducting tests be minimised, hence the need to automate the T&E process, namely, the TEMP, via the assistance of a computer has become apparent, and more so viable.

The next section will deal with the why and how requirements are needed to fulfill the need for automation, that is, the *why* and *how* of implementing requirements for the development of a Computer Software Configuration Item or CSCI..

5.4 Requirements for Software Implementation

The successful development of a large information system (Lalioti & Loucopoulos, 1994) is dependent on the use of a pertinent method for identifying the requirements on the target system and to make sure that the produced system will actually meet these requirements. Broadly, the first step in Requirements Engineering (RE), is the acquisition step, in which has the purpose of abstracting and conceptualising relevant parts of the application domain.

To begin with, one must first ascertain the requirements needed to automate the T&E process, the analysis of requirements (Johnson et al, 1993) is a difficult, often error-prone process because it relies on a wide range of domain and systems knowledge drawn from a variety of individuals and organisations.

Duke & Harrison (1995) state that formal approaches to software development have been mostly with problem descriptions that avoid expression of interactive behavior. However, rigorous software development emphasises the demonstration that a program correctly implements a specification, either through a process of verification or through the systematic derivation of programs from specification to valid refinement transformations.

Duke & Harrison go on to say that, refinement is therefore concerned with the construction of data structures and operations that are closer to the level of the machine that those in the original problem description.

For complex systems in the US DoD, there are certain standards that computer assisted systems should comply to, known as Computer-Aided Acquisition and Logistic Support or CALS compliancy. DoD MIL-HDBK-59B (1990) is the primary document for CALS. The primary goal of the CALS strategy is to migrate from manual, paper-intensive defence system operations to integrated, highly automated acquisition and support processes. The manual also states that effective implementation of the CALS strategy is achieved by addressing the following four elements throughout the life of a defence system:

1. Infrastructure for digital-based processes including computer hardware and software.
2. Process improvements in design, manufacturing and life cycle support.
3. Digital data acquisition.
4. Integrating technical data for use within weapon systems.

DeLauche and Reeves (1992) argue that the military services and DoD have developed specific, but different, road maps to get to the computer environment of tomorrow. Agendas differ relative to how CALS goals are reached. Surveys of the numerous automated support systems of today have resulted in a multitude of recommendations for a CALS-oriented support environment.

Within the US Armed Forces, a CALS Test Network (CTN) has been developed. The CTN (Lammers, 1992) is a logical network, that is, the emphasis is on a linkage between organisations to achieve objectives, rather than a physical telecommunications network. The objectives of the CTN are to:

- Develop distributed testing capability
- Demonstrate the complete data delivery process
- Evaluate the effectiveness of the CALS Standards
- Evaluate new technology

Poorly defined requirements are a sure recipe for disaster when software is involved. As described in IEEE STD 830-1984, characteristics of good software requirements are (Lacy, 1994) :

- Unambiguous
- Complete
- Verifiable
- Consistent
- Modifiable

- Traceable

5.4.1 Software Requirement Specification

Requirements for CSCI are often best described by a Software Requirement Specification, also known as an SRS in the software world. DoD Instruction DI-IPSC-81433 (1994) states that an SRS specifies the requirements for a CSCI and the methods to be used to ensure that each requirement has been met. This is a CALS compliant document and comprehensive guidelines for writing an SRS are contained within the Data Item Description or DID mentioned above.

An SRS for the CSCI AutoTEMP© Beta 2.0, comprising of the following CSCIs: T&E Information CSCI and Task Management CSCI, as described in Chapter 1 of this dissertation, has been compiled and sanctioned by Mark Dvorak of the ACTE, who is the ARC Collaborative Project Leader. The SRS is a fully endorsed eighteen page CALS compliant document, the details of which can be located in Appendix V, where a copy of the SRS is included in the Appendices section of this dissertation.

The SRS for the AutoTEMP© Beta 2.0 Software Shell[10] was developed as a voluntary addition, on the research work of the Flight Test Information Management System (FTIMS) Heuristic Transaction Shell (HTS), as per Chapter 1, and was also compiled to illustrate the natural progression of Software T&E documentation, the likes of which are as follows. The next progression from this document would have been the development of a System Design Description (SDD), had this been a software contract as opposed to a major research exercise.

Figure 5-2 illustrates this documentation process, that also acquires the purpose of representing a requirements traceability document. The diagram shows how and where the TEMP stands in this test documentation process, and was developed by the author to demonstrate the future direction of the traceability in software requirements.

[10] A tool developed by the author as a by-product of this research leading towards his Masters Degree.

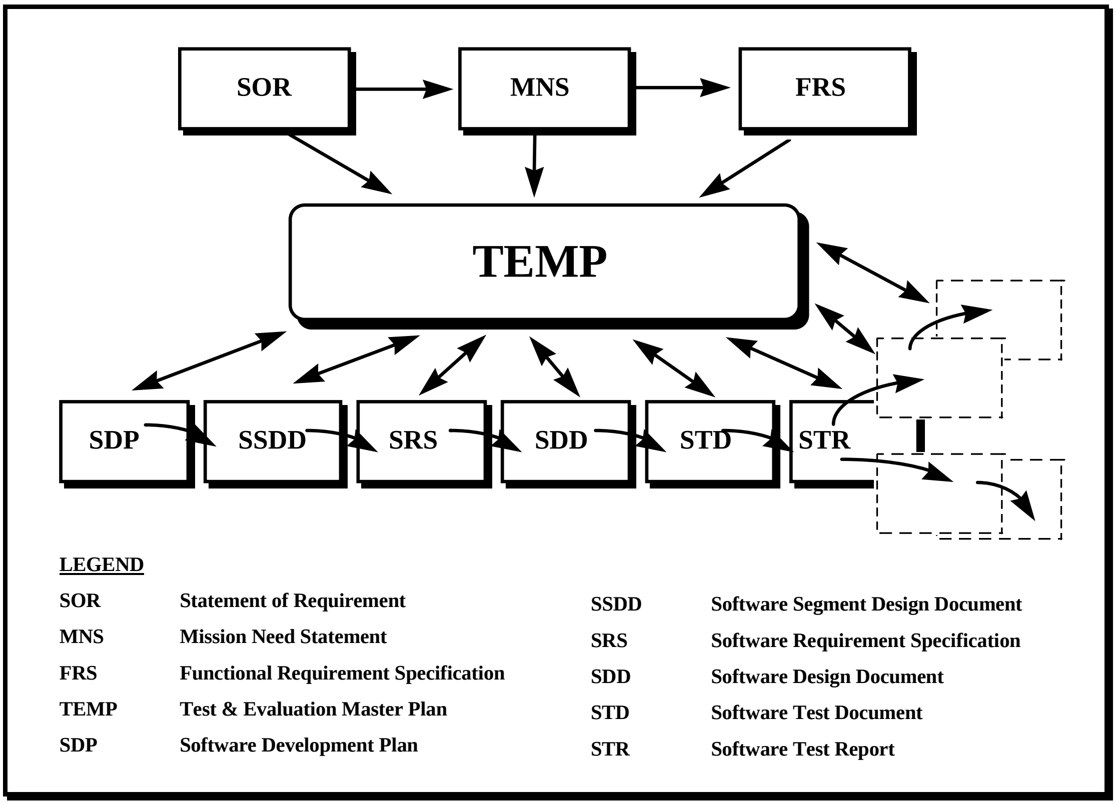


Figure 5-2 (Document Requirements Traceability Matrix)

As is evident from the diagram above, there is a lot of documentation for a particular system/product that is in the process of procurement, and this type of software T&E does not stop at any specific phase of the project, on the contrary, it continues right throughout the entire process, the TEMP is continually updated and hence requirements are somewhat "feedback" to the TEMP, for inclusion in the next update. A SSDD for the entire ARC Collaborative project has been developed by the Project Leader, Mark Dvorak of the ACTE, which outlines all four sub-research tasks as per chapter 1.

5.5 The Test & Evaluation Master Plan

5.5.1 Introduction

In this section a Test & Evaluation Master Plan (TEMP) will be defined, its role in the acquisition process, the US and Australian format will be presented and compared, and a generic version encapsulating the best parts of both formats, but primarily based on the Australian format will be defined and discussed comprehensively.

The United States has best described a TEMP for reasons mentioned previously in this dissertation. There are a number of US specific authors that have defined a TEMP and its format, namely, Rodriguez (1992), Przemieniecki (1993), DSMC (1993), DSMC (1995), Reynolds (1993), Reynolds & Damaan (1994), Dvorak and Equid (1994), and DoDI 5000.3-M-2 (1990).

5.5.2 What is a TEMP

Rodriguez (1992) defines a TEMP as an essential T&E document used by the Office of the Secretary of Defence (OSD) to support milestone decisions by the Defence Acquisition Board (DAB). The TEMP is the basic planning document for all T&E activity related to a particular system acquisition. It defines both DT&E and OT&E associated with system development and acquisition decisions. The TEMP relates program structure, decision milestones, test management structure, and required resources to critical operational issues, critical technical issues, evaluation criteria and procedures.

5.5.3 The Role of the TEMP

In the early 1980's, Reynolds (1993) states that the US DoD instituted the TEMP as the top level T&E planning document to be used in each "major" program, i.e., those that would come directly under the oversight of the Director of Operational T&E (DOT&E) and the Under Secretary of Defence for Acquisition, T&E (USD(A)(T&E)). The Services had adopted the use of the TEMP for lower level programs.

Dvorak and Equid (1994) states that the primary purpose of a TEMP is to establish a contract between the Project Manager (PM), the appropriate Australian Defence Force (ADF) decision maker, and the respective T&E agencies. The TEMP is essentially a living document that is updated prior to each milestone to report T&E progress completed and to provide a revised T&E plan for the next phase of activity. The TEMP is a multi-purpose document that:

- Enables the planning of test activities for demonstration of SPP's and TPP's,
- Details DT&E, PAT&E, and OT&E management structures and schedules,
- Provides a history of completed tests,
- Identifies critical performance parameters and operational issues,
- Provides a framework for generation of detailed test plans,
- Summarises required test resources, and
- Identifies new test resources.

For DoD programs where DT&E and OT&E are very distinct, the TEMP for each program combines both into an integrated master plan as is shown in Figure 5-3.

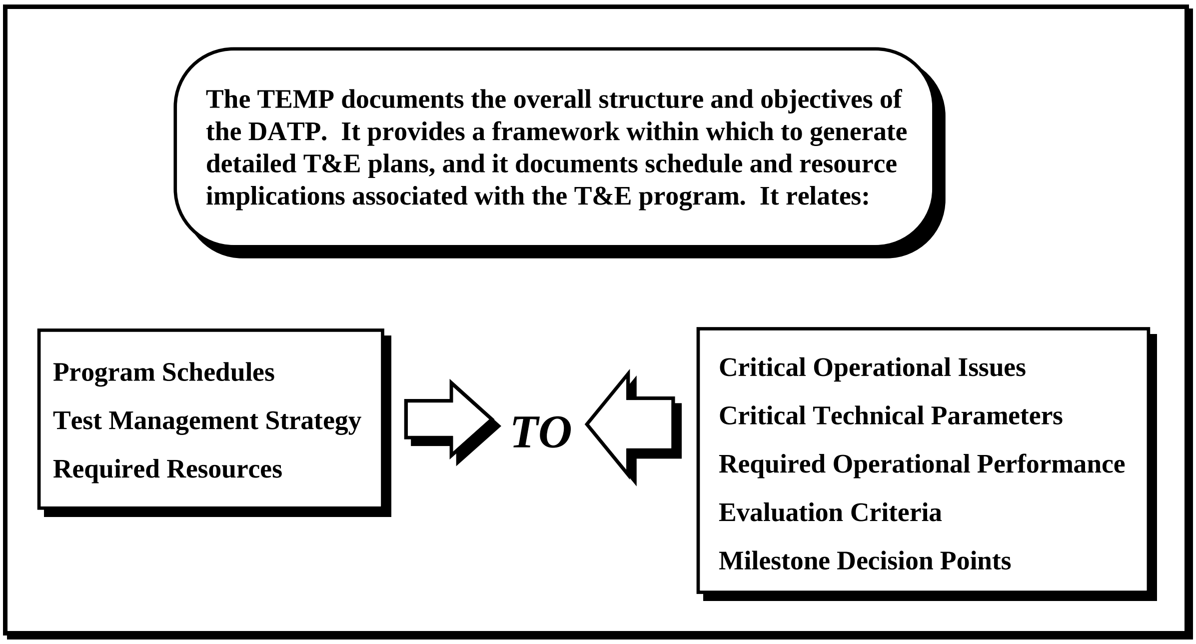


Figure 5-3 (Summary of the Purpose of a TEMP (based on Reynolds (1993))

The TEMP also documents a number of limitations in the DATP, more common types of limitations appearing in TEMP's are listed below (Reynolds & Damaan (1994):

- Cost
- Security Safety
- Ability to portray threat capabilities
- Ability to use full electromagnetic spectrum
- Test instrumentation
- Treaty constraints
- Available time
- Number and availability of test articles
- Test maneuver space
- Representative terrain
- Weather

5.5.4 Document Relationships

Figure 5-4 illustrates how the TEMP interrelates with other key program documents. In particular, the system performance requirements evolve from and expand upon those in the Operational Requirement Document (ORD), which result from threat analysis and Cost Effectiveness Analyses (CEA). This illustration is a merely an extension of Figure 5-2.

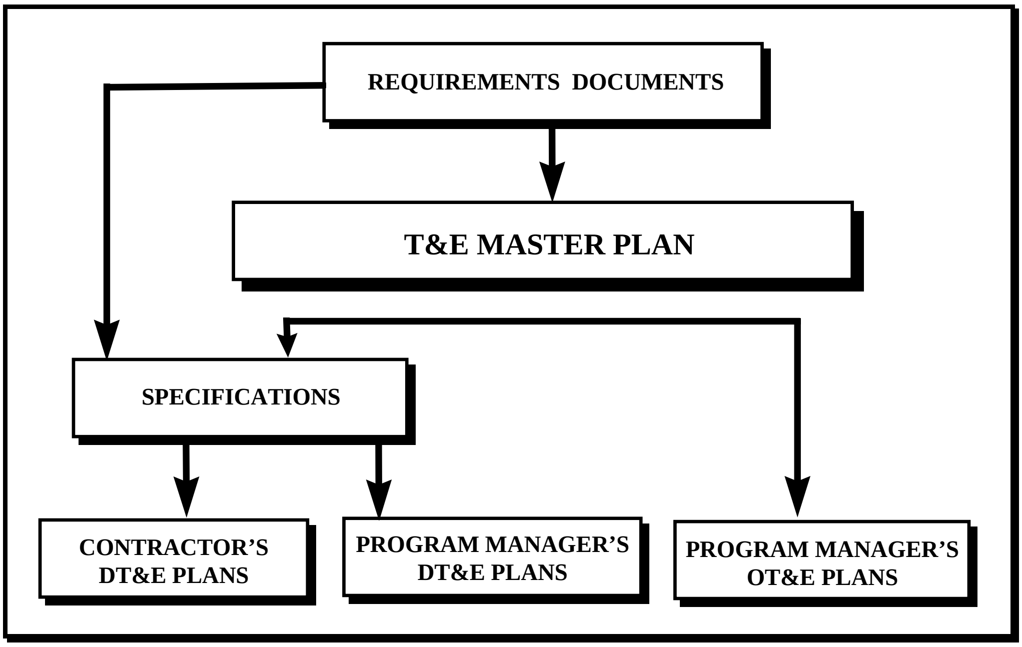


Figure 5-4 (TEMP Documentation Relationships (based on Reynolds (1993))

5.5.5 US TEMP Format

The United States was the first body to document a standard and format for generating a TEMP. This document was the Department of Defence Instruction 5000.3-M-1, first written in 1986 and then later updated in 1990, any further revisions are not known to the author's knowledge. The US TEMP format is shown in Figure 5-5.

The DSMC (1993) states that the TEMP is a living document that must address changes to critical issues associated with an DATP. Major changes in program requirements, schedule or funding usually result in a change in the test program. Thus, the TEMP must be reviewed and updated on program change, on baseline breach and before each milestone decision, to ensure that T&E requirements are current.

PART I	**SYSTEM INTRODUCTION (2 pages suggested)**
	Mission Description
	System Description
	Critical Technical Characteristics
	Required Operational Characteristics
PART II	**PROGRAM SUMMARY (2 pages suggested)**
	Integrated Schedule
	Management
PART III	**DT&E OUTLINE (10 pages suggested)**
	DT&E Overview
	DT&E to Date
	Future DT&E
	Special DT&E Topics
	LFT&E
PART IV	**OT&E Outline (10 pages suggested)**
	OT&E Overview
	Critical Operational Issues
	OT&E to Date
	Future OT&E
PART V	**T&E Resource Summary (6 pages suggested)**
	Summary
	Test Articles
	Test Sites and Instrumentation
	Test Support Equipment
	Threat Systems/Simulators
	Test Targets and Expendables
	Operational Force Test Support
	Simulations, Models and Testbeds
	Special Requirements
	T&E Funding Requirements
	Manpower/Training
	Key Resources
APPENDIX A	**BIBLIOGRAPHY**
APPENDIX B	**ACRONYMS**
APPENDIX C	**POINTS OF CONTACT**

Figure 5-5 (US TEMP Format (adopted from DoD 5000.3-M-1))

5.5.6 The Australian TEMP Format

In the Australian Defence Force, the underlying document that provides any related T&E guidance is the Capital Equipment Procurement Manual (CEPMAN 1) (Australian DoD, 1995), which outlines the conduct of test & evaluation in support of capital equipment projects.

Chapter 14, part 2, of this manual contains a brief overview of the requirements for the planning and conduct of test and evaluation to be performed by defence during projects in order to obtain factual data to assist in validating new or upgraded equipment. The manual states that organisations with responsibility for the design approval, certification or procurement of equipment have the authority and responsibility to conduct (or require the conduct of) T&E. All project T&E requirements are to be coordinated by the project manager, who should consider whether or not T&E can be conducted within available project resources and if it is preferable to seek assistance of an external agency to conduct or assist in conducting such T&E.

The manual also states that project manager, in consultation with operational, technical and maintenance authorities, is to fully investigate the necessity for, and likely scope of, Defence T&E. If a requirement exists for the conduct of T&E, its scope is to be documented in a Test & Evaluation Master Plan (TEMP) at the earliest possible stage in the project planning process. Annex B of the manual, details the role, content and format of a TEMP, and TEMP writer's guide is in Annex C.

A description of the Australian TEMP format is detailed in the author's software AutoTEMP©, beta version 2.0, in the form of a hypertext interactive software tutorial. This tutorial is the first of three software modules that make up AutoTEMP© and its hypertextability and human-computer interactivity as well as a detailed description is dealt with in more detail in chapter 6. For this reason, the proceeding description will merely give an outline of the TEMP format, and any detail that is not dealt with in the tutorial. The generic table of contents is shown in Figure 5-6.

1. SECTION I - DESCRIPTION

1.1. MISSION

1.1.1. Operational Need

1.1.2. Mission to be accomplished

1.1.3. Specified Environment

1.2. SYSTEM

1.2.1. Key Functions

1.2.2. Interfaces

1.2.3. Unique Characteristics

1.3. REQUIRED OPERATIONAL CHARACTERISTICS

1.3.1. Key Operational Effectiveness Characteristics

1.3.2. Key Suitability Characteristics

1.3.3. Thresholds

1.4. REQUIRED TECHNICAL CHARACTERISTICS

1.4.1. Key Technical Characteristics

1.4.2. Performance Objectives

1.4.3. Thresholds

1.5. CRITICAL T&E ISSUES

1.5.1. DT&E Critical Issues

1.5.2. OT&E Critical Issues

1.5.3. S3 Critical Issues

2. SECTION II - PROGRAM SUMMARY

2.1. MANAGEMENT ASPECTS

2.2. INTEGRATED SCHEDULE

2.3. FUNDING ASPECTS OF THE T&E PROCESS

3. SECTION III - DT&E OUTLINE

3.1. DT&E TO DATE

3.1.1. Summary of DT&E already Conducted

3.1.2. Difference for Plan

3.1.3. DT&E Events and Results

3.2. FUTURE DT&E

3.2.1. Equipment Description

3.2.2. DT&E Objectives

3.2.3. Limitations of Scope

3.2.4. Test Failure Procedures

3.3. CRITICAL DT&E ITEMS

3.3.1. Equipment Used

4. SECTION IV - OT&E OUTLINE

4.1. OT&E TO DATE

4.1.1. Summary of OT&E Date

4.1.2. Test Schedules

4.1.3. OT&E Events and Results

4.2. FUTURE OT&E

4.2.1. Equipment Description

4.2.2. OT&E Objectives

4.2.3. OT&E Events/Scope of Testing/Basic Scenarios

4.3. CRITICAL OT&E ITEMS

4.3.1. Highlights

5. SECTION V - PRODUCTION ACCEPTANCE T&E (PAT&E)

5.1. PAT&E TO DATE

5.1.1. Summary of PAT&E to Date

5.1.2. Test Schedules

5.1.3. PAT&E Events and Results

5.2. FUTURE PAT&E

5.2.1. Equipment Description

5.2.2. PAT&E Objectives

5.2.3. PAT&E Events/Scope of Testing

5.3. CRITICAL PAT&E ITEMS

5.3.1. Highlights

6. SECTION VI - SAFETY AND SUITABILITY FOR SERVICE (S3)

6.1. FEATURES

6.2. EQUIPMENT

6.3. SYSTEMS SAFETY PROGRAM

6.4. S3 EVALUATION

6.4.1. Descriptive Proceeding

6.4.2. A Laying-on Proceeding

6.4.3. A Reporting Proceeding

7. SECTION VII - SPECIAL RESOURCE SUMMARY

7.1. TEST SCHEDULES

7.2. INSTRUMENTATION

7.2.1. Targets

7.2.2. Threat Simulations

7.2.3. Test Sites

7.2.4. Facilities

7.2.5. Support

8. APPENDIX A - POINTS OF CONTACT

9. APPENDIX B - NOMENCLATURE

10. APPENDIX C - REFERENCED DOCUMENTS

Figure 5-6 (CEPMAN 1 TEMP Format (based on Australian DoD, 1995))

5.5.7 Comparison of US and Australian TEMP Format

Table 5-1 summarises the difference between the US DoD 5000.3-M-1 and the Australian DoD CEPMAN 1 TEMP format. As is evident the US format does not detail PAT&E and Systems, Safety and Service (S3) as the Australian format does.

US DoD 5000.3-M-1	AUSTRALIAN DoD CEPMAN 1
Part I - System Introduction	Section I - Description
Part II - Program Summary	Section II - Program Summary
Part III - DT&E Outline	Section III - DT&E Outline
Part IV - OT&E Outline	Section IV - OT&E Outline
	Section V - PAT&E Summary
	Section VI - S3 Evaluation
Part V - T&E Resource Summary	Section VII - Special Resource Summary
Appendix A - Bibliography	Appendix A - Bibliography
Appendix B - Acronyms	Appendix B - Acronyms
Appendix C - Point of Contact	Appendix C - Point of Contact
	Appendix D - User Information Matrix

Table 5-1 (The US DoD 5000.3-M-1 and Australian DoD CEPMAN 1 TEMP Format Compared)

The US denotes the sections of the TEMP with the terminology “Parts”, and the Australia has adopted “Sections”, of which there are five and seven respectively. The PAT&E and S3 sections are excluded. PAT&E is considered an element of DT&E in the US system. The S3 functions are examined by both the OT and DT communities.

5.5.8 Australian Conceptual TEMP Format

As mentioned previously, the author has conceptualised a generic format of the TEMP contents, which is primarily based on CEPMAN 1 but with modifications and additions with the help of the US TEMP format and other literature mentioned in section 5.5.1 previously. This conceptualisation is depicted in Figure 5-7 overpage.

1. SECTION I - DESCRIPTION

1.1 DOCUMENT DESCRIPTION

1.2 MISSION DESCRIPTION

1.2.1 Operational Need

1.2.2 Mission to be accomplished

1.2.3 Specified Environment

1.3 SYSTEM DESCRIPTION

1.3.1 Key Functions

1.3.2 Interfaces

1.3.3 Unique Characteristics

1.4 REQUIRED OPERATIONAL CHARACTERISTICS

1.4.1 Key Operational Effectiveness Characteristics

1.4.2 Key Suitability Characteristics

1.4.3 Thresholds

1.5 REQUIRED TECHNICAL CHARACTERISTICS

1.5.1 Key Technical Characteristics

1.5.2 Performance Objectives

1.5.3 Thresholds

1.6 CRITICAL T&E ISSUES

1.6.1 DT&E Critical Issues

1.6.2 OT&E Critical Issues

1.6.3 S3 Critical Issues

2. SECTION II - PROGRAM SUMMARY

2.1 MANAGEMENT ASPECTS

2.2 INTEGRATED SCHEDULE

2.3 FUNDING ASPECTS OF THE T&E PROCESS

3. SECTION III - DT&E OUTLINE

3.1 DT&E TO DATE

3.1.1 Summary of DT&E already Conducted

3.1.2 Difference for Plan

3.1.3 DT&E Events and Results

3.2 FUTURE DT&E

3.2.1 DT-I

3.2.1.1 Configuration Description

3.2.1.2 DT&E Objectives

3.2.1.3 DT&E Events

3.2.1.4 Limitations to Scope

3.2.2 DT-II TECHEVAL

3.2.2.1 Configuration Description

3.2.2.2 DT&E Objectives

3.2.2.3 DT&E Events

3.2.2.4 Limitations to Scope

3.2.3 Test Failure Procedures

3.3 CRITICAL DT&E ITEMS

3.3.1 Equipment Used

4. SECTION IV - OT&E OUTLINE

4.1 OT&E TO DATE

4.1.1 OT-I EOA

4.1.2 OT-II OPEVAL

4.1.3 Summary of OT&E Date

4.1.4 Test Schedules

4.1.5 OT&E Events and Results

4.2 FUTURE OT&E

4.2.1 OT-I EOA

4.2.1.1 Configuration Description

4.2.1.2 OT&E Objectives

4.2.1.3 OT&E Events

4.2.1.4 Limitations to Scope

4.2.2 OT-II OPEVAL

4.2.2.1 Configuration Description

4.2.2.2 OT&E Objectives

4.2.2.3 OT&E Events

4.2.2.3.1 Scenarios

4.2.2.4 Limitations to Scope

4.2.3 OT-III FOT&E

4.2.3.1 Configuration Description

4.2.3.2 OT&E Objectives

4.2.3.3 OT&E Events

4.2.3.4 Limitations to Scope

4.3 CRITICAL OT&E ITEMS

4.3.1 Effectiveness Issues

4.3.1.1 Document Generation

4.3.1.2 Traceability

4.3.1.3 Future Growth

4.3.2 Suitability Issues

4.3.2.1 Availability

7.2.4 Test Sites

7.2.5 Facilities

7.2.6 Support

8. APPENDIX A

8.1 POINTS OF CONTACT

9. APPENDIX B

9.1 NOMENCLATURE

10. APPENDIX C

10.1 REFERENCED DOCUMENTS

11. APPENDIX D

11.1 USER INFORMATION MATRIX

Figure 5-7 (Conceptualised TEMP Format (adopted from AutoTEMP© Beta 2.0))

Due to the size of the TEMP as is evident in Figure 5-7, it was more appropriate to give a detailed description of the TEMP format specified in Figure 5-7 as an attachment to this dissertation, which is located in Appendix VI. The description makes use of both the US DoD 5000.3-M-1 (1990) and the Australian DoD CEPMAN 1 (1995), as well as other sources annotated in the Appendix.

5.5.9 Summary

The Australian DoD (1995) CEPMAN 1 states that in summarising, the TEMP is a living resource document used by various agencies who often have differing T&E priorities. Updates are made prior to each milestone to ensure the document reflects the evolving system. Agencies can also make incremental changes as required to ensure the TEMP is aligned with current T&E objectives.

CEPMAN 1 also states that historically ADF TEMPs were written to identify T&E requirements only until a specific system reaches production. Recent policy changes have required the life of the TEMP to extend to the entire service life of the system (similar to US method). These changes were initiated for coordination of T&E in support of in-service system upgrades and future stores/weapons system integration.

5.6 Human-Computer Collaboration

In carrying out the action of automating any process one must certainly consider the consequences of the user and advantages or perhaps disadvantages that this action could impose. Terveen (1995) defines Collaboration as *"a process in which two or more agents work together to achieve shared goals"*. Terveen also states that the study of Human-Computer Collaboration (HCC) is highly disciplinary. Its two basic parent disciplines are Artificial Intelligence (AI) and Human-Computer Interaction (HCI). AI draws knowledge representation and reasoning techniques, and HCI draws interaction and information presentation techniques.

Rogers (1995) states that the enhancement of human performance in complex tasks is an issue which has long concerned researchers, particularly with respect to the role of automation. He goes on to say that, in order to build effective human-machine cognitive systems, techniques and concepts are needed to identify the decision-making/problem-solving requirements in some domain.

The US Army on the other hand, states that (Banister, 1995) the materiel acquisition process is replete with procedures, processes, and policies designed to eliminate or reduce the uncontrollable human variable in all phases of the weapons system acquisition process, defined in chapter 4. Both disciplines however, Software Engineering (SE) and HCI need ways of measuring how well their products and development processes fulfill their intended requirements, as argued by Preece & Rombach (1994).

Bishop (1994) states that the OPTEC has provided its operational evaluators and analysts to assess the user friendliness of computer software with the development of a guide known as "Handbook for the Evaluation of User Friendliness of Soldier-System Interfaces", in which its goal in life is "to quantify system user friendliness across the full range of subjective and objective data obtained from users, and others, who are familiar with a given system."

Thus, the author has designed the software shell AutoTEMP©, that is described in the proceeding chapter, used to assist the user (human) in generating a TEMP, so that there is some degree of user-computer friendly interaction. This consideration merely adds more thorough software T&E of the system at hand, and hence an increase in efficiency, and reliability.

5.7 Conclusion

This chapter has looked at the automation of the T&E process, in which a review of previous work such as, The Automated Test Planning System, Specriter 3©, and AutoSpec©, by the Science Applications International Corporation, Cook (1991) and Evdokiou (1994) respectively, was discussed, along with the need for and requirements for its automation.

The importance of adhering to and regularly updating a TEMP was emphasised as the most vital part of any defence acquisition test program, due to the fact that it outlines very crucial elements and parameters that all such test should aspire to, and only in this fashion can the cost and time of conducting a test be reduced and efficiency subsequently increased, via the assistance of a computer in automating this process.

The chapter then concluded with a comprehensive discussion of TEMP's, outlining the formats used by the United States and Australia, its role, and its conceptualisation into a generic form or template, along with a brief discussion on the collaboration between the software and the user operating it.

The next chapter will give an insight into the by-product of this research, namely, a detailed look at AutoTEMP© Beta 2.0, and its operation, via a breakdown of its three interlaced modules.

CHAPTER 6

6. AutoTEMP© - The Automated TEMP Generator

6.1 Summary

This chapter gives a comprehensive description of the results of this research, which is a KBSS to aid in the generation of TEMP's, that the author has called AutoTEMP©. Version Beta 2.0 of the software release clearly demonstrates the principles of the development of a TEMP according to a conceptualised revision of the Australian CEPMAN 1 (Australian DoD, 1995), as set out in the previous chapter.

The chapter will begin with a discussion and analysis of the CSCI AutoTEMP© requirements, outlining such things as the development software and programming language used for the development of the CSCI, along with a brief description of the hardware requirement specification for this system, a brief introduction and description of Visual Basic®, and then will describe the operation and use of AutoTEMP© and its three modules.

6.2 AutoTEMP© CSCI Requirements

The only requirement for developing the CSCI as stated by Nissyrios (1995a) was a Windows® environment such as Windows® for Work Groups (WFWG) version 3.11, or Windows® 95 based on an IBM compatible computer. It is envisaged that the CSCI will be compiled into a single executable file (EXE) depending on the application development software language.

6.2.1 The Selection of the CSCI Development Software

A number of software packages had been considered by the author for this task. Taking into consideration the SRS as documented in Appendix V, possible candidates for the software development that were PC based, at the time of its conception were:

- Modsim II®
- VP-Expert®
- HyperCard®

- Microsoft® Access
- Layout®
- DataEase®
- ObjectVision®
- Visual Basic®
- Delphi® (Visual Pascal)

As discussed in the SRS, Appendix V, the CSCI was to be developed using an application programming language that did not require vast amounts of specialised programming, such that it alleviates the necessity of software coding to a base minimum, and in particular one with a fast learning curve. Due to these requirements, the most prominent application software development tools were Visual Basic® (VB) or DELPHI (visual PASCAL).

However, DELPHI was and still is a lot more complex than VB and hence would require a long learning curve, the author estimated six months, as compared to one month for VB. This is not to say that it wasn't more than adequate to suit the task ahead, however, VB was chosen as the software and programming language for the development of AutoTEMP© due to reasons summarised below as follows:

- Event driven
- Alleviated the necessity of software coding to a bare minimum
- Quickest and easiest way to create Window applications
- Fast learning curve (about one month)

6.2.2 Computer Resource Requirements

6.2.2.1 Computer Software Requirements

The following software was required for CSCI development (Nissyrios, 1995a):

- DOS for Windows® 95 Version 4.00.950
- Microsoft Windows® 95
- Microsoft Office Professional Version '95
- Microsoft Access 2.0
- Visual Basic® Professional (VBP) Version 4.0
- Microsoft Project Version 4.0

6.2.2.2 Computer Hardware Requirements

Recommendation was an IBM personal computer with the following minimum characteristics (Nissyrios, 1995a):

- Three year on-site warranty.
- 90 Mhz Pentium PCI Processor.
- 16 MegaBytes of Random Access Memory (RAM).
- 17 Inch Multi-Sync Monitor (27mm Dot Inch)
- 1.2 GigaByte Hard Disk Drive (HDD)
- 512K Cache (Pipe-Line Burst).
- 64-Bit PCI, 2MB Video Card.
- 1.44 MegaByte Floppy Disk Drive (FDD).
- Twin Speed CD-ROM Drive.
- 16-Bit Sound Blaster Card.
- Ethernet compatible in both thin-net and twisted pair formats[11].

6.3 Visual Basic®

Visual Basic® is the quickest and easiest way to create applications for the Microsoft Windows® operating system. The Visual Basic® programming system allows you to create attractive and useful applications that fully exploit the graphical user interface (GUI). Visual Basic® is more productive by providing appropriate tools for the different aspects of GUI development.

The graphical user interface can be created for the application by drawing objects in a graphical way. It's simply a matter of setting the properties on these objects to refine their appearance and behavior. The second step is to make this interface react to the user by writing code that responds to events that occur in the interface. Using Visual Basic® the user can create powerful, full-featured applications. Some of these features are (Microsoft® Corporation, (1995b)):

- Data access features that allow you to create databases and front-end applications for most popular database formats, in particular Microsoft® Access.

[11] A network capability is essential for developing a multi-user, single session support system.

- Object Linking and Embedding (OLE) allows the user to use the functionality provided by other applications, such as Microsoft® Word for Windows® word processor, Microsoft® Excel spreadsheet, and Microsoft® Project project planning system.
- The completed application is a true .EXE (executable) file that uses a run-time Dynamic Link Library (DLL) that the user can freely distribute.

6.3.1 Working with Visual Basic® 4.0

Originally the author began with Visual Basic® version 3.0, professional edition, and Windows® for Workgroups 3.11 as the software platform, this combination however, was superseded with the release of Windows® 95 and Visual Basic® version 4.0, professional edition, so as to keep up with the technology and not to mention the additional features in both of these software packages. An outline of some of the new features in Visual Basic® 4.0, professional edition are (Microsoft® Corporation, 1995b):

- OLE custom controls
- Insertable projects as controls
- Development environment extensibility
- Conditional compilation
- Settable fonts and font sizes
- Menu and toolbar negotiation
- Improved debug window
- Data access object (DAO)
- New data-bound controls
- 32-bit support
- Microsoft Jet 2.5 and Microsoft Jet 3.0 databases
- TabStrip control
- Toolbar control
- StatusBar control
- ProgressBar control
- TreeView control
- ImageList control
- Slider control

6.3.2 Steps to Creating a Visual Basic® Application

There are three main steps to creating an application for Windows® in Visual Basic® (Microsoft Corporation, 1995b):

1. Create the interface.
2. Set properties.
3. Write code.

6.3.2.1 Creating the Interface

Forms are the foundation for creating the interface of an application. You can create forms to add windows and dialog boxes to your application. You can also use them as containers for items that are not a visible part of the application's interface. For example, you can have a form in your application that serves as a container for graphics that you plan to display in other forms.

The first step in building a Visual Basic® application such as AutoTEMP©, is to create the forms that will be the basis for that application's interface. Then you draw the objects that make up the interface on the forms you create.

6.3.2.2 Setting Properties

The next step is to set properties for the objects that have been created. The Properties window provides an easy way to set the properties for all objects on a particular form.

6.3.2.3 Writing Code

The *Code window* is where the Visual Basic® code for the application is written. Code consists of language statements, constants, and declarations. Using this code window, you can view and edit any of the code in the application.

6.3.2.4 Creating Event Procedures

Code in any Visual Basic® application is divided into smaller blocks called *procedures*. An *event procedure*, contains code that is executed when an event occurs (such as when a user clicks a button). An event procedure for a control combines the control's actual name (specified in the Name property), an underscore(_), and the event name. For example, if you want a command button named Command1 to invoke an event procedure when it is clicked, then you use the event procedure Command1_Click, and so on.

6.3.3 Structure of a Visual Basic® Application

All applications can contain several different types of files, such as (Microsoft® Corporation, (1995b)):

- Form modules (.FRM) contain the visual elements of a form, including all the control on the form and Basic code associated with that form.
- Standard (.BAS) and class (.CLS) modules contain Basic code.
- Custom controls (.VBX or .OCX) include specialised controls, as well as enhanced versions of standard controls.
- A single resource file (.RES) contains strings and bitmaps used by the application.

6.3.3.1 How an Event-Driven Application Works

An *event* is an action recognised by a form or control. Event-driven applications execute Basic code in response to an event. Each form and control in Visual Basic® has a predefined set of events. If any one of these events occurs, Visual Basic® invokes the code in the associated event procedure as mentioned previously.

Although objects in Visual Basic® automatically *recognises* a predefined set of events, you determine if and how they *respond* to a particular event. When you want a control to respond to an event, you write event procedure code for that event.

Many objects recognise the same event, although different objects can execute different event procedures when the event occurs. For example, if a user clicks a form, the Form_Click event procedure executes; similarly, if a user clicks a command button named Command1, the Command1_Click event procedure executes. This is what happens in a typical event-driven application such as AutoTEMP© (Microsoft® Corporation, 1995b):

1. The application starts and the startup form is automatically loaded and displayed.
2. A form or control receives an event. The event can be caused by the user (for example, a keystroke), by the system, or indirectly by your code (for example, a Load event when your code loads a form).
3. If there is an event procedure corresponding to that event, it executes.
4. The application waits for the next event.

6.3.3.2 Event Driven vs. Traditional Programming

In a traditional or “procedural” application, the application itself rather than an event controls the portions of code that execute. Execution starts with the first line of executable code (like a line-by-line assembler) and follows a defined path through the application, calling procedures as needed.

In event-driven programs, a user action or system event executes an event procedure. Thus, the order in which your code executes depends on which events occur, which in turn depends on what the user does. This is essence of graphical user interfaces and event-driven programming: The user is in charge, and your code responds.

6.4 A Description of AutoTEMP©

The AutoTEMP© CSCI is primarily designed to aid in the automatic generation of TEMP’s, however, in order to accomplish this task, it required a minimum of two modules, one for entering the data needed to fill the contents of the TEMP document, as well as a separate module for automatically generating it. An additional module was also included, this is a tutorial of the US phased acquisition process, of which is described in chapter 4, section 4.2.3. These three modules are depicted in Figure 6-1.

The header screen that the user sees once AutoTEMP has been invoked is depicted in Figure 6-2, as is evident from the three options to which module the user wishes to enter, under the File menu.

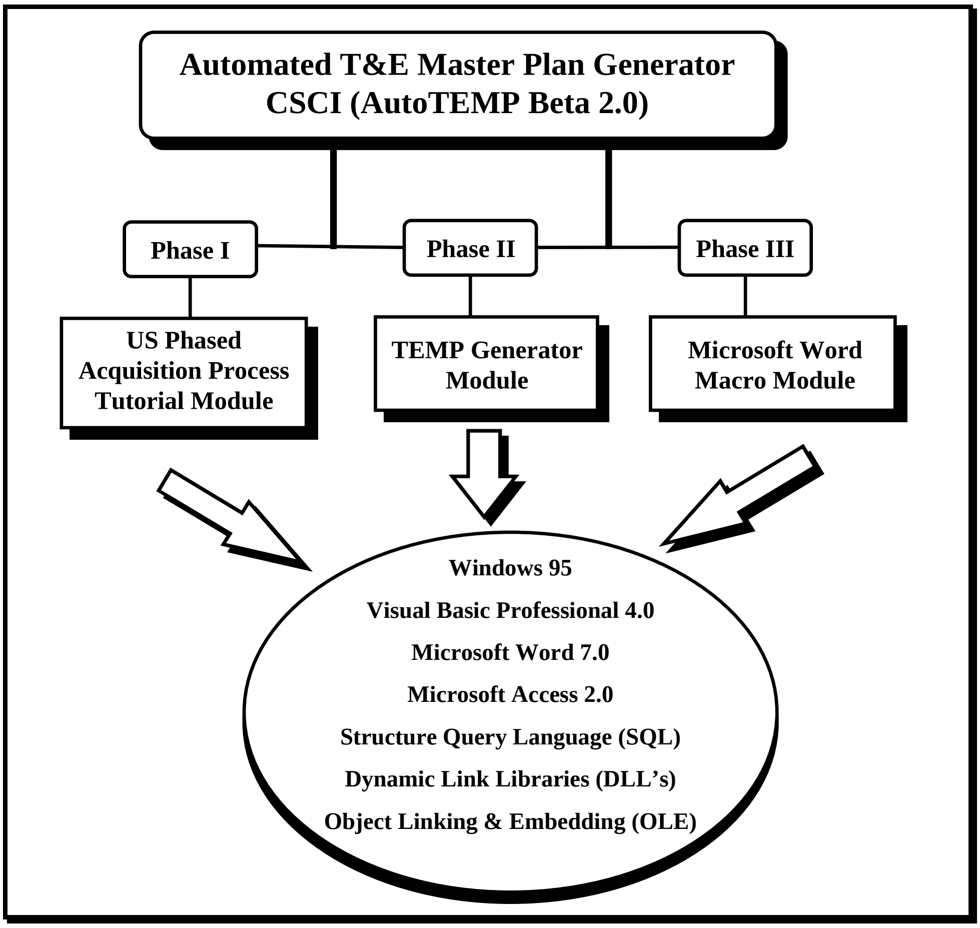


Figure 6-1 (AutoTEMP© Beta 2.0 CSCI Module Reticulation)

6.4.1 Module I - US Defence Phased Acquisition Process Tutorial

This CSCI module was developed as a means of educating ARDU personnel about the Phased Acquisition Process (PAP) which also encapsulates a concise description of the Australian CEPMAN 1 TEMP format as per chapter 5, and Appendix VI. The US version was chosen at the time as this was the best documented literature on the PAP and reasons as mentioned previously in the earlier chapters of this dissertation.

6.4.1.1 Features of Module I

The tutorial presents the user with a walk through user-friendly graphical software medium for educating oneself with testing and the PAP as well as the TEMP format. It is best to begin this tutorial by pressing the Mission Need Button, read the text and continue with Phase 0, right through to Phase IV, or similarly in an ad hoc fashion, pressing any button on the screen will provide information on the topic. You will notice that some words in the text are coloured green, and some blue.

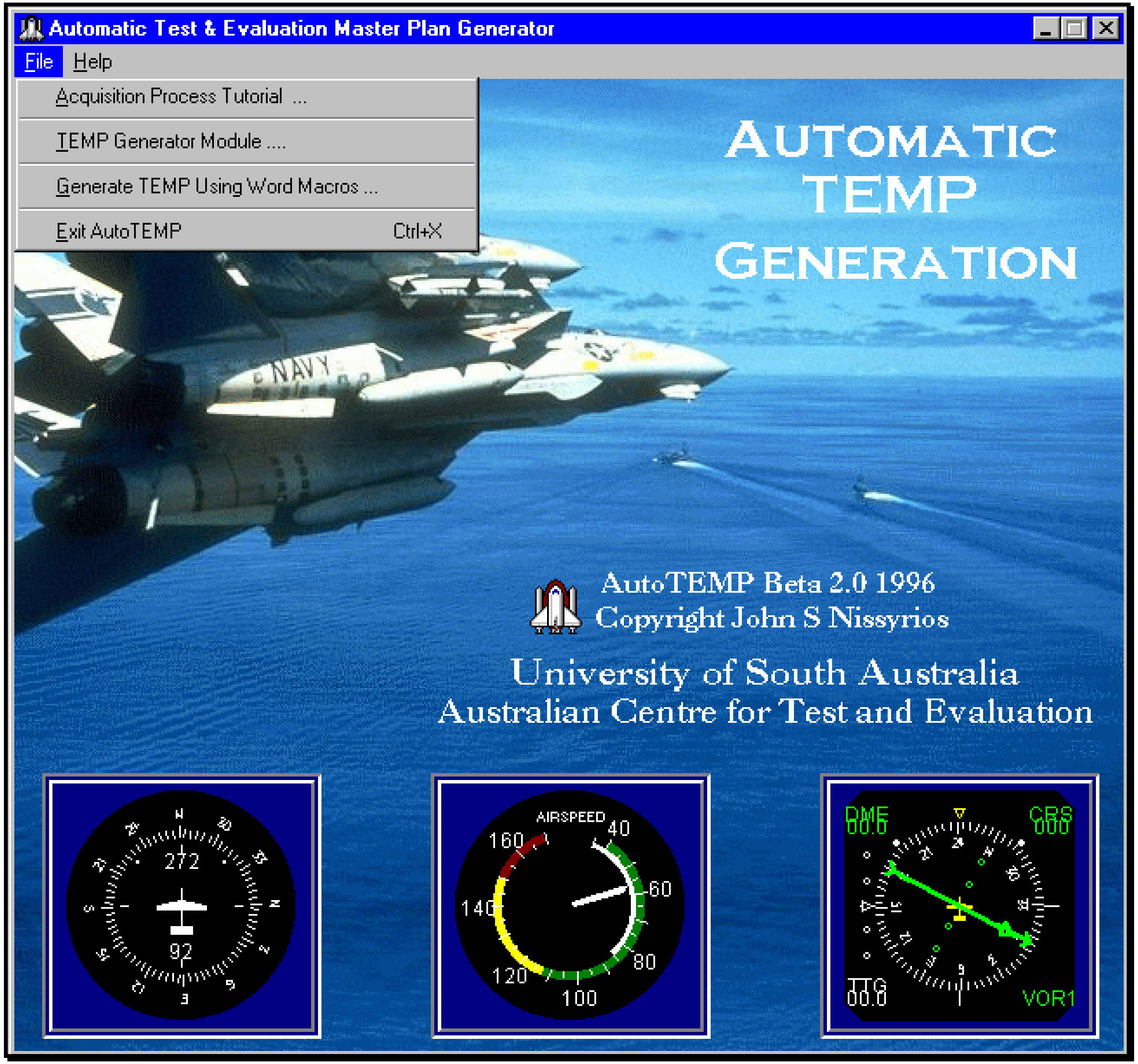


Figure 6-2 (AutoTEMP© Header Form)

By simply clicking on the green entries which represent hyperlinks[12] the software will provide other information about that entry. The hypertext entries or words are easy to locate, because first of all they are green and underlined, and second, the cursor changes from a pointer to a hand with the index finger over the text. This particular user screen (known as forms in Visual Basic®) referred to as the Module I "Home Page (HP)" is depicted in Figure 6-4. With reference to Figure 6-2, once the user has selected the first option, under the file menu, they will be presented with a help screen, and pre-tutorial information, such as instructions, background, as well as the option for printing this form. This introductory form is shown in Figure 6-3.

Simply by clicking with the left mouse button on any of the buttons shown on the menu bar, apart from the print and close buttons, which will print and close this form respectively, this will open new forms about that button pressed, similar to the one depicted in Figure 6-3.

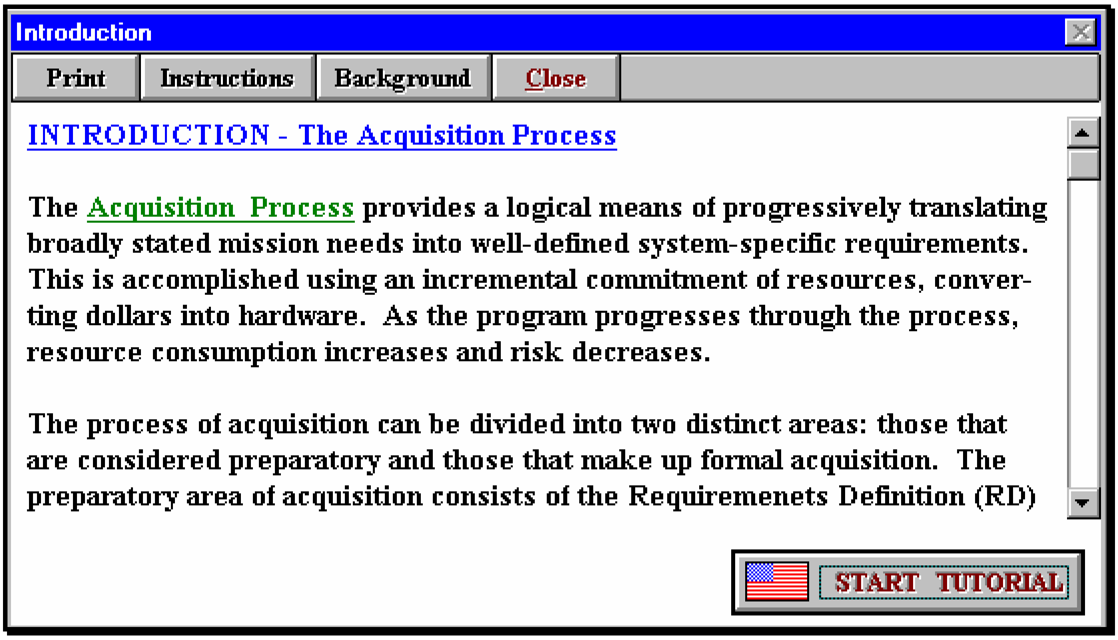


Figure 6-3 (Module I Introductory Form)

[12] Hypertext is a method of presenting information where selected words in the text can be "expanded" at any time to provide other information about the word. That is, these words are links (known as *Hyperlinks*) to other documents, which may be text, files, pictures, anything (Krol, 1992).

In order to instigate the tutorial, and load up the PAP Home Page, you simply press the Start Tutorial button with the icon of the US flag (clearly illustrating that this tutorial is Primarily US based, the exception being the TEMP information and format) as depicted in Figure 6-3.

The form depicted in Figure 6-4, presents the user with a number of options, they can either press buttons and educate themselves by reading, what the author refers to as on-line reading, or they have the option of printing the text shown on the form and reading the hard copy in their own leisure. So it really does depend on the liking of the person using the software.

The user knows whether they have “visited” a particular site (one of the button on the form in Figure 6-4) because the colour of the button changes from grey to purple, this is one of the user-friendly features of this module. The five phases, phase 0 to IV present the user with a comprehensive description of that phase with hyperlinks embedded that will guide you to other topics, and then a summary of this information. For illustrative purposes Phase II and the summary forms are depicted in Figure 6-5 and Figure 6-6 respectively.

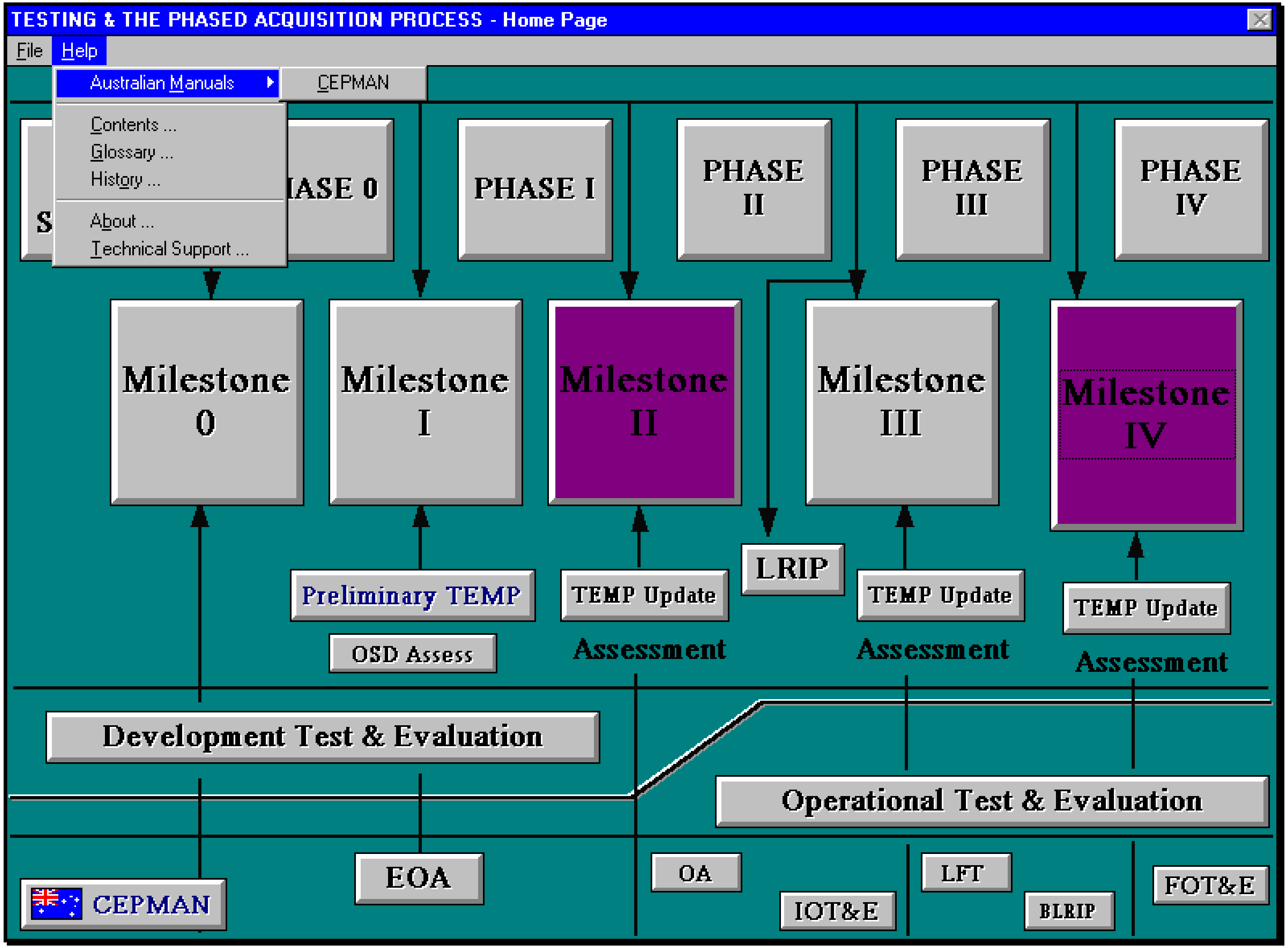


Figure 6-4 (Module I Home Page)

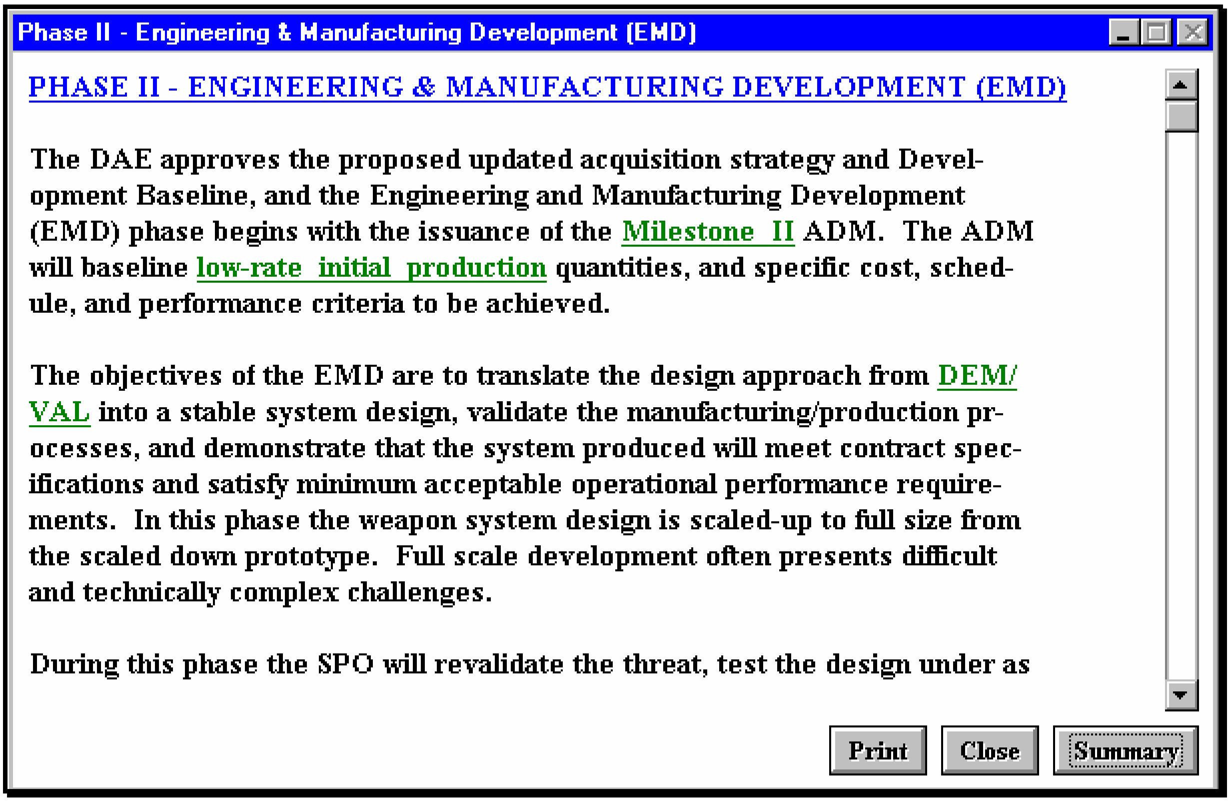


Figure 6-5 (Phase II - EMD Form)

As is evident from the above diagram, there are also scroll bars in each form, that allow the user to scroll down the form as it is being read, and also gives it versatility in its development[13]. In Figure 6-4, some of the other user-friendly features of this module are the Contents, Glossary, and History options under the Help menu.

[13] A handy 16-bit Control box (.VBX) of Visual Basic® known as Multitext.vbx, of which the author downloaded from one of the many Visual Basic® pages on the Internet, incorporates this facility.

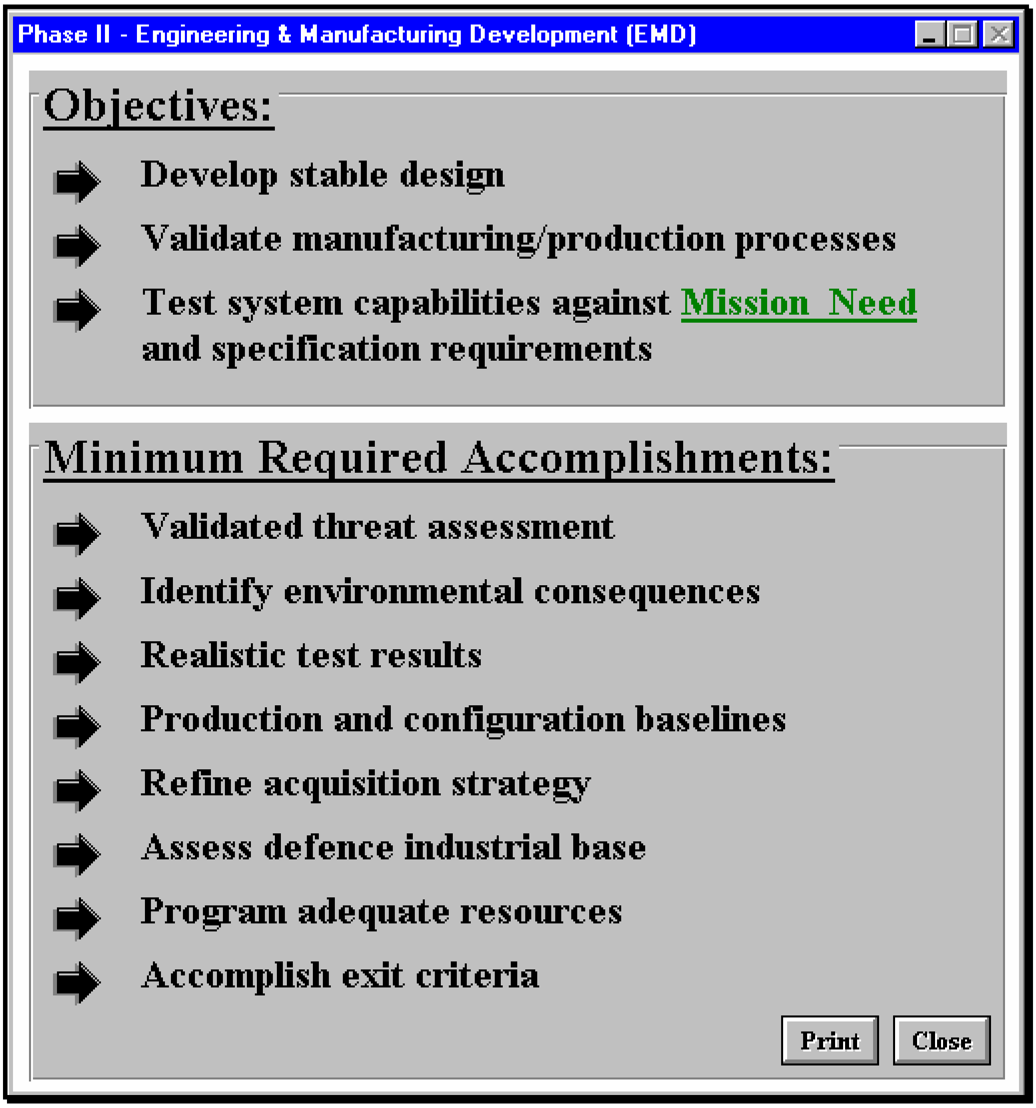


Figure 6-6 (Phase II - EMD Summary Form)

The Contents form lists all possible forms that the user could open of which there are 49 of them. Figure 6-7 shows all the possible forms that could be opened whilst Module I is active.

Acquisition Program Baseline (APB)
Air Force Operational Test & Evaluation Centre (AFOTEC)
Availability of Test Schedules
Background
Beyond Low-Rate Initial Production (BLRIP)
Capital Equipment Procurement Manual (CEPMAN)
Criticality Levels for Test & Evaluation
Developmental Operational Test & Evaluation (DT&E)
Early Operational Assessment (EOA)
Five Types of Test & Evaluation
Follow-on Operational Test & Evaluation (FOTE)
Independent Validation & Verification (IV&V)

Initial Operational Test & Evaluation (IOTE)
Instructions
Integrated Program Summary (IPS)
Introduction
Lethality
Live Fire Test & Evaluation (LFT&E)
Logistic Support Analysis (LSA)
Low-Rate Initial Production (LRIP)
Milestone 0 - Concept Studies Approval
Milestone 1 - Concept Demonstration Approval
Milestone 2 - Development Approval
Milestone 3 - Production Approval
Milestone 4 - Major Modifications Approval (As required)
Mission Need Statement (MNS)
Operational Assessment (OA)
Operational Test & Evaluation (OT&E)
Operational Test Agency (OTA)
Phase 0 - Concept Exploration and Definition (CE)
Phase 0 - Summary
Phase 1 - Demonstration and Validation (DEM/VAL)
Phase 1 - Summary
Phase 2 - Engineering and Manufacturing Development (EMD)
Phase 2 - Summary
Phase 3 - Production and Deployment (PD)
Phase 3 - Summary
Phase 4 - Operations & Support (OS)
Phase 4 - Summary
Production Acceptance Test & Evaluation (PATE)
Test & Evaluation Master Plan (TEMP)
Test & Evaluation Master Plan (TEMP) Format
Test & Evaluation Master Plan (TEMP) Update
Testing and the Phased Acquisition Process
Triangle of Measurement & Instrumentation and Test & Evaluation
Types and Applications of Test & Evaluation
Under the Office of the Secretary of Defence (OSD)
Verification & Validation (V&V)
Vulnerability

Figure 6-7 (Module I Contents)

The Glossary form, depicted in Figure 6-8, is designed so that the user can easily choose the letter of the alphabet (in the Index box) that the particular acronym or abbreviation starts with, press the letter which is a button and the software will then give you a list of all the acronyms or abbreviations that start with that letter. It is then simply a matter of clicking on the hypertext acronym or abbreviation, and the software will show you the meaning of the word in the right text box as is shown in Figure 6-8. As well as having the capability to scroll down as the user sees fit, the user can obtain a hard copy of the list of acronyms and abbreviations, of which there are approximately 100 (all that the tutorial uses), by hitting the Print List button.

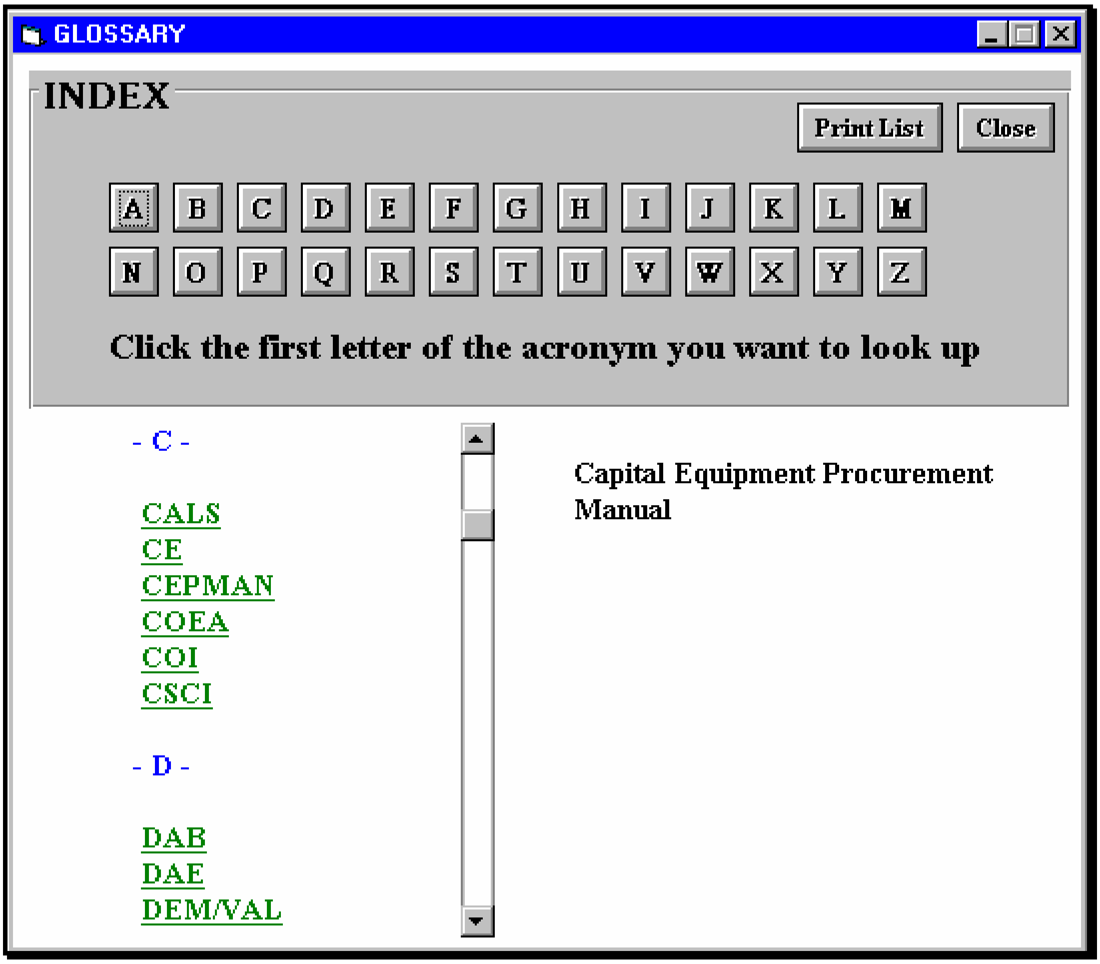


Figure 6-8 (Module I Glossary Form)

The history form depicted in Figure 6-9, has some intelligent software code encrypted in it that keeps a track of what forms are open, and allows you to quickly invoke a form that was opened during the tutorial. This feature was incorporated so as help the user navigate through the tutorial with some ease and direction, considering the 50 or so forms that can be opened at any one time.

Figure 6-9 (Module I Help History Form)

Finally, as mentioned previously, the major modification to US PAP in Figure 6-4, is the TEMP format, it outlines the Australian CEPMAN 1 format as per Appendix VI, and also incorporates Annex A and B to Chapter 14, part2 of CEPMAN 1 (Australian DoD, 1995), which are the Types and Applications of T&E as well as a description of the TEMP format, respectively. The TEMP Format form is illustrated in Figure 6-10.

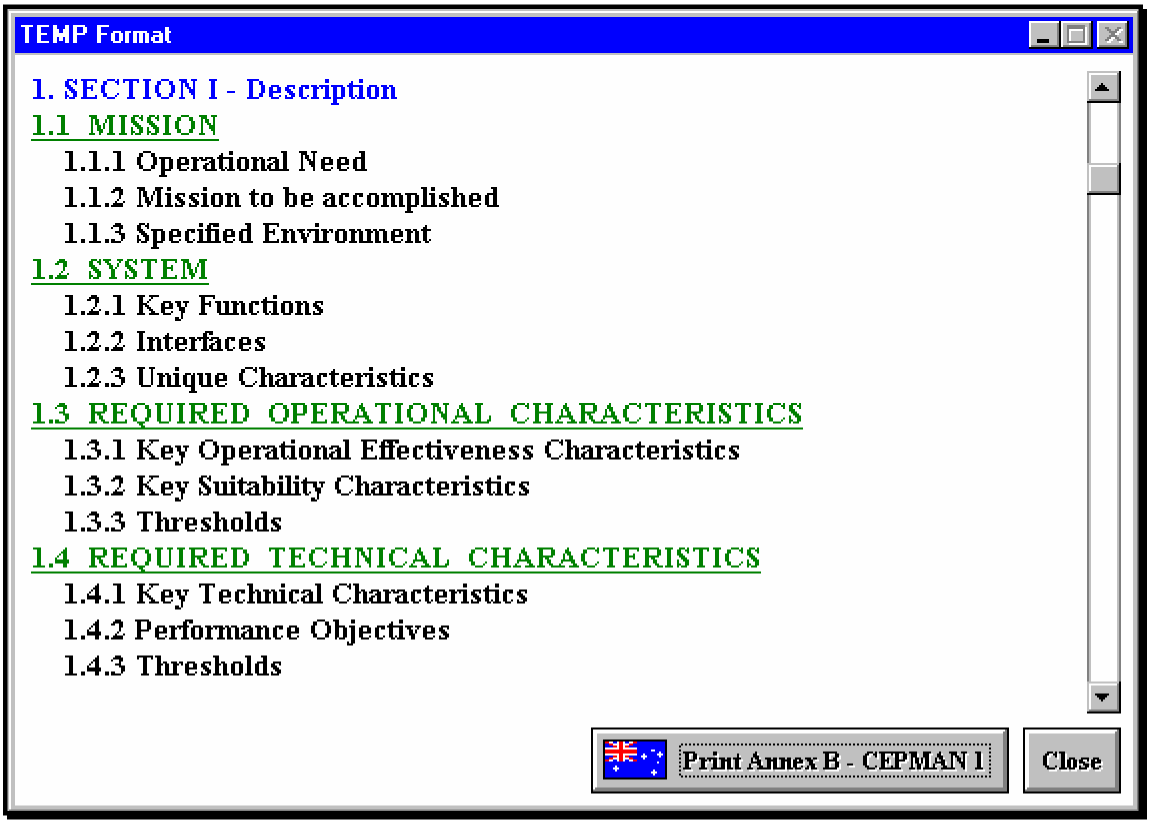
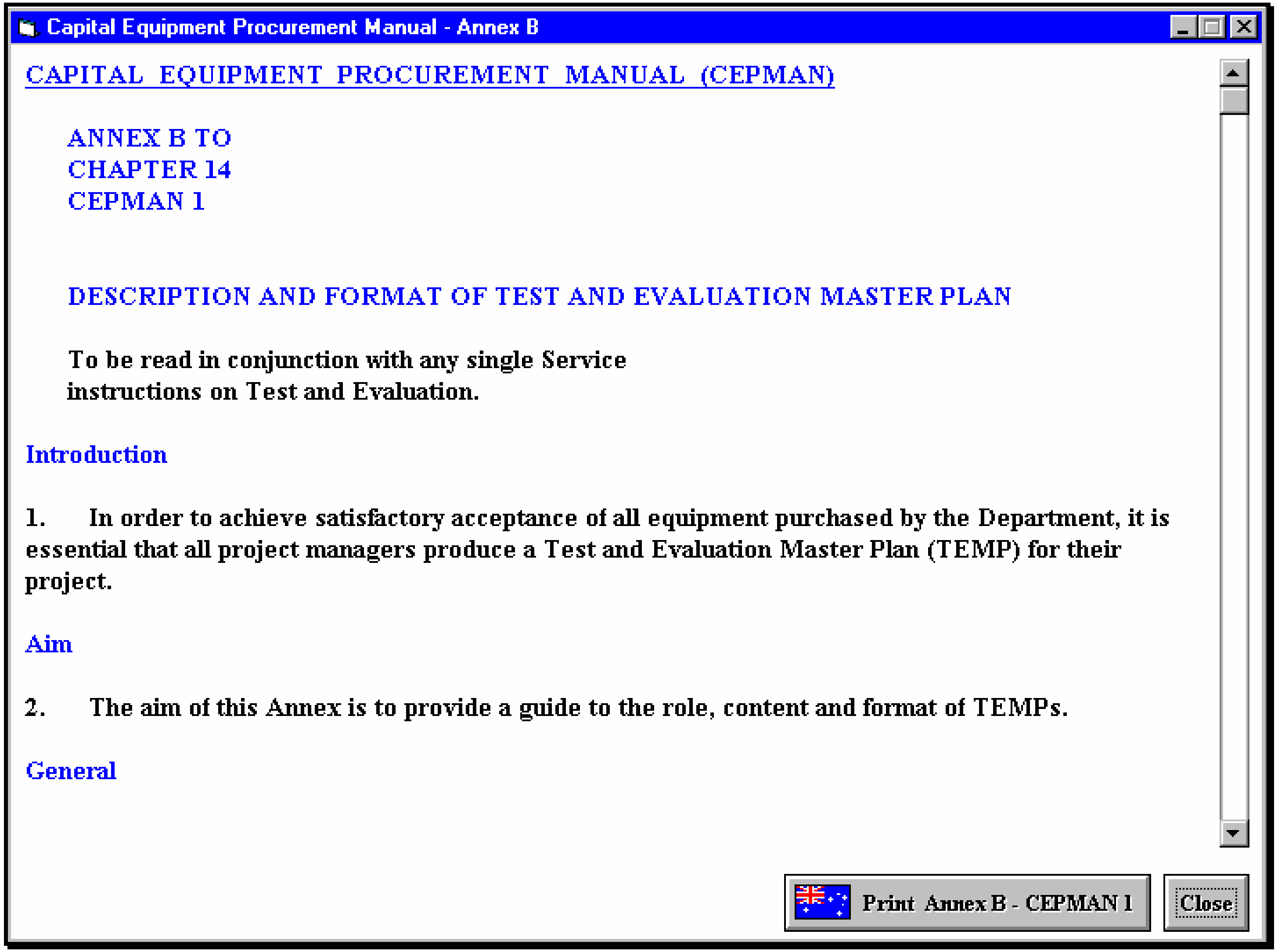


Figure 6-10 (Module I TEMP Format Form)

Annex B in Figure 6-10 is the description of the TEMP format according to the CEPMAN 1 (Australian DoD, 1995), and is depicted in Figure 6-11.



Capital Equipment Procurement Manual - Annex B

CAPITAL EQUIPMENT PROCUREMENT MANUAL (CEPMAN)

ANNEX B TO
CHAPTER 14
CEPMAN 1

DESCRIPTION AND FORMAT OF TEST AND EVALUATION MASTER PLAN

To be read in conjunction with any single Service instructions on Test and Evaluation.

Introduction

1. In order to achieve satisfactory acceptance of all equipment purchased by the Department, it is essential that all project managers produce a Test and Evaluation Master Plan (TEMP) for their project.

Aim

2. The aim of this Annex is to provide a guide to the role, content and format of TEMPs.

General

Print Annex B - CEPMAN 1

Close

Figure 6-11 (CEPMAN 1 - Annex B Form)

Figure 6-12 illustrates Annex A of CEPMAN 1, using hyperlinks and a contents page, which once clicked on invoke information on that topic. It also allows you to print the form, the hard copy of which would look exactly like the figure.

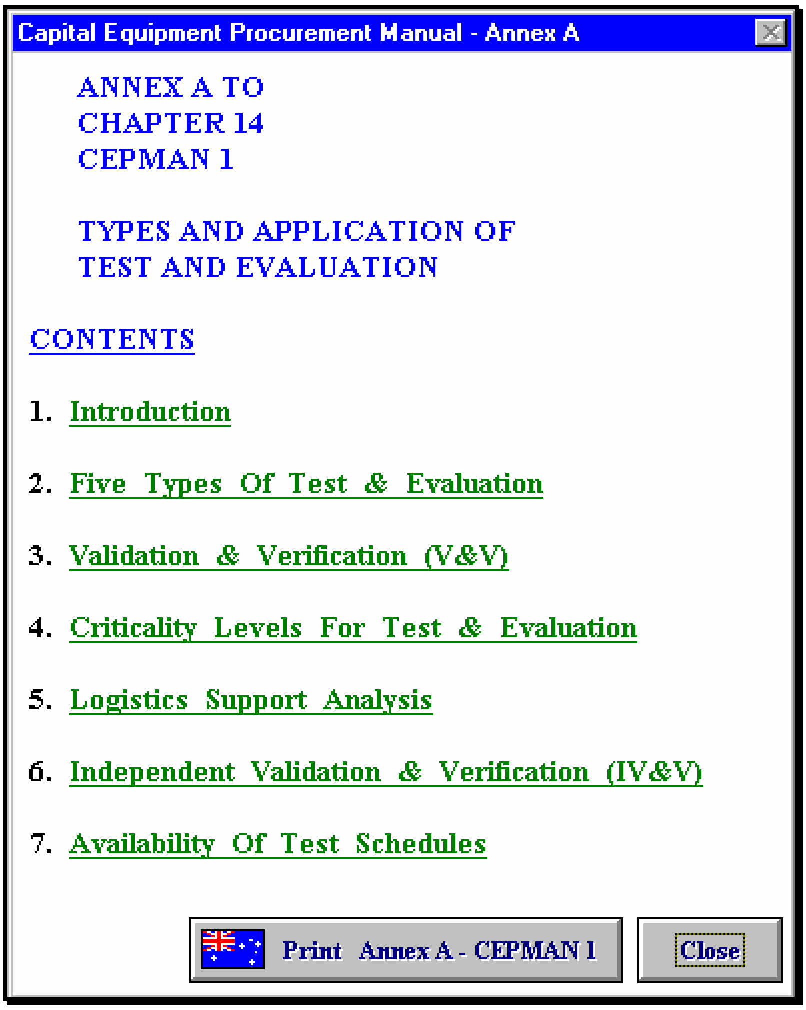


Figure 6-12 (CEPMAN 1 - Annex A Form)

6.4.2 Module II - TEMP Generator

This module is designed to allow the user to enter the necessary data required to fill the TEMP document, and hence in doing so populate the database used to store the data.

6.4.2.1 Features of Module II

This module follows a similar format with that of the of the previous module, so as to stay in "synch" and not confuse the user. That is to say, it is also a hyperlinked operated CSCI. In order to activate this module it is simply a matter of selecting the "TEMP Generator Module" under the File menu of Figure 6-2. This will invoke a similar introductory screen as that shown in Figure 6-3. This form is illustrated in Figure 6-13.

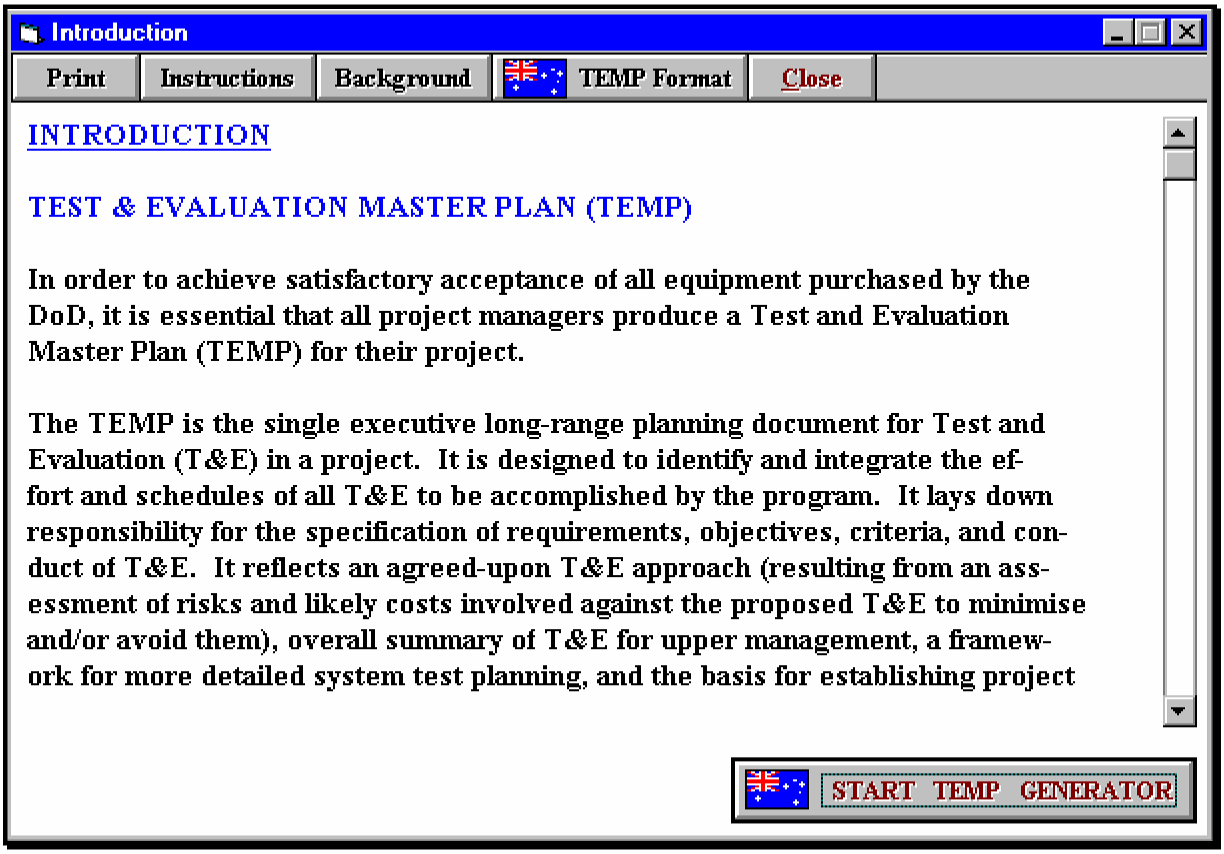


Figure 6-13 (Module II Introductory Form)

For those user's or in particular ARDU personnel who are quite literate on the PAP, they don't have to start with module I, and rather skip to module II, "dive into the deep end" and begin entering data. In the advent of this occurring the author has included the TEMP Format button as is shown in the menu bar, which invokes that information from module I, as is illustrated in Figure 6-11.

By pressing the "Start TEMP Generator" button shown in Figure 6-13, the software launches the form shown in Figure 6-14. This form allows the user to enter all their personal particulars as is shown[14]. Each TEMP created is assigned a default TEMP ID integer. In order to create a new TEMP you simply click on the "Create New TEMP" button, this action increments the TEMP ID Number by one and goes to the next record in the AutoTEMP© database.

[14] This form is also explained in section 11 of Annex I in Appendix VI (Description and Format of the T&E Master Plan)

The author has created some "dummy" TEMP's and populated the database for demonstration purposes. As is evident there are three dummy TEMP's shown, namely HTS, Submarine Mark III, and Falcon Air Fighter - 56, all of which are dummy names. By pressing the "Load Previous TEMPs" button, this will acknowledge all TEMPs previously written in the text box to the right of the Comments text box. By selecting the TEMP that needs to be updated or what have you, simply by clicking on the appropriate one, this will display this form with that record of information, much like a pointer does in a stack.

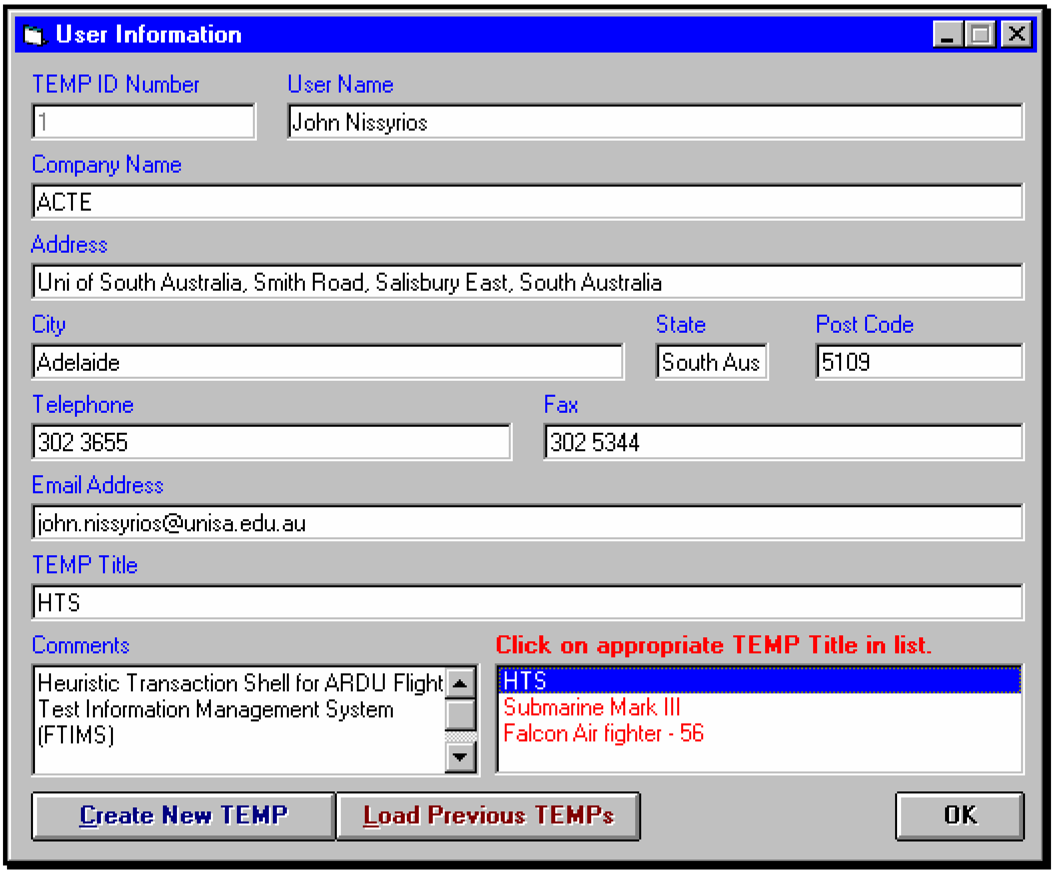


Figure 6-14 (Module II User Information Form)

Once the user has finished filling out this form, pressing the "OK" button will invoke this modules Home Page shown in Figure 6-15. This form is a hypertext Contents page of the TEMP format conceptualised in chapter 5, Figure 5-7 and is summarised in Table 5-1. This form also has the History and Glossary help facilities of module I, as well as the capability of invoking the user information form at any time to see which TEMP is being developed.

It is now a matter of invoking each section one at a time, and filling out each sub-section aspiring to that section of the TEMP.

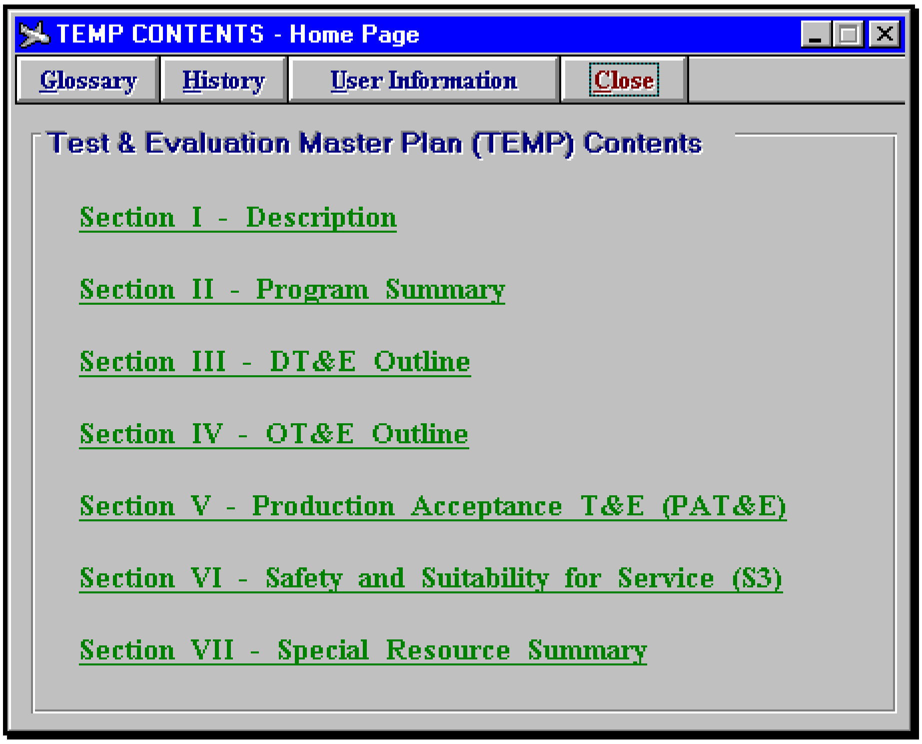
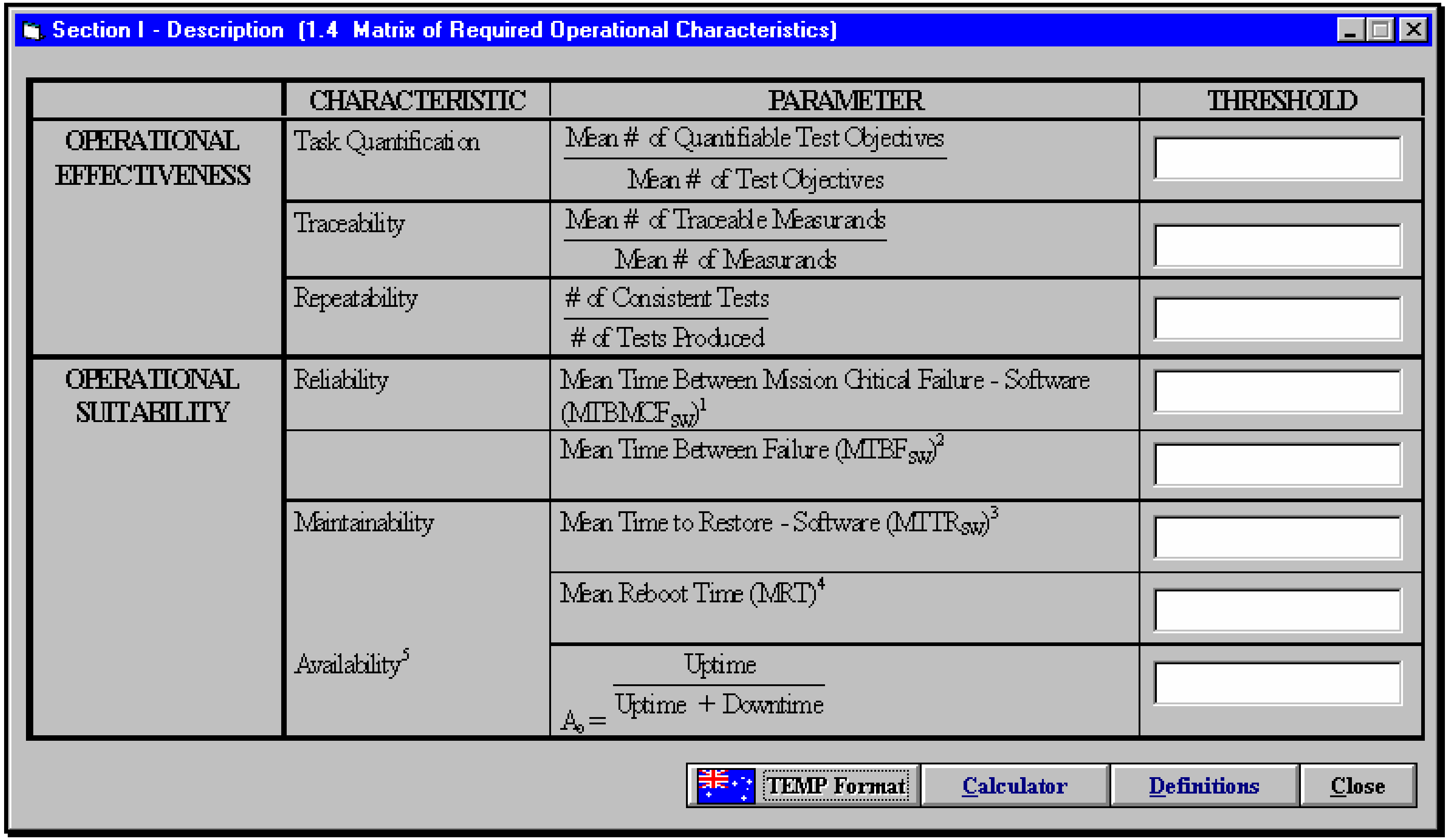


Figure 6-15 (Module II Home Page)

There is no other way to learn about the software and in particular this module without trying it out for oneself, however, for demonstration purposes, certain forms will be briefly analysed pertaining to the progression of Figure 6-15. Section 1.4 is illustrated in Figure 6-16. This form prompts the user to enter the thresholds for the operational effectiveness and suitability characteristics with the help of a calculator and definitions of each characteristic, imposed on the user. You'll notice that, the form also a "TEMP Format" button, this button invokes the Australian CEPMAN 1 TEMP format description at the position of the particular section of the form, in this case section 1.4.

Another form distinguishing sections 1.5 and 1.6 respectively is shown in Figure 6-17. This form allows the user to choose the hardware type of the system, and thus in doing so automatically assigns suitable Required Technical Characteristics for the user. For demonstration purposes the author has conveniently chosen Computers. These characteristics are clearly defined in Table 1-1 of Annex I in Appendix VI.



Section I - Description (1.4 Matrix of Required Operational Characteristics)

	CHARACTERISTIC	PARAMETER	THRESHOLD
OPERATIONAL EFFECTIVENESS	Task Quantification	Mean # of Quantifiable Test Objectives / Mean # of Test Objectives	
	Traceability	Mean # of Traceable Measurands / Mean # of Measurands	
	Repeatability	# of Consistent Tests / # of Tests Produced	
OPERATIONAL SUITABILITY	Reliability	Mean Time Between Mission Critical Failure - Software ($MTBMCF_{SW}$)[1]	
		Mean Time Between Failure ($MTBF_{SW}$)[2]	
	Maintainability	Mean Time to Restore - Software ($MTTR_{SW}$)[3]	
		Mean Reboot Time (MRT)[4]	
	Availability[5]	$A_o = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}}$	

TEMP Format | Calculator | Definitions | Close

Figure 6-16 (Section 1.4 - Matrix of Required Operational Characteristics Form)

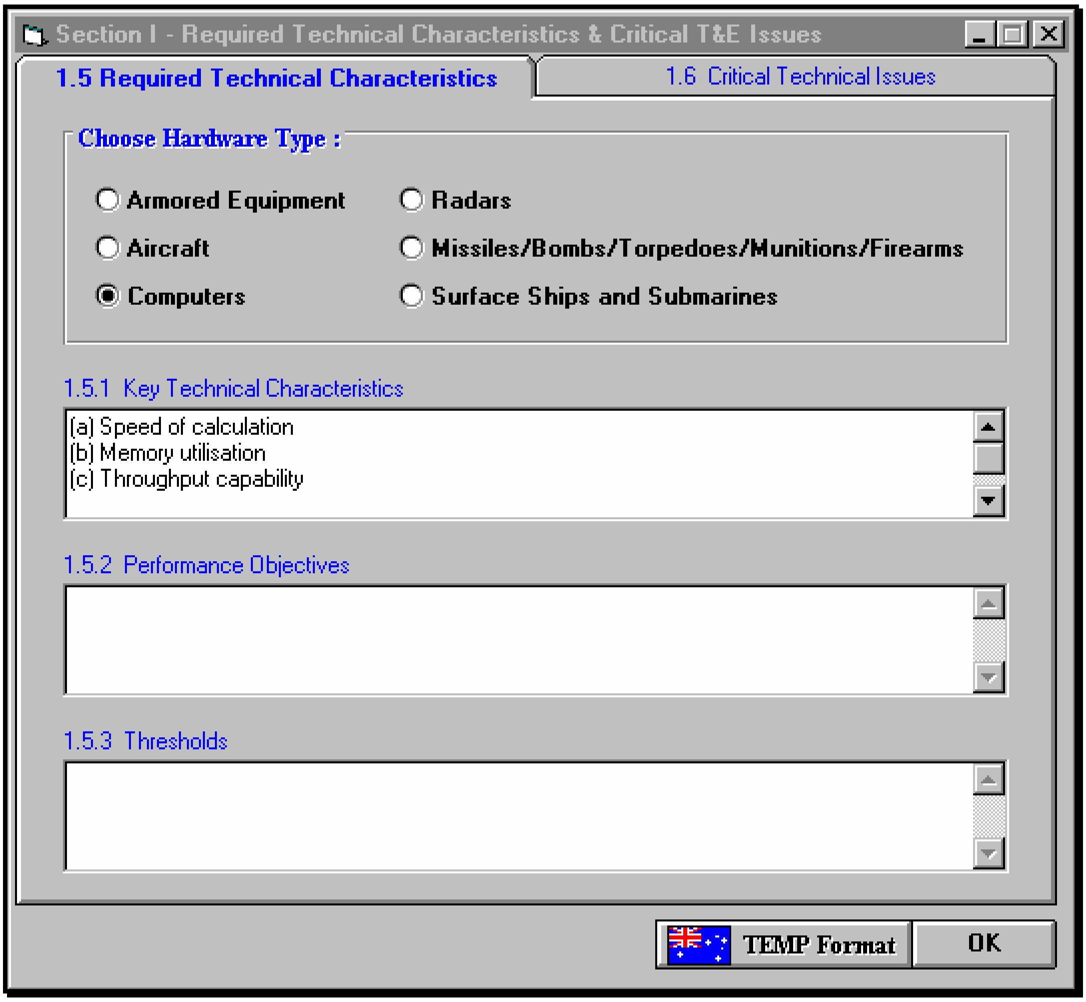


Figure 6-17 (Section 1.5 & 1.6 - Required Technical Characteristics & Critical T&E Issues Form)

As is evident the TabStrip Control is made use of in this form so as to incorporate more than one section on the one form. This 16-bit control box (.OCX) has decreased the amount of design time considerably, especially considering all the sub-sections of a document like a TEMP, it would of have implied a separate form for every sub-section, and meant a very tedious module development stage, and even more so a very difficult task for the user entering the data, having to change, open and close a form each time.

Another typical form for entering data is that of section 3.0, illustrated in Figure 6-18. This form would of had to be broken up into 6 individual forms, had the TabStrip Control not been used. This form shows section 3.2.2 selected for data entry.

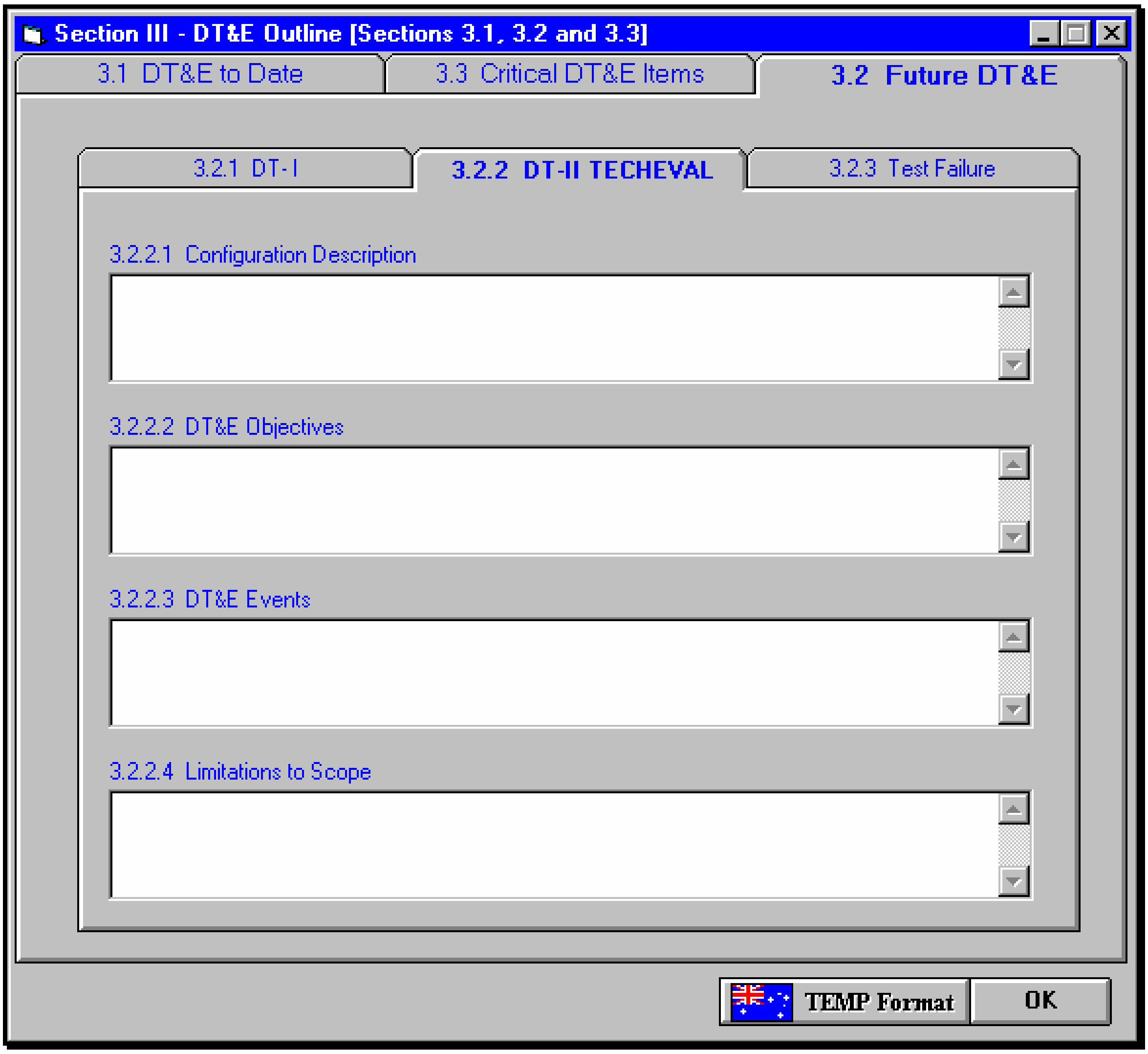


Figure 6-18 (Section 3.0 - DT&E Outline Form)

The final form that is of interest is section 7.2.4, illustrated in Figure 6-19. It details all the test phases and allows the user to enter the date, test site and test system for that phase. The test system column, uses a control known as a DBCombo Box Control. Simply put, the programmer can fill it with predefined text options, and hence the user can choose any one of these options, in this case, a Unix Workstation, IBM PC, or a Macintosh, to fill in that box. However, this type of control cannot learn, i.e., can be updated during run-time, only during design-time. There are other controls that incorporate this facility.

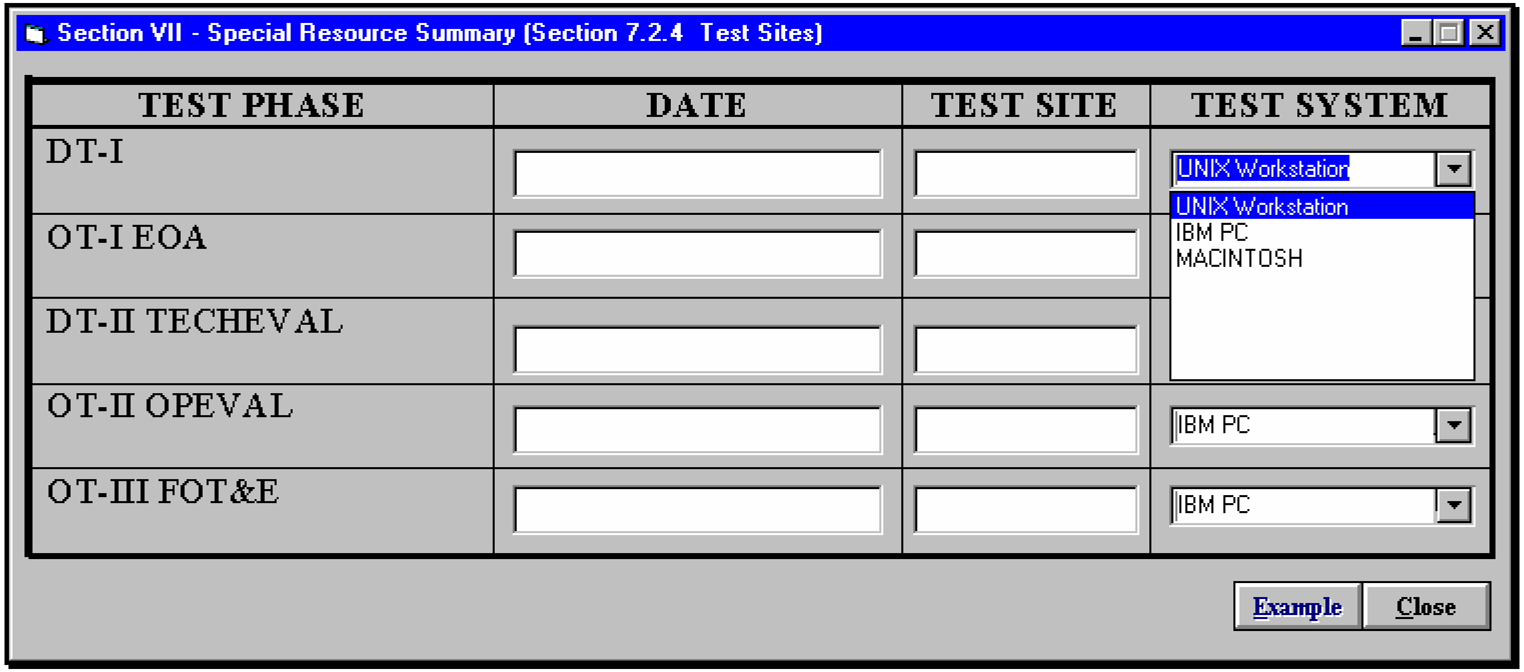


Figure 6-19 (Section 7.2.4 - Test Sites Form)

6.4.2.2 Communication Mechanisms

As is insinuated in Figure 6-1, all the three modules communicate with other applications such as Microsoft® Word 7.0 for the development of the TEMP document via the use of Word macros, and Microsoft Access® 2.0 for the storage and access of data entered by the user needed to fill the TEMP document. The mechanisms used for this communication is Dynamic Data Exchange (DDE), Object Linking and Embedding (OLE) Automation, and Structure Query Language (SQL). These three mechanisms are defined and discussed in the following sections.

6.4.2.2.1 Dynamic Data Exchange

As described by Microsoft Press (1994), DDE is a mechanism supported by Microsoft® applications in Windows that enables two applications to "talk" to each other. DDE automates the manual cutting and pasting of information between applications, providing a faster vehicle for updating information. More specifically, DDE essentially provides three capabilities (based on Microsoft Press (1994):

- You can request information from an application. For example, in a DDE conversation with Microsoft Access®, Word or Visual Basic® macro can request the contents of a record or range of records in a Microsoft Access® database.
- You can send information to an application. In a DDE conversation with Microsoft Access®, a Word or Visual Basic® macro can send text to a record or a range of records in that database.
- You can send commands to an application. For example, in a DDE conversation with Microsoft Access®, a Word or Visual Basic® macro can send a command to open a database from which it wants to request information. Commands sent an application must be in a form the application can recognise.

The Microsoft Press (1994) also states that two applications exchange information by engaging in a DDE *conversation*. In a DDE conversation, the application that initiates and controls the conversation is the *client* and the application that responds is the *server*. The role of the client and server application is best described by Figure 6-20. Each conversation is identified by a separate *channel* number.

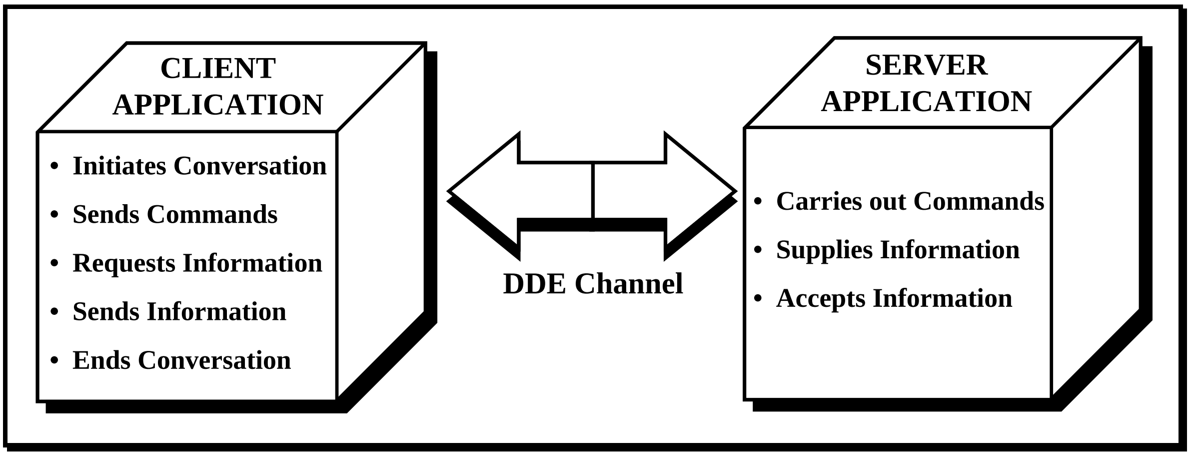


Figure 6-20 (The Roles of the Client and Server Applications in DDE (based on Microsoft Press (1994))

A key requirement for a DDE conversation is that both applications be running. If an application is not running, a client can not initiate a DDE conversation with it. For that reason, a macro that initiates a DDE conversation usually includes instruction's that carry out the following three steps (Microsoft Press, 1994):

1. Determine whether the application you want to talk to is running.
2. Start the application if it is not already running.
3. Initiate the DDE conversation.

6.4.2.2.2 Object Linking and Embedding

OLE Automation is a protocol (Microsoft Press, 1994) to replace DDE. As with DDE, an application can use OLE automation to share data or control another application.

Microsoft Press (1994) also states that in OLE automation, Word provides another application (called the "container" application) with an *object* - a unit of information similar to a topic in DDE. Word supports a single object called "Basic" for OLE automation. You use the "Basic" object to send WordBasic instructions to Word. The technique is similar to sending commands to Word through DDE, the difference being with OLE automation, WordBasic instructions can return numbers or strings directly to the container application.

This makes it possible to use the WordBasic instructions as an extension of the container application's macro or programming language[15].

6.4.2.2.3 Structured Query Language

The Structured Query Language (SQL) as stated by the Microsoft Press (1994) is an industry-standard database language used by the Microsoft Jet database engine. SQL is a database programming language with origins closely connected to the invention of the relational database by E.F. Codd in the early 1970's. Modern SQL has evolved into a widely used standard for relational databases, and is defined by the American National Interchange Standard (ANSI).

The SQL language is composed of commands, clauses, operators, and aggregate functions. These elements are combined into statements used to create, update, and manipulate databases. SQL provides both Data Definition Language (DLL) and Data Manipulation Language (DML) commands. Although there are some areas of overlap, the DDL commands allow you to create and define new databases, fields, and indexes, while the DML commands allow you to build queries to sort, filter, and extract data from the database.

The Microsoft Jet database engine provides two separate methods for accomplishing most database tasks (Microsoft Press, 1994):

- A *navigational* model that is based on moving around directly in the database records.
- A *relational* model that is based on the Structured Query Language.

Thus, the beauty of SQL is that you can implement software routines for the manipulation of the data entered by the user, such as sorting, collecting, filtering, in two or three lines, as opposed to pages of code to carry out the same task. Of the many areas that SQL was made use of, it was particularly used to implement the routines to search and locate the personal particulars record of data that belongs to the TEMP title chosen by the user to modify or create, in the user information form of Figure 6-14.

[15] It is important to note that Word can provide an object to another application for OLE automation, but it cannot use OLE automation to access objects in other applications. In other words, applications that support OLE automation, such as Visual Basic®, which can use OLE automation to access Word, but Word cannot use OLE automation to access them. In DDE terms, Word can act as a server for another application, but it cannot use another application as a server.

6.4.3 Module III - Automating the TEMP Generator (Autotemp.doc)

The task of preparing the final TEMP document named Autotemp.doc in Microsoft® Word 7.0 (herein referred to as Word), involves acquiring the requirements (user input) from AutoTEMP© fields which are inserted into a Microsoft Access® 2.0 (herein referred to as Access) database file called Autotemp.mdb. Hence, automatically generating the Autotemp.doc, the TEMP complying to the CALS conceptualised template of Figure 5-7 (detailed in Appendix VI).

The template however is not in the required Word format so as to allow for the correct DDE to take place between Access and Word. This is due to the fact that Word requires special Field Codes to establish the links between itself and other Windows applications, prior to the "transaction" taking place. This Windows application data requirement acquisition process is illustrated in Figure 6-21.

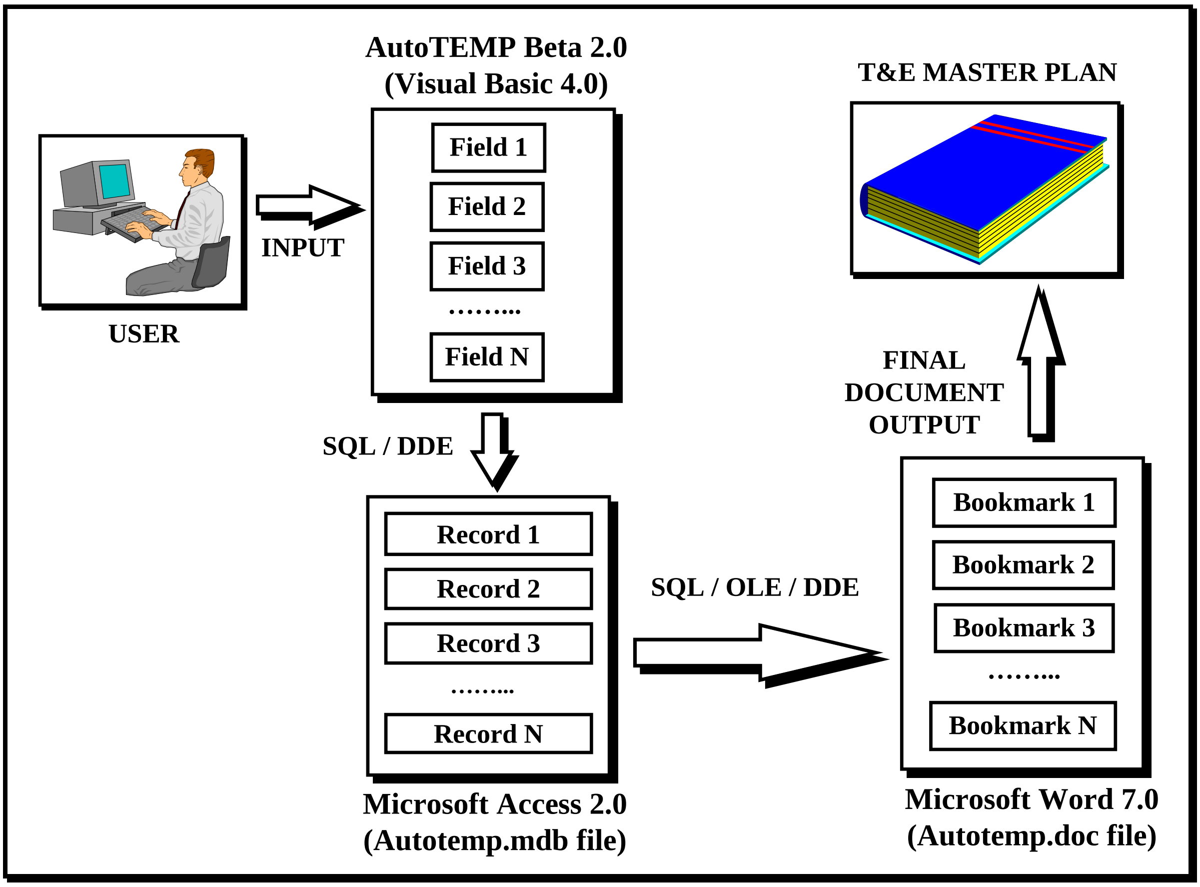


Figure 6-21 (Data Requirement Procurement Process using Windows Applications)

6.4.3.1 Data Requirement Procurement

Figure 6-21 illustrates that the Visual Basic® 4.0 module II communicates with Access via the use of SQL code. It utilises DDE to store data entered by the user into fields 1 through to N as is shown in the diagram, to the accompanying records 1 through to N in the Autotemp.mdb database file. At this stage both VB and Access are active applications. Once the user has successfully completed this task, then by closing all modules and going back to the header form and pressing the "Generate TEMP using Word Macros" option under the file menu in Figure 6-2, after a short question to double check whether or not this option was not inadvertently chosen, AutoTEMP© opens Word and automatically loads the Autotemp.doc document template that has the attached Word macros written in the WordBasic language mentioned previously. At this stage Access becomes minimised along with VB and Word is now the active application. The user is then prompted by the software telling them that the Word menu bar will be modified to accommodate a menu option for the instigation of the Word macros as is illustrated in Figure 6-22. The modification to the menu bar is illustrated in Figure 6-23.

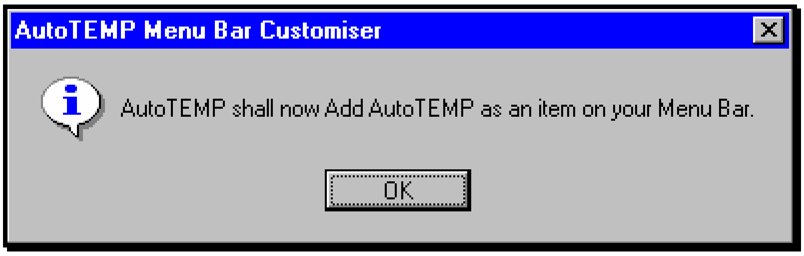


Figure 6-22 (AutoOpen Macro Menu Bar Customizer Dialog Box)

6.4.3.2 Microsoft® WordBasic

WordBasic is a structured programming language as stated by the Microsoft Press (1994) originally modeled on the Microsoft QuickBasic® language. It combines a subset of the instructions available in standard Basic languages with statements and functions based on the Word user interface. You can use WordBasic to modify any Word command or to write your own, which are known as macros. These macros can be assigned to menus, toolbars, and shortcut keys so that they look and function like regular Word commands. Word is actually written by the use of macros, for example the menu bar facilities such as File Open, File Close, File Save, and so forth, are all sub-macros that are executed automatically each time the user invokes them.

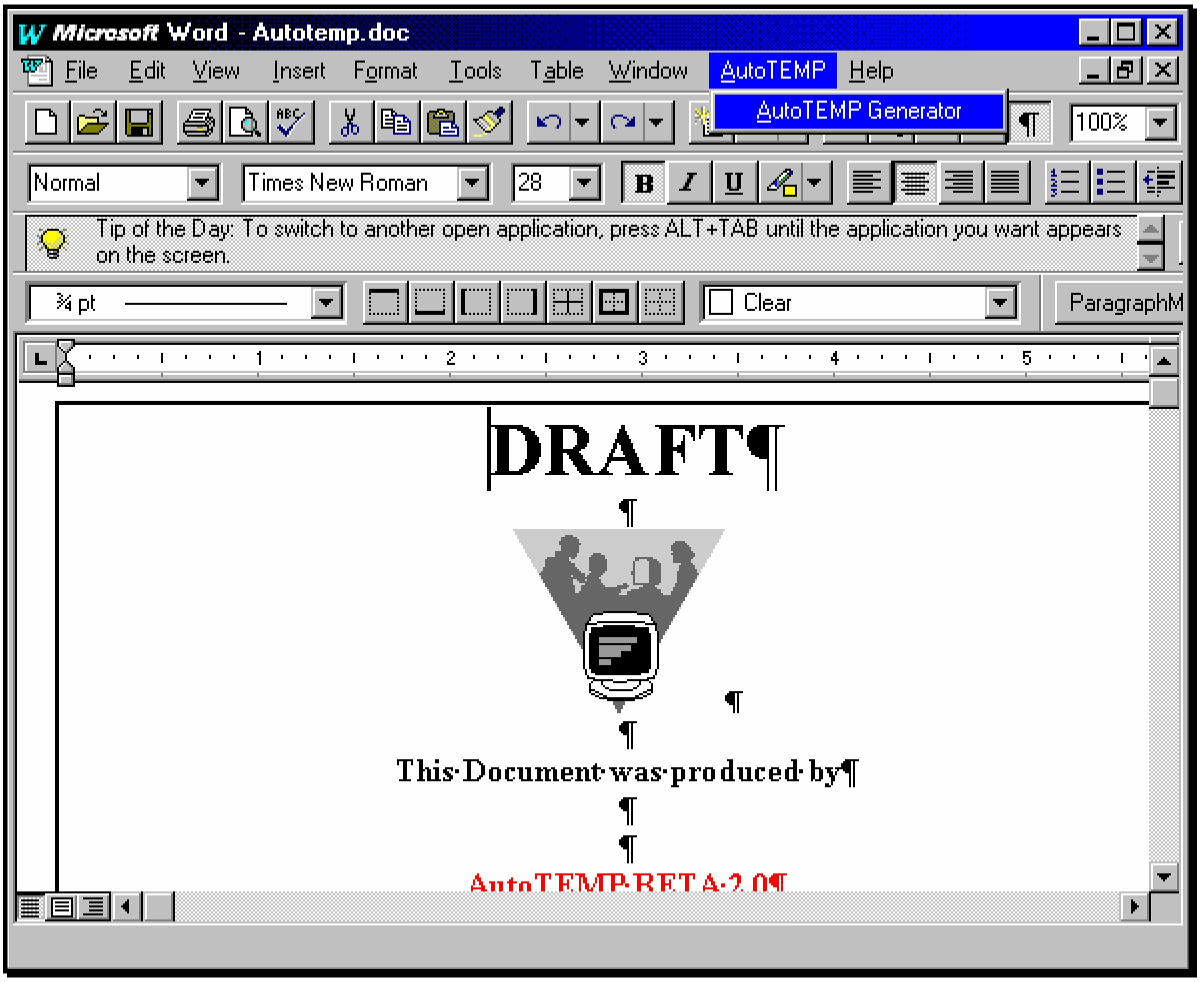


Figure 6-23 (Word Menu Bar Modification)

The only documentation apart from on-line help in Word (which is quite comprehensive), for writing Word macros is the Microsoft® Word Developer's Kit by Microsoft Press (1994), and is essentially considered as an accessory to Word, as opposed for using Word simply as a Word processor. The advantage of WordBasic over other languages and applications that could of have been used to construct the Autotemp.doc TEMP document is that VB also uses a Basic language almost identical in structure and syntax, hence the ease and compatibility whilst programming.

WordBasic allows the user to write and/or record complex macros, and the ability to insert many file types using DDE and OLE automation as described previously, including Access (.MDB) database files.

6.4.3.3 *Word Macro Facility*

A number of macros, approximately 150, have been written by the author, that are attached to this document whenever it is opened. Figure 6-23 shows some of the Autotemp.doc document, by choosing the Macro option under the Tools menu bar, you can access these macros. This action prompts the “Macro dialog box” as is shown in Figure 6-24.

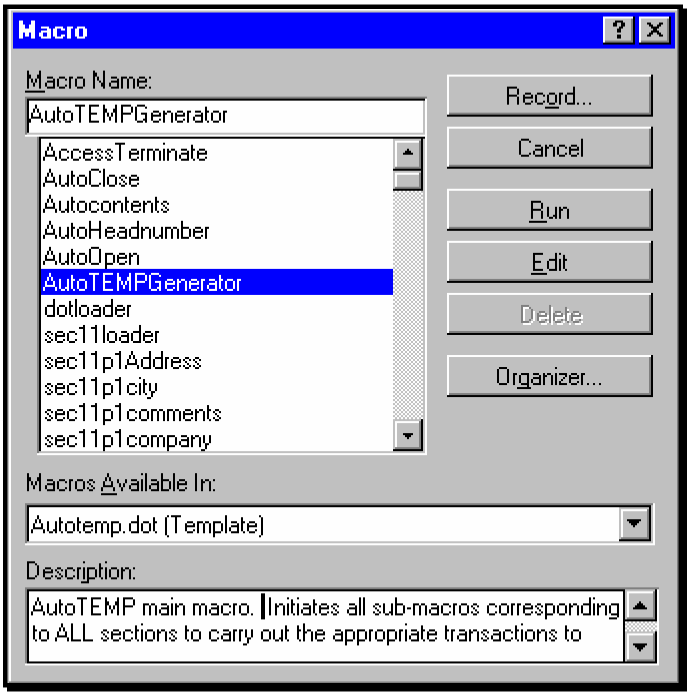


Figure 6-24 (AutoTEMP Macro Dialog Box)

Figure 6-24 illustrates that all of these 150 macros are available in the Autotemp.dot template file, which is a template containing the macros with extension .DOT as opposed to .DOC for normal Word files. The diagram illustrates the selection of the “AutoTEMPGenerator” macro. This macro is the “main program” that initiates all other sub-macros corresponding to all sections of the Autotemp.doc document, of which there are seven, to carry out the appropriate DDE and OLE automation actions between the Access database file, Autotemp.mdb and the Word file Autotemp.doc. A table of all the macros filenames and their descriptions in Autotemp.dot in chronological order, i.e., the order that they are executed, are listed in Figure 1 of Annex I in Appendix IV. Word incorporates macros that run automatically, these are listed along with their description in Table 6-1. AutoTEMP© utilises the “AutoOpen” and “AutoClose” macros. These are the macros that automatically install and un-install the AutoTEMP© menu bar modification, and open and close the Autotemp.doc document, respectively. Hence, by simply attaching them to the Autotemp.doc document template Autotemp.dot, this causes automatic execution each time the Autotemp.doc document is opened and closed.

MACRO NAME	WHEN IT RUNS
AutoExec	When you start Word
AutoNew	Each time you create a new document
AutoOpen	Each time you open an existing document
AutoClose	Each time you close a document
AutoExit	When you quit Word

Table 6-1 (Automatic Executable Macros)

A similar dialog box prompting the user that the menu bar modification will be un-installed is executed automatically when the user closes the Autotemp.doc document, illustrated in Figure 6-25. A complete listing of all the macro routines used to generate the TEMP document Autotemp.doc, is given in Annex II of Appendix IV.

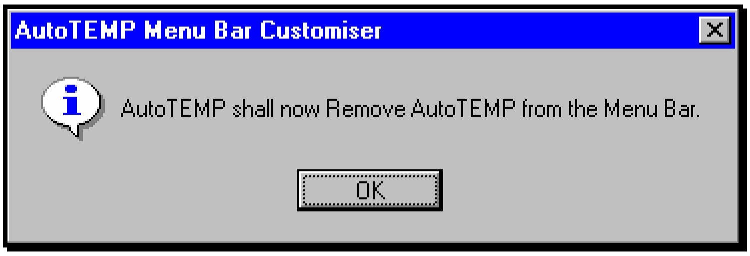


Figure 6-25 (AutoClose Macro Menu Bar Customizer Dialog Box)

6.4.3.4 Acquisition of Requirements via the use of Bookmarks and DDE

The most useful tool Word provides for identifying discrete parts of documents is the use of bookmarks. A simple use for bookmarks is just to mark a selection or location in a document. You can also use bookmarks to select text between two arbitrary locations in a document. Bookmarks are particularly useful for jumping to a specific location in a document, marking an item so that it can be referred to in a cross-reference, or generating a range of pages for an index entry. AutoTEMP© uses the bookmark feature in this module extensively to position the insertion points in the Autotemp.doc document. This allows the macros to locate the particular bookmark, and insert the data from that particular record in the Access database file Autotemp.mdb, as is illustrated in Figure 6-21, at that insertion point. This process is continued until all the requirements, i.e., all the fields in the Autotemp.doc document are filled. A comprehensive description of each bookmark, section number, and field names, along with corresponding macro names is given in Figure 2 of Annex I in Appendix IV. The macro routines are sufficiently commented so as to guide the user through their operation. Appendix II of this dissertation contains the actual Autotemp.doc document that shows the field codes, bookmark placements and more or less "raw" document, ready for extracting and inserting requirements required to fill all of its fields at the specified bookmarks.

Once the user selects the "AutoTEMP Generator" option under the AutoTEMP menu item as is illustrated in Figure 6-23, this action instigates the commencement of the "main program" "AutoTEMPGenerator" macro, to run and begin the DDE between Access and Word, for each section until the document Autotemp.doc is filled. At each section the user will be prompted with a similar dialog box as that in Figure 6-25, instructing them that the next section will commence DDE exchange and OLE automation to fill its sub-sections fields. If there is no data to be entered into particular sections the software is instructed to fill those sections with TBD's, or To Be Determined. This action is demonstrated in Appendix III, which depicts a completed TEMP filled with TBD's, what the author would call a "dry run". This action demonstrates that all the macros operate accordingly, i.e., they do what their programmed to do. Once this action has completed, that is all sections 1 through 7 and all the Appendices have been filled, the software then updates each section with the appropriate heading numbering, and jumps to the table of contents bookmark, and inserts a table of contents. Finally, for the document to be complete as a draft at least, there are two very important sections that need planning charts inserted into, these are firstly section 1.3, which requires a diagram of the system to be inserted into, and secondly section 2.2, which requires an integrated schedule. The integrated schedule lists the following T&E aspects, normally in the form of a graphical planning chart:

- Milestones,
- Test article availability,
- Phases of DT&E, OT&E, PAT&E,
- Initial Operational Capability (IOC),

- Full Operational Capability (FOC),
- Funding, and
- Key reports.

The user is prompted at each of these sections and informed of the above, in the case of section 2.2, the user is also prompted with an example of what the schedule should look like as a guide.

6.4.4 Lessons Learnt from Sample TEMP's (Testing)

This section will briefly discuss certain problems encountered whilst developing AutoTEMP© (DT&E) as well as those discovered during operation (OT&E), focusing on the detection of bugs and the quality of the resulting TEMP document.

6.4.4.1 Developmental and Operational Related Software Bugs

A number of software bugs were detected within all three modules whilst developing the CSCI AutoTEMP©. The majority of these bugs were obvious and simple to detect and hence fixed at the time of detection. This was possible because Visual Basic® 4.0 allows two modes of operation, namely, design mode and run mode. In run mode you have access to what is known as a debug window. This feature was widely used as a means of debugging the AutoTEMP© CSCI, and is described in the following section.

The bugs that were more difficult to detect were those in module III, i.e., infested within the macros written in the Word document, Autotemp.doc. These bugs were primarily due to such things as incorrect naming of bookmarks, and field name incompatibilities within the Access database file, Autotemp.mdb. The only mechanisms for detecting those bugs were by trial and error techniques, redesign, fix, test, and so forth, i.e., via thorough T&E.

Module I had some bugs and traps with the printing routines designed to print the forms or their textual contents, especially with line feed and carriage returns, when upgrading from Windows® 3.11 to Windows® 95. Some alterations had to be made to the font types and sizes, as well as to the page alignment, in order to get it right, however these were "ironed-out" in the end, and the CSCI now operates correctly.

Module II was a very tedious module to finally complete because of the vast number of sections in the TEMP document. During its development there were certain bugs occurring due to the volume of this module with respect to, for example, the user information form. The SQL code used in this form would not access the appropriate record aspiring to the current TEMP that the user had supposedly chosen, as well as assigning the incorrect TEMP ID number. Being new to the SQL programming language, this took longer than the author originally intended to debug, but through the use of the debug window, described in the proceeding section, this was eventually solved, by tracking the operation of the code, line by line.

Module III is now quite "bug-free" and Word no longer detects any operational errors, syntax errors, and so forth, and as previously mentioned all the information captured in the Access database, Autotemp.mdb, is correctly placed into the appropriate insertion points in the Word document, Autotemp.doc, as required.

6.4.4.1.1 Debug Window in Visual Basic®

The Debug window automatically opens at *run time* (the time when code is running). In *break mode*[16] you can use the Debug window to execute individual lines of code, view or change values of *variables* (a named storage location that can contain data that can be modified during program execution) and properties, and view *watch expressions* (a user defined expression that allows you to observe the behavior of a variable or expression). At run time, you can use it to display data or messages as the program runs. At *design time*, the time at which you build an application in the building environment by adding controls, setting control or form properties, and so on, you can view previous output to the Debug window, but you can not execute code.

6.4.4.2 User Related Problems

As stated previously, AutoTEMP© provides the user with a direct link to the TEMP format specified by the CAL compliant CEPMAN 1 instruction (Australian DoD, 1995), with the click of a button, on each form at the appropriate section, as well as a walk through tutorial on the United States Phased Acquisition Process, module I, not to mention a history and glossary form, again easily accessed by the press of a button. This enabled the user's to be directed to their particular form, backtrack, or acronym/abbreviation that they desired, as well as a reference to the most asked question, "well what should I write in this section ?". Most user's

[16] Temporary suspension of program execution while in the development environment. In break mode you can examine, debug, reset, step, or continue program execution.

simply wanted to explore for themselves, by simply clicking this button or that button, printing a form, looking up an acronym, using each module in turn and in reverse.

This is all very well when there is only one TEMP document to worry about. However, the biggest user related problem was when the user had created more than one TEMP, using the user information form, Figure 6-14, say three or four, and attempted to navigate through each TEMP, and attempting to build one or more TEMP documents. This was due to the simple fact that they would literally get lost, and simply would not know which TEMP their currently working on and which TEMP record would be used to build the TEMP document, the first ?, the second ?, and so forth. This problem was anticipated by the author, and still requires some thinking. From such lessons learnt through all these sample tests, and OT&E, it was clear that the software needed some work in this area, and would have to be looked at within the next version of AutoTEMP©.

It should be noted at this stage, that the software written, namely, AutoTEMP© Beta 2.0, is intended solely for the demonstration of concepts, that is, the ability to conceptualise and automatically generate a TEMP from a functional requirement specification, and not as a commercial piece of software. Perhaps a later version, with some appropriate funding or sponsorship from a defence related agency, would incorporate protuberant commercially viable modifications and additions.

6.4.4.3 Quality of the Final TEMP Document

The quality of the final TEMP document produced by AutoTEMP©, ideally can only be as good as the conceptualisation of the TEMP model or template allows it to be. Merz (1995) states as per The Prince, Machiavelli:

> *"It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who would gain by the new one."*

One can only say that the effectiveness of this software in increasing the efficiency, and decreasing the time and cost in generating a TEMP has by far been accomplished, however, the fruits of the author's labor has still yet to be seen, in the eyes of the lukewarm defenders who will gain even greater quality by the next version. It must be remembered that, this work can only be appropriately compared to that of the work of Roth (1994), with his Automated Test Planning System (ATPS) software, that is reviewed and analysed in chapter 5. In a nut shell Roth's ATPS software does not produce a formatted draft TEMP, but simply a skeleton in the form of a text document with answers entered by the user to a number of questions, that would aid in the development of a TEMP. However, on the same token it incorporates a Test and Evaluation Program Risk Assessment module that looks at the possibility of risk involved, in the T&E process, that AutoTEMP© does not. One can argue that this was not part of the original objectives of the software.

CHAPTER 7

7. Conclusions and Future Proposals

7.1 Conclusions

This thesis described the author's research contribution and findings on the collaborative project, involving both the ACTE and the ARDU of the RAAF, which was to conduct research which would "assist in the design of telemetry data formats and contribute to assuring end-to-end data traceability of test programs" as stated by ARDU (1993). Among the four primary areas of interest mentioned in chapter 1, was the primary focus of the author's research, an attempt to conceptualise and thus automate via the assistance of a computer, the manual generation of Test & Evaluation Master Plans, for the real-time test & evaluation of complex systems, such as the highly instrumented fighter aircraft F/A-18 Hornet of the RAAF, from the functional requirements specification of any defence acquisition test program. The TEMP document produced by the by-product of this research, namely, a non-commercial piece of software known as AutoTEMP© Beta 2.0, was designed to comply with the Australian Defence Force Capital Equipment Procurement Manual, often referred to as the CEPMAN 1, instruction.

Chapter 2 gave a comprehensive overview of the genesis of test & evaluation, and hypothesised that T&E is essentially a process and synonymous to the systems engineering process, not to mention merely a natural progression of the traditional scientific method, and is the phrase implies, a two part process. The test which involves the planning and execution of an experiment in an effort to collect data, whilst evaluation is the assessment of this data, against a known standard, in an approach to obtain some knowledge regarding the quality of the subject under test.

Chapter 3 outlined a genealogy of the discipline of this research, namely, aircraft flight test. It was determined that the T&E practitioners were taking more measurements and raw data than they could simply cope with, and as a consequence increased the cost of testing not to mention manpower and equipment required to carry out these tests, hence it was imperative to keep tests simple, small, economical and manageable, i.e., comply to the philosophy of parsimony. In order to assist in the design of telemetry data formats, a brief outline to telemetry formats used in flight testing was also discussed.

Chapter 4 analysed and compared the United States of America and Australian T&E structures and processes that these countries follow. The reason for only looking at the United States Department of Defence and not other countries, was solely because it is the best documented T&E system in the world, and because of this fact, many non-US based countries have the tendency of adopting its basic principles, terminology, and structure.

Chapter 5 gave a concise description on the research methodology utilised in the attempt to conceptualise and automate the Australian T&E process. It was concluded that the last few years, in particular since the birth of the Australian Centre for Test & Evaluation, that the Australian Department of Defence and respective T&E community realised the importance of the entirety of this process, and the immense importance to adhere to a Test & Evaluation Master Plan. It was further determined that only by regular updates of the TEMP, i.e., from the genesis to the actual demise of the particular product/system, would it prove to be the most vital part of any defence acquisition test program, considering it outlines strict critical issues, measures, and thresholds that all such test programs must follow.

Chapter 6, the penultimate chapter in this dissertation gave a concise description of the by-product of this research, namely, AutoTEMP© Beta 2.0, outlining descriptions of all three modules, i.e., the US defence phased acquisition process tutorial, the TEMP generation module, and the automatic generation of the TEMP document, Autotemp.doc, along with a summary of the lessons learnt from sample tests, and the final quality of the TEMP document as compared to other attempts in the past.

AutoTEMP© is the result of a two and a half year research program at the Australian Centre for Test & Evaluation of the University of South Australia. This research has accomplished its objectives in conceptualising and automating the manual generation of TEMP's for any defence acquisition test program.

In conclusion, this research has contributed to the T&E process in the way of immediate benefit to ARDU, and a spin off value to other Australian agencies faced with test and evaluation problems on a similar scale. In particular, those agencies involved with aircraft, ships, submarines, large modeling and simulation tasks, command, control, and communication (C^3I) systems, air traffic control systems, and space related activities. More specifically, this research has contributed to the perfection of the T&E process via views of T&E in the future, which are prospects of a paperless test and evaluation process.

7.2 Further Research

AutoTEMP© Beta 2.0 breaks new ground in the preparation of TEMPs for DATPs. There are, inevitably, an ensemble of areas which can be developed to a higher calibre. AutoTEMP© Beta 2.0 is now well advanced, and has been moulded to a stage where it can be commercialised for use in the many defence sectors around the world, those of which are mentioned in Chapter 1. Possible avenues are the prospects of using AutoTEMP© on the Internet. A very brief overview of the Internet is given in the section.

7.2.1 Access and Use of AutoTemp© Beta 2.0 on the Internet

7.2.1.1 Introduction to the Internet

As it stands today the most prominent need would be to make this information accessible to the rest of the world, much like on the Information Superhighway, more commonly known as the *Internet*. There is ample information on the Internet to learn from, and probably more then one would need, and be somewhat overwhelmed with knowledge, from what is the Internet, to creating your own home pages using the Internet's own language known as Hypertext Text Mark-Up Language or HTML.

In order to make this information accessible to the rest of the world, entails invoking the software onto a World Wide Web server such as the one created by the Centre for University Teaching and Learning or CUTL at the University of South Australia. The World Wide Web, or WWW, is the newest information service to arrive on the Internet. The Web is based on a technology called *hypertext*, defined in chapter 6. To try the Web, all you need to do is telnet to it. This will automatically drop you into a public-access client program or *browser*, to use the Web's technology. There are several browsers available on the market today, most of which can be directly downloaded from the Internet itself. The most advanced browser available is called Netscape. It works on UNIX under the X Windows system (where its called xnetscape), the Macintosh, and Microsoft® Windows (Krol, 1992).

The ACTE has created it's own WWW server with information pertaining to the centre, it's structure, people, and so forth. The address of which can be invoked using a protocol more commonly known as Hyper Text Transfer Protocol or HTTP address, namely, ***http://www.acte.unisa.edu.au***.

In this fashion we create an electronically accessible Automated TEMP generator. As well as having the Knowledge Based Software System resident on the Internet the author envisages that one could also add to this "Knowledge Base" via access to the following information :

- A Test & Evaluation Bibliography Database.
- Digitised pictures/diagrams (aircraft in flight, flow diagrams, etc.,)
- A database of T&E definitions.
- National and Global access to information and or other databases (such as *TECNET)*

7.2.2 Extensions to the TEMP Format & Hardware Domain

Another possible suggestion is to extend the Knowledge Base, and have AutoTEMP© Beta 2.0, automatically generate TEMPs according to other TEMP formats, for instance, the US DoD 5000.3-M-1 instruction, or other unique TEMP formats, hence allowing the user to have the ability to choose the format that the TEMP must follow, and not fixed to that of the ADF CEPMAN 1 instruction. Needless to say, the software has the ability to grow and be modified with ease. The improvements are limited only by the programmers imagination, or specifications for that matter, but more likely by the application domain it is used in.

Extending the hardware domain to other platforms such as Unix and Macintosh is also another possible and legitimate extension to the software, more so Unix, as this would allow large Main Frame Computers that are based on this technology to access the information more readily.

7.2.3 PhD Research Extension

This research was intended to lead to a Masters Degree, however it is envisaged that there is great potential based on the complexity and size of the associated area of interest, that there could be prospects of the program being extended to a Doctoral level. The need for carrying out this research is, currently in the DoD and subsequent defence departments there is more rigorous testing and evaluation, and thus V&V of these tests. However these processes are not well documented, far from universal, and usually carried out by a highly trained person that has experience in fields such as DT&E and OT&E. A generic *T&E Process Document Traceability and Cognition Software System* would be great importance to the global defence sector as a support tool in which mature methodology could be embedded (Nissyrios, 1995c).

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