8-2004

A Model for the Application of Test and Evaluation Concepts by the Air Element of the Canadian Forces During the Materiel Acquisition and Support Lifecycle

Troy M. Crosby
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Troy M. Crosby entitled "A Model for the Application of Test and Evaluation Concepts by the Air Element of the Canadian Forces During the Materiel Acquisition and Support Lifecycle." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Dr. U.P. Solies, Major Professor

We have read this thesis and recommend its acceptance:

Dr. Ralph Kimberlin, Mr. Richard Ranaudo

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A MODEL FOR THE APPLICATION OF TEST AND EVALUATION CONCEPTS BY THE AIR ELEMENT OF THE CANADIAN FORCES DURING THE MATERIEL ACQUISITION AND SUPPORT LIFECYCLE

A Thesis
Presented for the
Master of Science
Degree

The University of Tennessee, Knoxville

Troy M. Crosby
August 2004

DEDICATION

This thesis is dedicated to my family: without your patience, sacrifice and encouragement I would not have seen this through.

ACKNOWLEDGEMENT

I wish to thank the Canadian Forces for providing me with the education, training and experience that underpin this work.

During my time at the Aerospace Engineering Test Establishment I had the good fortune to work with, and be influenced by, a great number of exceptionally dedicated and talented individuals. I would, however, like to take this opportunity to single-out a few key test and evaluation professionals who, through many hours of thought-provoking debate and insightful discussion, provided the groundwork for the concepts presented in this paper: Major W. (Billy) Allan, Major Andrew Fleming, Major James Tutte and Mr. Larry Dublenko. In particular, I would like to acknowledge Major Allan's concept for a circular model illustrating the continuous link between flight test and evaluation and the materiel acquisition and support lifecycle.

ABSTRACT

Recent experience has proven that the Test and Evaluation (T&E) terms and responsibilities described in Department of National Defence and Canadian Forces policies and orders – particularly those related to the Category flight test system – are poorly understood and frequently in conflict with contemporary approaches to Materiel Acquisition & Support. As a result, financial and airworthiness authorities may not be recognizing the benefits inherent to the timely application of T&E by the Air element of the Canadian Forces during the Materiel Acquisition & Support lifecycle. At the same time, the on-going inconsistent application of T&E is resulting in frustration between T&E agents and project managers, in the inefficient use of resources, and in delays in achieving project objectives.

This paper proposes a rationalized model for Air T&E as it relates to the Materiel Acquisition & Support lifecycle. The model has been developed by linking legal requirements and the Department of National Defence accountability framework with T&E concepts that are consistent with current airworthiness and financial management policies, and with Materiel Acquisition & Support milestones.

Implementation of these Air T&E concepts will provide clarity and consistency to Materiel Acquisition & Support processes leading to needed operational capability being fielded as quickly and cost effectively as possible; project management staff and Air T&E agents will benefit from a common basis from which to plan T&E activities. Additionally, clarification of the associated roles and responsibilities will focus available resources where they are needed, and when they will have the most consequence.

PREFACE

The objective of this document is to provide a common basis from which Canadian Forces and Department of National Defence personnel can best integrate test and evaluation in acquisition and support processes for materiel destined for the Air element of the Canadian Forces. The ultimate objective of a rationalized Air test and evaluation framework is to ensure that the Canadian public and Canadian Forces operational personnel are well served through effective, efficient acquisition programs and materiel management practices.

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LIST OF ACRONYMS

CF	Canadian Forces
CAS	Chief of the Air Staff
CDS	Chief of the Defence Staff
COTS	Commercial Off-the-Shelf
DMASP	Director Materiel Acquisition and Support Programme
DMS	Defence Management System
DND	Department of National Defence
DAOD	Defence Administrative Orders and Directives
DT&E	Developmental Test and Evaluation
ET&E	Engineering Test and Evaluation
FOT&E	Follow-on Operational Test & Evaluation
IOA	Initial Operational Assessment
IOT&E	Initial Operational Test & Evaluation
MA&S	Materiel Acquisition and Support
MOTS	Military Off-the-Shelf
MTF	Maintenance Test Flight
NDHQ	National Defence Headquarters
OAA	Operational Airworthiness Authority
OT&E	Operational Test and Evaluation
R&D	Research & Development
SEMP	Systems Effectiveness Monitoring Program
SOF	Safety of Flight
SOR	Statement of Operational Requirement
TAA	Technical Airworthiness Authority
T&E	Test and Evaluation

1.0 INTRODUCTION

This paper begins with a summary of relevant legal requirements that direct individuals in the conduct of their decision-making authorities and responsibilities. It is the requirement for factual information that normally necessitates the conduct of flight test and evaluation.

The paper then goes on to propose expanded definitions of Developmental and Engineering Test and Evaluation (T&E) for use by the Air element of the Canadian Forces. While these definitions are based on concepts that are in common use in the wider flight test community, they have been adapted and clarified for Canadian Forces use based on extensive discussions with flight test and project management professionals. The paper then refines existing definitions of Operational T&E, again from the perspective of the Air element of the Canadian Forces. Together these definitions provide a clear, common understanding of Air T&E objectives, essential to minimizing risk during materiel acquisition and support through the timely and appropriate commitment of Air T&E resources.

Based on the framework of these definitions the paper proposes a model for the application of Air T&E during the Materiel Acquisition & Support lifecycle.

2.0 BASIS FOR AIR T&E

The need for Test & Evaluation activities within, or on behalf of, the Department of National Defence (DND) and Canadian Forces (CF) is fundamentally driven by legal requirements. These legal requirements have the broad objective of defining individual accountabilities for the governance of public property and for the expenditure of public funds in pursuit of national objectives.

Three Acts of parliament are particularly relevant to a discussion of test and evaluation within the context of the Air element of the Canadian Forces:

- the National Defence Act assigns accountability for ensuring the operational capability of the Canadian Forces
- the Aeronautics Act assigns accountability for matters related to the airworthiness of military aircraft and systems
- the Financial Administration Act assigns accountability for the prudent expenditure of public funds

The sponsorship of Air T&E activities is directly related to the responsibilities, authorities and accountabilities for decision making that have been established in these statutes of law. The fundamental aim of the conduct of Air T&E within the Materiel Acquisition & Support lifecycle is, therefore: to provide the factual information required by decision makers to establish operational capability and to preserve public resources.

2.1 NATIONAL DEFENCE ACT

"The Minister of National Defence carries legal responsibility and is accountable to Parliament for the administration of the National Defence Act…."[1] The principal

[1] "The Minister"

advisors to the Minister in the exercise of this responsibility are the Deputy Minister and the Chief of the Defence Staff (CDS).

The Deputy Minister is appointed under the National Defence Act and has responsibility for Department of National Defence resources. The Assistant Deputy Minister (Materiel) is primarily responsible to the Deputy Minister for ensuring effective materiel acquisition and logistics support to the Canadian Forces and the Department of National Defence.

The Chief of the Defence Staff advises the Minister on military requirements and capabilities and is accountable to the Minister for the readiness of the Canadian Forces. Within the Air element of the Canadian Forces the Chief of the Air Staff (CAS) plays a vital role in generating and supporting the forces assigned to force commanders and in providing the Chief of the Defence Staff with strategic advice on technical and operational matters.[2] The Chief of the Air Staff fulfills this role in part through the identification of operational deficiencies and requirements by the Director of Air Requirements and 1 Canadian Air Division staffs: "In principle, [a Statement of Operational Requirement (SOR)] is a pure statement of the characteristics that must be delivered in the operational system in order for it to satisfy fully [a] validated capability deficiency."[3]

2.2 AERONAUTICS ACT

The scope of the Aeronautics Act extends to all 'aeronautical products', which means, "…any aircraft, aircraft engine, aircraft propeller or aircraft appliance or part or the component parts of any of those things, including any computer system and

[2] "The Minister"
[3] DMS Manual

software."[4] The Aeronautics Act identifies the Minister of National Defence or, under the direction of the Minister, the Chief of the Defence Staff as being responsible for 'any matter relating to defence, including any matter relating to military personnel or a military aircraft, military aerodrome or military facility of Canada or a foreign state'. Specifically, the Minister is responsible for the development and regulation of military aeronautics and supervision of all matters connected with military aeronautics, including the control and management of all military aircraft and equipment.

The Aeronautics Act is then interpreted and implemented by Department of National Defence through Defence Administrative Orders and Directives (DAOD) 2015-0 (Draft), "Airworthiness Policy". DAOD 2015-0 (Draft) defines the responsibilities and authorities of the Airworthiness Authority, the Technical Airworthiness Authority (TAA), the Operational Airworthiness Authority (OAA) and the Airworthiness Investigative Authority. In particular, the Technical Airworthiness Authority is responsible for regulating engineering, manufacturing, maintenance and materiel support of aeronautical products, and the Operational Airworthiness Authority is responsible for regulating flying operations, including operational procedures, and operator training and qualifications.

2.3 FINANCIAL ADMINISTRATION ACT

> "It is government policy to conduct contracting in a manner that will ensure operational requirements are met; stand the test of public scrutiny for prudence [careful and responsible management of public resources] and probity [acting as one ought]…."[5, 6],

[4] "Aeronautics Act"
[5] DND Resource Manager's Guide, pg 63.
[6] Definitions of prudence and probity from: DND Resource Manager's Guide, pg 58.

The Financial Administration Act provides legal authority to initiate expenditures, to enter into contracts on behalf of the Minister, and to confirm contract performance and price. Authority to confirm contract performance and price is the authority delegated by the Minister under the Financial Administration Act to, "…certify that goods have been received, work or services rendered and that the payment made is according to the arrangements of the contract or is reasonable."[7]

The delegation of financial authority is detailed in Defence Administrative Orders and Directives 1004-0 (Draft), "The Delegation of Authority for Financial Administration in the Department of National Defence and the Canadian Forces". Where appropriate financial authority is assigned to a Project Manager through a Project Charter: "A Project Charter establishes the mandate for project organization and provides guidance to the project team in the form of assigned responsibilities, broad project objectives, and constraints."[8] The Project Manager is thus charged with determining if performance and design characteristics extracted from the related Statement of Operational Requirement have been met.

2.4 MATERIEL ACQUISITION & SUPPORT

> "The objective of good resource management is to achieve an organization's objectives effectively and efficiently using the resources provided to it."[9]

The Canadian Defence Management System (DMS) provides Department of National Defence and Canadian Forces project and weapons system management staffs with a framework on which all Materiel Acquisition & Support activities are based,

[7] DND Resource Manager's Guide, pg 65.
[8] DMS Manual
[9] DND Resource Manager's Guide, pg 8.

ensuring that legal requirements are met and that best practices are followed. Acquisition and weapons system management staff are thus able to provide consistent, efficient and effective project management.

The Materiel Acquisition & Support (MA&S) framework details the inter-relationships between various project management activities and defines milestones within the Materiel Acquisition & Support lifecycle. The Materiel Acquisition & Support lifecycle, broadly defined, begins with acquisition and extends to the final disposal of the materiel component of a defence capability. MA&S includes in-service support activities, but does not include the initial identification of a requirement.

Defence Administrative Orders and Directives 3000-0, “Materiel Acquisition and Support” states that, “The DND and the CF shall carry out all MA&S activities in a manner that: ensures the pre-eminence of Canadian Forces operational requirements; obtains the best possible value; ….” DAOD 3000-0 further identifies a requirement for Department of National Defence and the Canadian Forces to, “use test and evaluation methodologies e.g. operations research methods, simulation and physical testing”.

3.0 FUNDAMENTALS OF AIR T&E

Air T&E involves two major areas of activity:

- Information gathering. Information gathering includes:
    - the application of specialized flight and related ground test methods (i.e. planning and reporting processes, and test techniques), and
    - the instrumentation of aircraft for other than routine operational data gathering or monitoring purposes; and
- Making Findings. While most flight test reports include recommendations based on data gathered during flight test activities, the ultimate objective of flight testing is to provide a project sponsor with factual information required for decision making. These findings are based on the evaluation of test information, specifically:
    - reduction and analysis of quantitative data, and/or
    - interpretation of qualitative results.

Defence Administrative Orders and Directives 3011-0 (Draft), "Test and Evaluation" provides the following Department of National Defence recognized definitions related to these activities:

- Test: means the critical examination of test items to obtain data, quantitative and qualitative, relevant to developing new capabilities, managing the process, or making decisions on the allocation of resources; and
- Evaluation: the review and analysis of quantitative or qualitative data obtained from design review, hardware inspection, modeling and simulation, and testing or operational usage of equipment.

Test and evaluation activities result in data and, typically, recommendations used by those in positions of decision making authority. While exhaustive information

gathering during Air T&E would be prohibitively expensive and time consuming, the judicious application of resources to Air T&E activities at appropriate points in the Materiel Acquisition & Support lifecycle is a fundamental aspect of risk management. In the words of the Australian Auditor General:

> "The fundamental purpose of T&E, whether at concept, design, acquisition or in-service phase of an equipment's life cycle, is to reduce the risk that equipment will not satisfy user expectations regarding cost, quality, delivery time (schedule), mission success, system vulnerability and personnel safety."[10]

Alternatives to flight testing include design analysis or comparison to existing designs, bench and ground testing, simulation and inspection; however, flight testing has the unique advantage of engendering confidence in data and recommendations that result from a fully integrated system being tested in its intended operating environment.

3.1 TYPES OF AIR T&E

As summarized in Figure 3-1, there are three general types of T&E: Developmental, Engineering and Operational.[11]

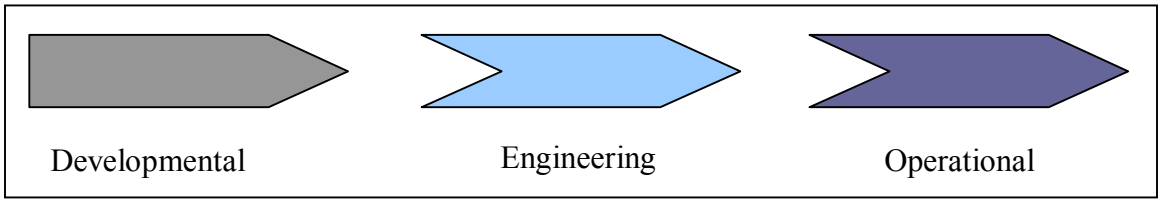

Figure 3-1. Generalized T&E

[10] Australian National Audit Office, para 2.
[11] DAOD 3011-0 (Draft) provides definitions of Developmental, Engineering and Operational T&E that are applicable to all elements of the CF, and that differ from the ones developed in this paper.

3.1.1 Category Test Concept

An over-simplified concept of a serial application of classes of T&E was reinforced by the Canadian Forces test community as recently as the Canadian Search and Rescue Helicopter acquisition program (circa 2002) through reference to Categories of flight test (i.e. Cat I – Developmental, Cat II – Engineering, Cat III – Operational) resulting in inefficient and even incorrect sequencing of T&E activities by project staff. The category flight test numbering convention (i.e. Cat I, Cat II, Cat III) subtly constrained the scheduling of test activities, and contributed to test objectives being poorly defined by association with non-descriptive language.

The category test concept was inaugurated by the United States Air Force on 19 August 1958 and lasted only until 1972 as a result of recommendations made on 1 July 1970 to then President Nixon by a Blue Ribbon Defense Panel. The Blue Ribbon Defense Panel concluded that the Category test concept resulted in too little attention being given to operational considerations during Cat I and II, too few resources being assigned to Cat III, and the three categories being too duplicative and time consuming. "On 12 May 1972, the [U.S.] Air Force dispensed with the Category Testing concept and officially implemented the [Developmental T&E/Operational T&E] DT&E/OT&E generalized concept of flight testing which exists to this day."[12,13]

3.1.2 Generalized Test Concept

While Figure 3-1 implies that the three types of Air T&E occur in sequence, from initial design through to in-service, the reality is that they frequently overlap, generally

[12] Taken from an untitled, unsigned report, circa 1981.
[13] The U.S. Department of Defense defines DT&E as that T&E conducted to assist in both engineering design and development *and* to verify the attainment of technical performance specifications.

occur out of order, and may be repeated throughout the materiel lifecycle. A product may undergo incremental design changes, be modified or overhauled by contractors, or have its operational role changed. In each instance one or more types of Air T&E likely will be required. A clear understanding of T&E objectives and concepts will allow correct scheduling of T&E activities in order to reduce the time and cost associated with bringing operationally acceptable new equipment into service.

The key to the generalized Developmental, Engineering and Operational test and evaluation concepts detailed in this paper are that they include descriptive sub-titles that can be flexibly associated by the Air element of the Canadian Forces with Canadian Defence Management System project milestones and the Materiel Acquisition & Support lifecycle.

3.2 DEVELOPMENTAL T&E

Developmental Air T&E often conjures up images of the X-series of American aircraft. The concepts of 'Commercial Off-the-Shelf' (COTS) and 'Military Off-the-Shelf' (MOTS) acquisitions have created an expectation in many project managers' minds that Canadian Forces involvement in Developmental T&E, and the associated high schedule and financial risks, are issues of the past. In reality, T&E of any prototype should be approached as Developmental T&E.

Developmental T&E is sub-divided as follows:

- Research and Development (R&D). Developmental Test & Evaluation (R&D) applies to experimental designs and technology; and
- Integration. Developmental Test & Evaluation (Integration) applies to test articles that are the result of novel integration of systems.

The distinguishing characteristic of Developmental T&E is that it applies to test articles/systems that have a high probability of incremental modification resulting from T&E activities. Developmental Test & Evaluation is normally the responsibility of the developer/integrator and should be concluded prior to a procurement decision.

3.3 ENGINEERING T&E

Systems are submitted for Engineering T&E at the point when a design is reasonably expected to meet airworthiness and contractual specification requirements. In other words, a configuration should be viewed as 'frozen' at the beginning of an Engineering Test & Evaluation effort. (In reality, Engineering Test & Evaluation may reveal shortfalls in performance, for example, that will result in further modification or redesign.)

Engineering T&E is sub-divided as illustrated in Figure 3-2.

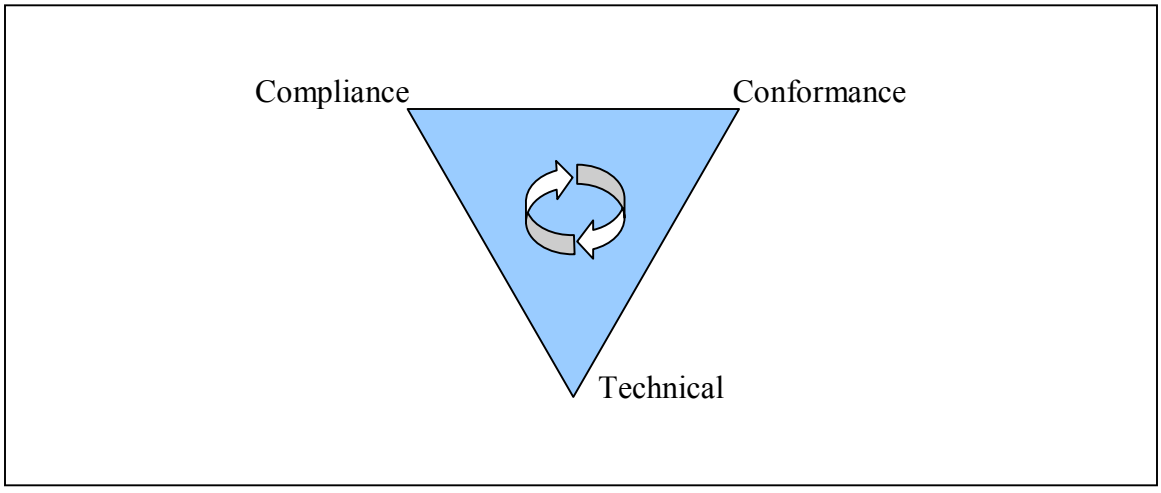

Figure 3-2. Engineering T&E

- Compliance. The aim of Compliance T&E is to determine whether or not a particular specification has been met. Compliance T&E is further sub-divided according to the type of specification:
    - Certification. The aim of Certification T&E is to determine whether or not technical airworthiness specifications have been met, and
    - Qualification. The aim of Qualification T&E is to determine whether or not contractual specifications have been met.
- Conformance. The aim of Conformance T&E is to determine if a particular item conforms to its approved design. Conformance testing is further sub-divided as follows:
    - Acceptance. Acceptance testing is normally conducted as part of the process of transferring an item from a contractor's manufacturing or modification process to the customer, and
    - Maintenance Test Flight. Maintenance Test Flights are normally conducted as part of the continuing airworthiness plan which ensures that an aircraft or aircraft system has been returned to its approved type design following a maintenance activity and that it is ready to return to service.
- Technical. The aim of Technical T&E is to provide technical authorities with information required for making engineering decisions related to in-service and possibly disposal issues.

3.4 OPERATIONAL T&E

Operational T&E is conducted by representatives of the user community to ensure that equipment or a system meets, or will meet, the user's validated requirement

in a realistic scenario.[14] The overall aim of Operational Test & Evaluation is to bring into service an operationally acceptable weapon system, as defined in the associated Statement of Operational Requirement.

Operational Test & Evaluation is sub-divided as illustrated in Figure 3-3.

- Initial Operational Assessment (IOA). The objective of an Initial Operational Assessment is to provide estimates of a system's operational effectiveness and operational suitability prior to an acquisition decision.
- Initial OT&E (IOT&E). Initial Operational Test & Evaluation occurs prior to a production decision. The objectives of Initial Operational Test & Evaluation are to establish the operational airworthiness of a system, to provide a complete assessment of a system's operational capability and to begin development of tactics for its employment.
- Follow-on OT&E (FOT&E). Operational suitability and effectiveness evaluations are common to both Initial Operational Test & Evaluation and Follow-on Operational Test & Evaluation. The basic difference between Initial Operational Test & Evaluation and Follow-on Operational Test & Evaluation is their relationship to the production decision. Follow-on Operational Test & Evaluation follows the production decision.

[14] DAOD 3011-0 (Draft)

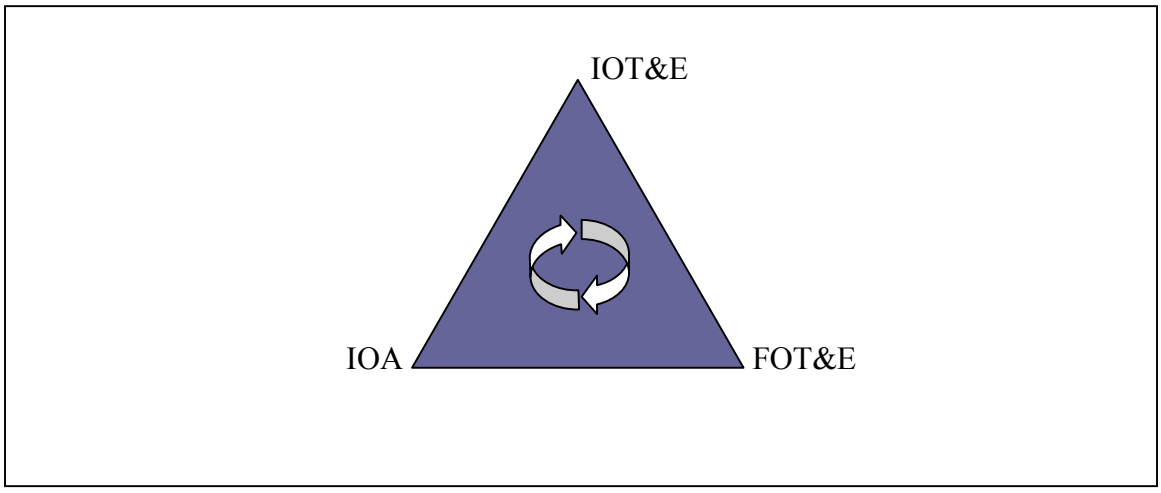

Figure 3-3. Operational T&E

4.0 DEVELOPMENTAL T&E

Developmental Test & Evaluation applies to test articles that are still undergoing development, whether that development applies to a specific piece of equipment, or to the first-time integration of a system into an aircraft. Developmental Test & Evaluation should result in system characterization, or for articles that will be submitted for Engineering Test & Evaluation, the definition of an operating envelope.

Even a simple modification to an existing piece of equipment, the incremental expansion of an operating envelope, or modification of an operating role or environment should be considered first from the perspective of Developmental Test & Evaluation. The concept of Developmental Test & Evaluation should conjure up in the minds of project managers the spectre of iterative design changes and 'fly-fix-fly' test efforts, along with the associated high financial and schedule risks.

4.1 RESEARCH & DEVELOPMENT

"The DND and CF will: …promote needs-specific research and development; …."[15] Assuming that existing 'off the shelf' components and systems are not adequate or available:

> "A high priority should be given to building and testing prototype systems and sub-systems before proceeding with full-scale development. This early phase of R&D should…demonstrate that the new technology under test can substantially improve military capability, and should as well provide a basis for making realistic cost estimates prior to full-scale development decision."[16]

Developmental Test & Evaluation (R&D) is largely forward looking. Research & Development often uses simulation & modeling, as well as mock-ups, scale tests and

[15] DAOD 3000-0
[16] Packard, D.

the T&E of component parts to complete early assessments of the feasibility of a capability and the achievability of critical system technical characteristics.

An example of Developmental Test & Evaluation (R&D) could relate to the development of a new configuration of survival suit. Each successive suit mock-up and pre-production design could be tested in a lab, or in simulated or actual environments. The characteristics of component parts (e.g. the fire resistivity of material) could be determined. Evaluation of test data could result in further refinements being made as test subjects from the operational user community make observations on the projected operational suitability and effectiveness of the prototype test article.[17] When the design of the test article is ready to be frozen and a decision to procure is made the design would then begin Engineering and Operational T&E.

Either the Assistant Deputy Minister (Science and Technology) or the Director of Air Requirements normally sponsors developmental Test & Evaluation (R&D).

4.2 INTEGRATION

> "With few exceptions, the Australian approach is geared to acquiring and integrating weapons and platforms developed by the US and other countries that have already completed rigorous T&E including OT&E."[18]

Many suppliers of Commercial Off-the-Shelf or Military Off-the-Shelf systems have proven unprepared for the challenges of integrating their equipment into aircraft. As a result, acquisition projects run far behind schedule, over-budget, and involve far too much Canadian Forces expertise as unexpected integration issues turn what are supposed to be simple, low-risk Engineering T&E projects into iterative Developmental Test & Evaluation efforts.

[17] See Part 6.3 for details on OT&E (Initial Operational Assessment).
[18] Australian National Audit Office, para 2.56.

The integration of new equipment, such as radios and collision avoidance systems into existing platforms should be approached from the perspective of Developmental Test & Evaluation. For example, integration of a proven digital radio into a 40-year-old aircraft may reveal only during testing of the complete system that there are issues with electromagnetic interference, or power systems incompatibilities that will require significant modifications to either the radio or to the aircraft. Similarly, integrating new software into an existing design may reveal discrepancies between the test bench and actual aircraft. Software, for example, may have been developed for one model of an aircraft, only to discover on installation in another model that the lack of a particular hardware sub-system has an unexpected effect on the software; iterative changes to the software should then be considered developmental. Even changing the intended operating environment of a previously approved system to the high arctic from the hot-humid environment of the U.S. southeast could result in time-consuming and expensive modification requirements.

Project managers must anticipate these types of developmental issues and build sufficient time and resources into their projects. Wherever possible, project managers should make Developmental Test & Evaluation (Integration) the business of the equipment supplier.

5.0 ENGINEERING T&E

The application of Engineering Test & Evaluation begins at the point in the materiel lifecycle when a 'frozen' design is submitted to the Department of National Defence and Canadian Forces for acceptance, and continues through the in-service phase to disposal. Engineering Test & Evaluation projects are typically low-to-medium risk activities, depending on how well specifications have been stated. Engineering Test & Evaluation projects become medium-to-high risk when unsubstantiated findings are made based on similarity (e.g. design, role, operating environment), often with a desire to avoid Developmental Test & Evaluation.

Engineering Test & Evaluation activities are summarized in Figure 5-1.

5.1 COMPLIANCE

The aim of Engineering Test & Evaluation (Compliance) activities is to determine whether or not a particular specification has been met. Specifications are selected based on statements of operational requirement and intent that have been endorsed by the operational commander. The purpose of these documents is to describe what an aircraft or piece of equipment is required to do, who will operate it, and in what type of environment (tactical, atmospheric) – the more descriptive the requirement, the more likely that an article will fully meet expectations.

A statement that a helicopter is required to fly certain types of precision approaches in a given environment should result in the associated airworthiness, human factors and performance specifications being designed into the system. Similarly, if an unmanned aerial vehicle is intended for operation in a particular environment, the associated performance specifications should be translated into contractual terms of

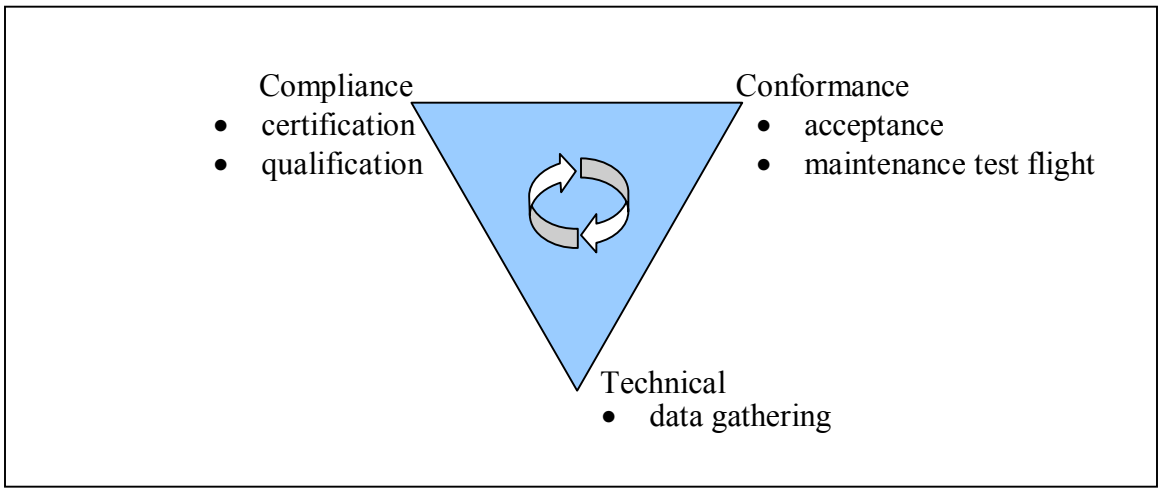

Figure 5-1. Engineering T&E (Expanded)

required atmospheric conditions, such as density altitudes, wind speeds and precipitation.

At its extreme, Engineering Test & Evaluation (Compliance) may involve verification of system operating limits or safety factors. This type of testing is not considered Developmental Test & Evaluation (R&D); rather, it is a method of ensuring that performance specification can be met when the test article is exposed to environmental conditions expected at the extremes of the operating envelope, and that operating instructions of an aircraft or system accurately reflect the operating envelope developed during Developmental Test & Evaluation.[19]

Compliance T&E is further sub-divided according to the type of specification to be verified: airworthiness, or contractual. Project managers should anticipate that airworthiness and contractual specifications will overlap, providing ready opportunities to reduce overall test effort. In any case, in order to ensure that specifications are 'testable', flight test expertise should be involved very early in the procurement process:

> "In order to build mutual trust and confidence, and to focus on system operating characteristics that can be tested in a way that makes sense, the expertise of the testers should be sought by the users and developers as the system requirements are being formulated. This means that the testing community should be part of the *requirements development process*."[20]

5.1.1 Certification

The aim of Certification T&E is to determine whether or not technical airworthiness specifications have been met. The authority for making findings of compliance with technical airworthiness specifications is vested in individuals authorized

[19] Limited system characterization may be required to establish Safety of Flight (SOF) early in a test program (ET&E or OT&E); the system characterization and associated Flight Authority may be expanded incrementally as testing continues.
[20] Defense Science Board, pg 17.

to do so under the Aeronautics Act by the Technical Airworthiness Authority. The Technical Airworthiness Authority is also involved in approving technical basis of certification, identifying data requirements and the acceptable means of gathering and reducing data.

Airworthiness specifications are normally selected by the project technical authority from existing civil and military specifications, such as: Canadian Air Regulations, US Federal Air Regulations, European Joint Airworthiness Regulations, Technical Standard Orders, US Military Specifications, and UK Defence Standards. When approved by the Technical Airworthiness Authority, these specifications form a Basis of Certification. When compiled in a tabular format the specifications form a technical airworthiness certification compliance matrix. The compliance matrix identifies the method by which compliance will be demonstrated.

In general, airworthiness specifications ensure the safety of a design. Note, however, that the safety of a design must be judged (and specifications selected) in the context of the intended role of the aircraft/system. Most civil specifications were conceived for aircraft operating in the passenger/cargo transport role. A civil-certified passenger transport aircraft is not necessarily safe to operate in the Anti-Submarine Warfare role. Similarly, civil approval of equipment and modifications are valuable starting points in a certification effort, but systems engineers have a responsibility to challenge their applicability to the military role.

5.1.2 Qualification

The objective of Qualification T&E is to determine whether or not contractual requirements have been met. Contractual specifications may define minimum levels of performance or functionality, or particular design or human factors requirements. The

authority for making findings of compliance with contractual specifications is linked to the Financial Administration Act and rests with the Project Manager or contract technical authority.

As with Certification T&E, contractual specifications must be clear, comprehensive and applicable to the intended military role and environment. Contracts, however, cannot exhaustively describe the operational environment, required aircraft/equipment characteristics and performance, or the tactics that ensure operational effectiveness. This leads to the requirement for most Operational T&E.

One notable distinction between Certification and Qualification compliance Engineering Test & Evaluation is that not all aviation systems are associated with technical airworthiness requirements and therefore do not require Certification testing. For example, flight simulators.

5.2 CONFORMANCE

A product must be manufactured and maintained in conformance with its approved type design. Testing to assess conformance is further sub-divided to clarify responsibilities where contract payments are involved.

5.2.1 Acceptance

Acceptance T&E follows the manufacture, modification or repair of an aircraft by a non-CF organization. The result of successful Acceptance T&E should be a recommendation to the contract authority to pay the contractor and take possession of the item.

5.2.2 Maintenance Test Flight

Maintenance Test Flights (MTFs) represent one method, other than bench and ground testing, to verify that in-service preventative and/or corrective maintenance actions have been completed in accordance with approved instructions, resulting in an aircraft/system that conforms to its approved type design, and that it functions as expected. Maintenance test flights differ from Acceptance efforts in that Maintenance Test Flights do not have contractual implications.

As part of the approved continuing airworthiness program, the aircraft Technical Authority, in cooperation with the Technical Airworthiness Authority, identifies those aspects of an aircraft's technical airworthiness that can only be verified through flight test following maintenance. (Other techniques for verifying conformity include bench test, inspection and ground test.) For example, the final step in verifying that an aircraft's flight control system installation and rigging have been properly completed may require a functional test under airborne conditions.[21]

5.3 TECHNICAL T&E

Technical T&E is normally carried out in order to collect data that will be used by the fleet technical authority to make fleet management decisions, or to characterize or monitor in-service system performance. An example of a Technical T&E project would be the acquisition of airframe load data at particular points-in-the-sky (i.e. combinations of airspeed, altitude, attitude, centre of gravity and normal acceleration ('g')).

[21] A full discussion of partial card MTFs and flight functionals can be found in C-05-020-007/AM-000, "Flight Test Orders for the Canadian Forces".

6.0 OPERATIONAL T&E

Operational T&E is an essential part of the acquisition process and represents the majority of T&E undertaken by the Canadian Forces. Without Operational Test & Evaluation we are likely to provide our operational personnel with safe, inexpensive, but completely useless equipment. Similarly, project management errors in the past have resulted in airworthy, contractually compliant airframes being delivered without the training or documentation being available to prepare crews to actually operate them. Acquisition specialists must consider the measure of their success to be the entry into service of a new piece of operationally acceptable equipment, and not simply the on-time, on-budget delivery of unusable, unsuitable or ineffective materiel.

While Operational Test & Evaluation is generally a low-risk activity it can be time consuming. It can be difficult to determine when 'enough' Operational Test & Evaluation has been completed. Operational Test & Evaluation becomes risky for project managers only when the basis for operational suitability and effectiveness testing is poorly written, leading to incomplete or inaccurate design and performance specifications. A well-written Statement of Operational Requirement:

> "…communicates the characteristics of the operational requirement for weapons/information/support system to technical and procurement staffs and contains the critical performance criteria necessary for evaluating technical options and assisting in the post-project completion evaluation of system performance."[22]

The fleet operational authority normally sponsors assessments of operational suitability and effectiveness.

Operational Test & Evaluation activities are summarized in Figure 6-1.

[22] DMS Manual

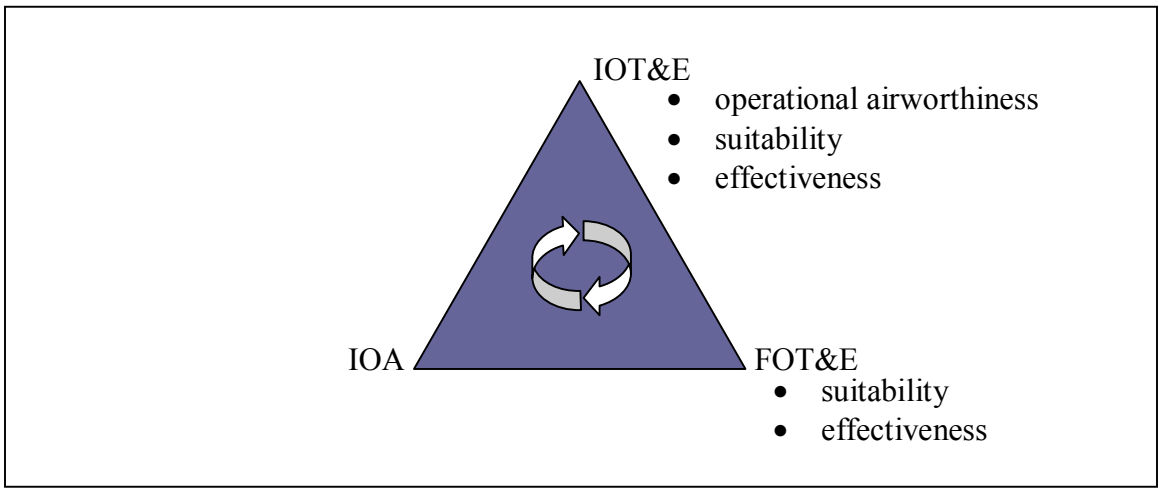

Figure 6-1. Operational T&E (Expanded)

6.1 OPERATIONAL T&E – OBJECTIVES

The objectives of any Operational Test & Evaluation program should be selected from the sub-components that comprise operational airworthiness, effectiveness and suitability as shown in Figure 6-2.

6.1.1 Operational Airworthiness

As assigned through the Aeronautics Act, the Operational Airworthiness Authority is concerned with provision of adequate procedures, documentation and training to aircrew and ground crew, such that an aircraft or system can be safety operated under specific circumstances (e.g. local-area, peacetime training). Operational airworthiness authorities must be involved whenever consideration is being given to modifying an existing design, changing an operational role or training concept, or acquiring a new aeronautical product or simulator.

The decisions of operational airworthiness authorities may be based on information resulting from Operational Test & Evaluation activities, such as the validation of procedures or the development of flight training plans.

6.1.2 Operational Capability

The availability of operationally capable weapon systems is a requirement of the National Defence Act.

Operational capability is a measure of the suitability and effectiveness of a weapon system. It involves a determination of whether or not a system can perform its intended function or fulfill its intended role in the anticipated operating situation. This ‘situation’ goes beyond just the heat, cold, humidity, dust, precipitation, shock and

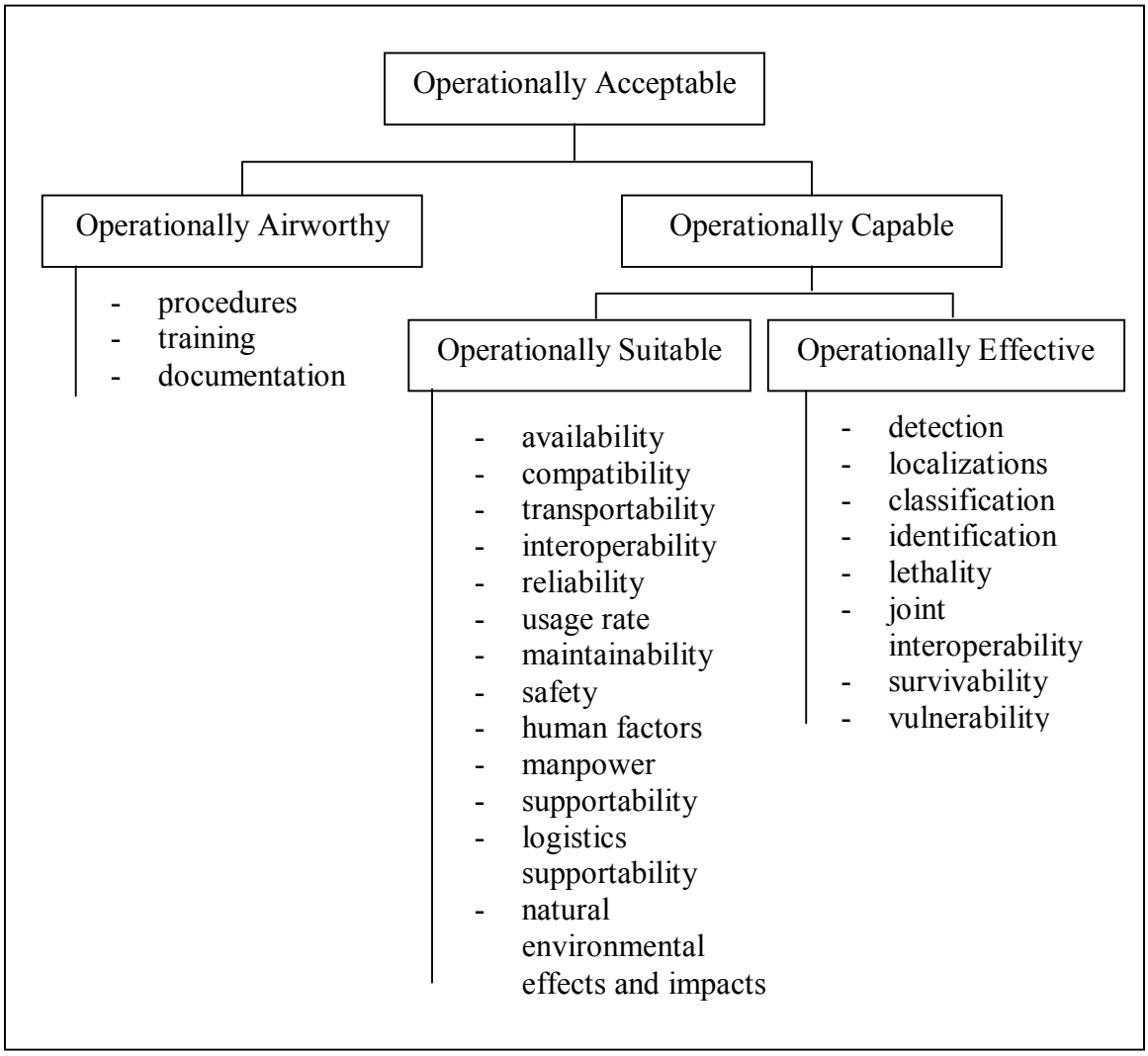

Figure 6-2. Operational T&E Objectives[23]

[23] Each of the terms listed in Figure 6-2 is defined in 1 Canadian Air Division Order 1-611.

vibration of a typically harsh military operating environment. It also considers threats, interoperability, support and intensity of usage.

Clear statements of intended operation allow Operational Test & Evaluation to address critical measures of operating performance and effectiveness. The results of Operational Test & Evaluation allow an understanding of a system's characteristics that then forms the basis for the development of doctrine and tactics.

6.2 SAFETY OF FLIGHT PRIOR TO OPERATIONAL TESTING

Safety of flight must be established prior to the start of any type of operational testing. This is normally documented by the issuance of applicable Flight Authority. Although Flight Authority may be issued, the Operational Airworthiness Authority must consider the safety implications of any unacceptable or unsatisfactory findings that were made during Engineering Test & Evaluation and accepted by the Technical Airworthiness Authority. The Operational Airworthiness Authority may decide to impose mitigating measures, such as test point build-up or test crew training as part of the Operational Test & Evaluation program. Alternatively, the Operational Airworthiness Authority may sponsor Engineering Test & Evaluation specifically aimed at characterizing Operational Test & Evaluation risk factors, or with the objective of defining more conservative operating limits in order to mitigate known risks.

6.3 INITIAL OPERATIONAL ASSESSMENT

An Initial Operational Assessment (IOA) by representatives of the intended user group allows for early influence of the design, development or selection of a system. An Initial Operational Assessment may also be conducted early in the acquisition process as a method of short-listing systems that have the promise of meeting operational

suitability and effectiveness requirements.[24] Like most types of T&E, Initial Operational Assessment is a risk reduction tool that can be employed by Materiel Acquisition & Support decision makers.[25]

The Director of Air Requirements or Project Manager normally sponsors Initial Operation Assessment.

6.4 INITIAL OPERATIONAL T&E

Initial Operational Test & Evaluation occurs prior to a production decision. The objectives of Initial Operational Test & Evaluation are to establish the operational airworthiness of a system, to provide a complete assessment of a system's operational capability and to begin the development of tactics for its employment.

From Defence Administrative Orders and Directives 3011-0 (Draft), to the extent possible, the Department of National Defence and Canadian Forces will not authorize full-scale production or modification of equipment until the project sponsor certifies that: the proposed equipment or modification meets the stated operational requirement; or, an optimum performance/cost/schedule condition exists.

The fleet operational authority normally sponsors Initial and Follow-on Operational Test & Evaluation.

6.5 FOLLOW-ON OPERATIONAL T&E

> "Continuing in-service T&E assists Defence to develop and refine military doctrine, procedures and tactics that are fundamental to effective employment of new and established capabilities."[26]

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[24] These efforts are often referred to as 'Pre-Qualification', and usually include estimation by ET&E agents of the likelihood that a test article will meet critical airworthiness and contractual specifications.
[25] IOA may be preceded by '(Restricted) Safety of Flight' testing which is typically carried out by Engineering T&E agents.
[26] Australian National Audit Office

Follow-on Operational Test & Evaluation includes efforts to develop new tactics or to validate existing tactics, to validate changes in training, or as the result of changes in threat/allied technology or doctrine. Follow-on Operational Test & Evaluation includes the Systems Effectiveness Monitoring Program (SEMP) during which weapons systems, including elements of their deployable support structure deploy to participate in operationally representative exercises, or to locations where crucial ranges or facilities are available.

Follow-on Operational Test & Evaluation can lead to preparation of Statements of Capability Deficiency, and to the development of Statements of Operational Requirement. No matter what format Follow-on Operational Test & Evaluation follows, the measure of any T&E program is detailed, comprehensive reporting by trained evaluators. In the case of Operational Test & Evaluation, the T&E results and recommendations should rely heavily on input from a spectrum of users.

7.0 AIR T&E SUPPORT TO THE MA&S LIFECYCLE

In response to an Audit Report by their country's Auditor General the Australian Defense Department stated that their 'capability development process' had been changed to require:

> "…the development of agreed test concepts and related T&E funding arrangements to be incorporated into project proposals before they are approved. This approach will overcome current inconsistent adherence to T&E policies and funding of T&E."[27]

The Director Materiel Acquisition and Support Programme (DMASP) is responsible to the Assistant Deputy Minister (Materiel) for developing Materiel Acquisition & Support policies and guidance, including for test and evaluation management. In response to these responsibilities a MA&S Desktop has been implemented which in part provides project and functional managers with advice on systems engineering management, project integration management and T&E management.[28]

While many of the terms and concepts presented in this paper are consistent with current DMASP direction, a number of key differences do exist. The following paragraphs provide details on how the Test & Evaluation concepts presented in this paper can be integrated with stages of the Materiel Acquisition & Support lifecycle, consistent with activities of the Defence Management System.

[27] Australian National Audit Office, para 3.25.
[28] MA&S Desktop

7.1 MA&S LIFECYCLE

The lifecycle management system defines four broad stages in the materiel lifecycle: conception, acquisition, in-service and disposal. In general, materiel must be evaluated and testing considered:[29]

- Prior to its introduction
- Prior to fielding it in a modified condition or in a new application or environment
- As part of the analysis of its in-service problems or failures
- Prior to extending its life, or disposal

7.1.1 Conception

The Conception stage of the materiel lifecycle may involve Developmental Test & Evaluation (R&D; Integration) and Operational Test & Evaluation (Initial Operational Assessment). While this may be apparent for research and development activities, it may be less apparent that verification of novel integrations should also be verified prior to committing to acquisition. In this way, the system developer retains risk.

Past acquisition projects have run into problems when novel integration problems, coupled with a contractor's lack of T&E expertise, have led to iterative 'fly-fix-fly' test programs at the expense of Canadian Forces resources.

7.1.2 Acquisition

The Acquisition stage of the materiel lifecycle may involve Engineering Test & Evaluation (Compliance; Conformance) and Initial Operational Test & Evaluation. Evidence suggests that past success-oriented acquisition programs have led to project

[29] DAOD 3011-0 (Draft)

managers involving testers too late in the acquisition cycle. As a result, contractual specifications are found to be untestable, and when problems are uncovered, the project office and test agency find themselves at odds whenever test results point to schedule delays or cost increases. In the worst cases, unsuitable or even unacceptable equipment is pressed into service with operational crews while integration issues are still being resolved: "Early involvement of testers (and also users), who are independent of the development, provide the feedback essential for the design refinements that lead to truly excellent procurements."[30]

Project managers must keep in mind, however, that:

> "An important T&E principle is that the organisation responsible for OT&E be, and be seen to be, independent of the equipment acquisition organisation and system contractors who are responsible for developmental and production T&E."[31]

7.1.3 In-Service

Once in-service materiel will be subject to effectiveness monitoring programs through Follow-on Operational Test & Evaluation and may also undergo Engineering Test & Evaluation (Technical) to provide information required to make weapons system management decisions. In either case, T&E results must be assumed to be unique to a given aircraft configuration, operating environment, role or intended use. Any changes to these elements may invalidate the findings that have previously been made.

For example, vibration test results on a helicopter would require validation if the type of materiel used in the construction of the cabin floor were changed. The cold weather operating clearances for an aircraft/engine manufactured in Europe may not be

[30] Defense Science Board, pg 1.
[31] Australian National Audit Office.

appropriate in Canada. Other examples include: operating an aircraft for the first time near the high power radio frequency emissions of naval ships; moving an aircraft from a medium level operating environment to a low level environment; changing the range of acceptable anthropometric measurements (e.g. sitting height, min/max weight) of the operating crew. Even simply changing the type of flying glove being used in a cockpit from lightweight to heavy weight (winter) could adversely impact a pilot's ability to actuate critical cockpit controls.

7.1.4 Disposal

There may be a requirement for Engineering Test & Evaluation (Technical) in order to establish the condition of an item that is being deactivated, demilitarized or sold.

7.2 T&E MANAGEMENT

> "Attention must be given to ensuring the test schedule is not so success-oriented that retesting of failures causes serious program delays for either the government test agencies or the contractor."[32]

While many aspects of T&E can be integrated, certain limitations and sequences must be respected: safety of flight must be assured prior to Initial Operational Assessment and Operational Test & Evaluation; Developmental Test & Evaluation should be completed prior to a procurement decision; Engineering Test & Evaluation (Compliance) must be completed, and a production decision made, before Engineering Test & Evaluation (Conformance) begins; and, Initial Operational Test & Evaluation must be completed before an aircraft/system is initially declared operationally capable.

Project managers must also understand that Developmental Test & Evaluation

[32] Test & Evaluation Management Guide, pg 4-3.

and Engineering Test & Evaluation are typically conducted by trained, experienced test crews in a controlled environment with the objective of taking precise measurements using particular test techniques in order to verify specification compliance. Operational Test & Evaluation involves the operational crews employing tactics in realistic operational environments. During early Initial Operational Test & Evaluation the objective is to determine suitability and effectiveness; this evolves through Follow-on Operational Test & Evaluation into tactics development where system shortfalls or limitations must be overcome. While it is possible to coordinate Engineering Test & Evaluation and Initial Operational Test & Evaluation access to test articles, it is exceedingly difficult to achieve both Engineering Test & Evaluation and Initial Operational Test & Evaluation objectives during a particular flight test mission.

With an understanding of the fundamental aim and objectives of Air T&E, its relationship with the stages of the materiel lifecycle, and of the limitations, constraints and imperatives for T&E scheduling, a model has been developed that provides a coherent framework for integrating T&E in to the Materiel Acquisition & Support lifecycle.

7.3 MODEL

Figure 7-1 provides a model for integrating Air T&E activities into the Materiel Acquisition & Support lifecycle.

7.4 EXAMPLE

An example of a flight test program involving the development and installation of a new Operational Loads Monitoring system by a contractor will illustrate how the model can be

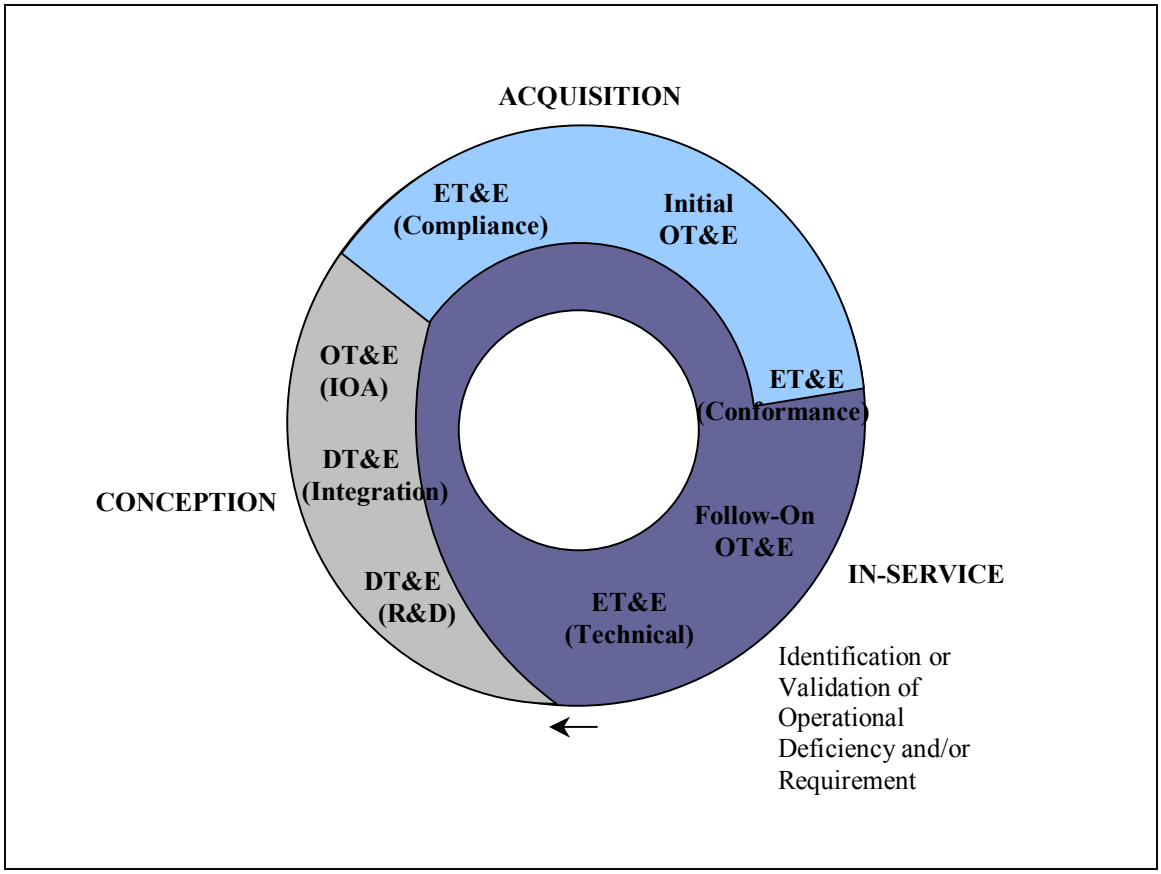

Figure 7-1. Air T&E Support to the MA&S Lifecycle[33]

[33] DT&E – Developmental Test & Evaluation
ET&E – Engineering Test & Evaluation
IOA – Initial Operational Assessment
OT&E – Operational Test & Evaluation
R&D – Research & Development

applied:

- The fleet technical authority identifies the requirement for structural fatigue data with which to make fleet management decisions.
- The Contractor designs and integrates a prototype system into a test aircraft. This effort may involve Developmental Test & Evaluation (R&D), and will very likely involve design and integration refinement through to Developmental Test & Evaluation (Integration). In this case the Project Manager may be contractually responsible for supplying the test aircraft and pilot(s) to support the Contractor, but responsibility for the financial and schedule risks associated with any 'fly-fix-fly' efforts remain with the Contractor.
- An Initial Operational Assessment of the design may be conducted to ensure that the design has no obvious operational suitability issues (e.g. user interface).
- When the Operational Loads Monitoring system design and integration are considered 'frozen' by the contractor, they are submitted to the Project Manager. The Project Manager will sponsor Engineering Test & Evaluation (Compliance – Certification; Qualification). The objectives of this testing are to verify that the Operational Loads Monitoring design is airworthy (e.g. does not cause electromagnetic interference with navigation systems), and that it meets all contractual performance specifications (e.g. sample rates under all flight loads).
- As part of the Operational Airworthiness Clearance, Initial Operational Test & Evaluation may then be required to validate contractor supplied operating instructions.

- Acceptance of second, third, etc aircraft from the Contractor's modification line could require Engineering Test & Evaluation (Conformance) tests to ensure that each installation is properly installed and calibrated.
- Finally, testing at specific points-in-the-sky (i.e. ET&E – Technical) could be sponsored by the Fleet aircraft engineering officer / technical authority in order to gather data required to make fleet management decisions. (Note that once made part of the baseline configuration of the aircraft, the Operational Loads Monitoring system's in-service use to passively gather data would not be considered T&E.)
- Follow-on Operational Test & Evaluation might be required at some time during the in-service phase of the equipment lifecycle in order to validate amended operating instructions.

While this description presents the involvement of T&E in the Operational Loads Monitoring acquisition process to be fairly lengthy, involving successive T&E efforts, there are many more efficient scenarios possible. For example: the Initial Operational Assessment could be conducted by military crews supporting the contractor's Developmental Test & Evaluation integration efforts; and Engineering Test & Evaluation and Initial Operational Test & Evaluation could be conducted by a combined test force.

> "A combined or concurrent testing approach may offer an effective means of shortening the time required for testing and achieving cost savings. If such an approach is used, extensive coordination is required to ensure the development and operational requirements are addressed."[34]

This coordination can be achieved through effective documentation of T&E requirements identified by various authorities. Finding authorities requirements are summarized in compliance or verification matrices, including data requirements (testing)

[34] Test & Evaluation Management Guide, pg 9-4.

and data reduction plans (evaluation). The various airworthiness and contractual matrices can then be compared, rationalized, coordinated and the resulting test effort summarized in a single document referred to as a Test and Evaluation Master Plan.[35]

[35] MA&S Desktop

8.0 T&E RESPONSIBILITIES, ACCOUNTABILITIES & AUTHORITIES

> "Having a *responsibility* involves having the *authority* and the obligation to act, including the authority to direct or authorize others to act. It also means being *accountable* for how those responsibilities have been carried out in light of agreed expectations. In a public sector organization such as the CF or DND, each individual is obliged to *account* fully and promptly to those who, in the hierarchy, conferred the responsibilities, for the way they have been carried out and for how the relevant authorities have been used."[36]

8.1 T&E SPONSORS

Those who have authority for decision-making may have legitimate need to sponsor test and evaluation activities; alternatively, a project sponsor may be identified who is responsible for providing factual information and recommendations to a finding authority. Findings may be related to either contractual obligations or airworthiness requirements.

To summarize, spending/contractual authorities are responsible for ensuring that contractual obligations are met. Specifically, they are obligated to ensure that an accepted design meets contractual performance specifications (i.e. ET&E – Compliance – Qualification), and that the effectiveness of the manufacturing or modification process consistently delivers products that conform to the approved design (i.e. ET&E – Conformance – Acceptance).

Similarly, airworthiness finding authorities may sponsor Air T&E activities based on the requirements to establish compliance with certification specifications (i.e. ET&E – Compliance – Certification).

Other authorities who may engage Air T&E in order to attain needed factual information for decision making are those involved with the development and integration

[36] "Organization and Accountability"

of new systems and technologies (i.e. DT&E – R&D; Integration), and those who are responsible for the in-service management and disposal of materiel (i.e. ET&E – Technical).

The selection of Air T&E agents is the responsibility of the Air T&E sponsor and, where applicable, must be endorsed by the finding authority who requires the factual information provided by Air T&E for decision making.

8.2 T&E AGENTS

> "The matrix structure of [National Defence Headquarters] NDHQ is grounded in the need for mutual understanding of what must be done by each of the parties mandated to participate in achieving results. It is essential that every one of those responsibilities for a specific issue both consult and work with colleagues who should be involved. Nevertheless, those responsible remain accountable for the overall results, even though they may have collaborated with others in getting the job done."[37]

T&E agents are responsible for the thorough, efficient conduct of data acquisition and for the accurate analysis of test data. While T&E agents normally provide recommendations based on their findings, and may even be delegated finding authority, accountability for decisions cannot be delegated by those with legal responsibilities.

Due diligence of project managers and airworthiness authorities would suggest that even when Engineering Test & Evaluation is carried-out by a non-CF organization, Canadian Forces T&E agents should be engaged to act as smart customers of T&E services. It is largely so that the Department of National Defence can preserve its independence and expertise as a customer that it maintains an in-house pool of Developmental and Engineering Test & Evaluation expertise. Even when not actually conducting T&E, the Department's Developmental and Engineering Test & Evaluation

[37] "Organization and Accountability"

experts are able to advise project managers and airworthiness authorities on the quality and thoroughness of non-CF T&E activities.

Operational Test & Evaluation on the other hand must be carried out by representatives of the intended operational user group – only they really understand their business, and it is their uncompromising assessment of a delivered system that determines the true success of any acquisition or modification program: operational suitability and effectiveness.

9.0 CONCLUSIONS

While T&E is not itself required by law, those with legal accountability for decision making often require the factual information provided by T&E activities in order to make sound decisions.

Descriptive definitions of T&E objectives will contribute to lower risk Materiel Acquisition & Support project management activities, in terms of schedule and cost, through the timely and judicious application of Air T&E.

A concise model illustrating the link between Air T&E activities and the Materiel Acquisition & Support lifecycle will contribute to a consistent approach to T&E. Application of this model requires that Air T&E sponsors and agents understand the role of Air T&E in providing factual information required for risk management and decision making by those in positions of authority.

10.0 RECOMMENDATIONS

Based on the preceding discussion, the following recommendations are made for the consideration by those interested in improving the Materiel Acquisition & Support system through the rationalized application of Air T&E:

- Redefine the Department of National Defence and Canadian Forces definitions of Developmental Test & Evaluation and Engineering Test & Evaluation, and refine the definition of Operational Test & Evaluation to reflect the 'Canadianized' concepts described in this paper.
- Drop reference to the Category T&E concept.
- Adopt the Generalized T&E concept and embed the Figure 7-1 Model in the MA&S Desktop for access by project managers, systems engineers, weapons systems managers and T&E agencies.
- Amend or develop Air element, Assistant Deputy Minister (Materiel) and Assistant Deputy Minister (Science & Technology) orders and instructions to reflect the expanded Air T&E concepts detailed in this paper.

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