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# T AND E GUIDELINES FOR AIRCRAFT SYSTEMS

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DEPUTY DIRECTOR (TEST & EVALUATION)

# T&E GUIDELINES FOR AIRCRAFT SYSTEMS



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OFFICE OF THE DIRECTOR OF
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DEPUTY DIRECTOR (TEST AND EVALUATION)

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OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, D. C.

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## FOREWORD

This report is an outgrowth of the work of the Defense Science Board Task Force on Test and Evaluation, and the checklists herein have been derived from the study of past major weapon system programs.

The T&E expert in reading this volume will find many precepts which will strike him as being too obvious to be included in checklists of this type. These items are included because examples were found where even the obvious has been neglected, not because of incompetence or lack of personal dedication by the people in charge of the program, but because of financial and temporal pressures which forced competent managers to compromise on their principles. It is hoped that the inclusion of the obvious will prevent repetition of the serious errors which have been made in the past when such political, economic and temporal pressures have forced project managers to depart from the rules of sound engineering practices.

In the long run, taking short cuts during T&E to save time and money will result in significant increases in the overall costs of the programs and in the delay of the delivery of the corresponding weapon systems to the combatant forces.

## T&E GUIDELINES FOR AIRCRAFT SYSTEMS

The checklist items presented here are specifically applicable to aircraft testing and evaluation. It is suggested that the user of this volume also refer to the Report of the Defense Science Board on Test and Evaluation which contains general checklist items also applicable to this system T&E program. The checklist items presented here are organized into time phases of the acquisition process oriented to the DSARC cycle.

The checklists cover various aspects of the major activities that should be underway during a given time period. Hence, a checklist might cover the (1) evaluation of work that occurred in the previous phase, (2) conduct of tests planned in the previous phase and executed in the subject phase, and (3) plans and other preparatory actions for test schedules to be conducted in a subsequent phase. For reasons such as this, items on some subjects, such as development test plans, may appear in more than one phase. In addition, since the Services and the DSARC have flexibility in deciding how rapidly to progress in the Validation Phase, there may be cases where the Request for Proposals (RFPs), proposal evaluations, source selections, or contract negotiations may occur after the DSARC approves full-scale development instead of before. For this reason, it is recommended that previous checklists in the Validation Phase be reviewed when entering the Full-Scale Engineering Development Phase. The following are the phases used in this report.

### CONCEPTUAL PHASE

The checklist items in this phase are for guidance in evaluating T&E activities during the Conceptual Phase of the acquisition of the system. This phase (often research and exploratory development) precedes the first DSARC milestone and is focused on the development of a weapon system concept that offers high prospects of satisfying an identified military need.

Although not called for in DoD Directive 5000.1 specifically, the objectives of this phase should be:

1. To verify that there is a military need for the proposed system.
2. To demonstrate that there is a sound physical basis for a new weapon system.
3. To formulate a concept, based on demonstrated physical phenomena, for satisfying the military need.
4. To show that the proposed solution is superior to its competitors in terms of potential effectiveness, probability of success, probable cost, impact on the U.S. military posture, and development risks.
5. To analyze the technology outlook and the military need to show that it is better to start advanced development now rather than to wait for future technological improvements.
6. To identify the key risk areas and critical issues that need to be resolved before full-scale development is initiated.

The most important product of this phase is the Development Concept Paper (DCP) or its equivalent. The DCP defines program issues, including special logistics problems, program objectives, program plans, performance parameters, areas of major risk, system alternatives, and acquisition strategy.

VALIDATION PHASE

The checklist items in this phase are for guidance in conducting T&E during the Validation Phase (the time between when the DSARC recommends approval of the DCP for the first time and when the DSARC recommends full-scale development of the system).

While these objectives are not spelled out in the DoD Directive 5000.1, the objectives of the Validation Phase should be to confirm:

1. The need for the selected system in consideration of the threat, system alternatives, special logistics needs, estimates of development costs, preliminary estimates of life cycle costs and potential benefits in context with overall DoD strategy and fiscal guidance.
2. The validity of the operational concept.
3. That development risks have been identified and solutions are in hand.
4. Realism of the plan for full-scale development.

In the pursuit of the above objectives, it is likely that advanced development T&E will be conducted to resolve issues. In some cases, an RFP for full-scale engineering development will be prepared, proposals will be received and evaluated, and contracts negotiated in preparation for seeking DSARC approval for the next phase. Therefore, some checklist items are included to help ensure that this work properly reflects the T&E interests in this and subsequent phases. For example, the RFP must include adequate guidance to ensure that sufficient resources and time are available so that the engineering effort can properly support the initial DT&E with hardware, software, technical data, and training.

The primary emphasis of OSD/T&E activities is with items 3 and 4 above. Special attention should be given to the planning of IOT&E activity as it is incorporated in the engineering development contract as well as the DT&E associated with addressing the critical issues and areas of major risk identified in the DCP.

## FULL-SCALE ENGINEERING DEVELOPMENT PHASE

The checklist items contained in this phase are for guidance in conducting T&E during the Full-Scale Engineering Development Phase. This includes the major DT&E and the IOT&E conducted prior to the major production decision. By this time, the system is well-defined and is becoming a unique item and, hence, sound judgment must be applied in using these checklist items.

To enter the Engineering Development Phase, the DSARC will have:

- Confirmed the need in consideration of the threat, alternatives, logistic needs, cost, and benefits.
- Identified development risks.
- Confirmed the realism of the development plan.

Given the above, the primary objectives of the DT&E should be to:

1. Demonstrate that the engineering and design and development process is complete and that the design risks have been minimized (the system is ready for production).
2. Demonstrate that the system will meet specifications.

The primary objectives of the IOT&E should be to:

3. Assess operational suitability and effectiveness.

4. Validate organizational and employment concepts.

5. Determine training and logistic requirements.

In addition, the validity of the plan for the remainder of the program must be confirmed by the DSARC before substantial production/deployment will be recommended to the Secretary of Defense.

The level of OSD/T&E activity is highest during this phase. The IOT&E plan must be designed, the tests conducted, and the data analyzed to evaluate the inputs associated with the primary objectives. These tests should not be conducted until the primary objectives of the DT&E have been met. Thus, OSD/T&E activity is required to assess that the DT&E major milestone--the system is ready for production--has been achieved. Close monitoring of the T&E Service activity is required during the latter stages of this phase.

## SUBSTANTIAL PRODUCTION/DEPLOYMENT PHASE

The checklist items contained in this phase are for guidance in conducting T&E after the substantial production decision has been made by the DSARC. This includes DT&E and follow-on OT&E to be conducted on the early production items.

To enter the Production/Deployment Phase, the DSARC will have reviewed the program to confirm:

- The need for the system.
- A practical engineering design with adequate consideration of production and logistic problems is complete.
- All technical uncertainties have been resolved and operational suitability has been determined by T&E.
- The realism of the plan.

The primary objective of the DT&E in this phase should be to:

1. Verify that the production system meets specifications.

The primary objectives of the follow-on OT&E should be to:

2. Validate the operational suitability and effectiveness.
3. Optimize organization and doctrine.
4. Validate training and logistic requirements.

At this point, the OSD/T&E activity is similar to that in the previous phase; however, much of the testing is verification that the production system performance is as expected. Hence, most of the items in the previous phase are appropriate to this phase, especially those related to OT&E.

# I. CONCEPTUAL PHASE

During this phase the program is being conceived and the DCP is being prepared. The test and evaluation checklist covers the following:

1. Test Program/Total Costs
2. Test Facilities and Instrumentation
3. Test Resources and Failures
4. System Interfaces
5. Major Weapon Subsystems
6. Propulsion System
7. Operational Scenario
8. Evaluation Criteria
9. Untried Elements
10. Brassboard Avionics Tests
11. Nuclear Weapons Effects



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1. TEST PROGRAM/TOTAL COSTS

Prior to DSARC I, all the phases of the aircraft test program should be considered so that the total costs and the development schedules include consideration of all likely activities in the overall program.

In an aircraft program this might include the cost of related missile interface development, missiles used, new test range instrumentation, drone or manned targets, new facility requirements, chase aircraft, the cost of the OT&E program (both IOT&E and follow-on OT&E including test gap closing provisions), the direct costs of test support provided by national test facilities and the cost of special tests such as underground nuclear radiation exposure tests, EMP tests, and offensive/defensive tests. Include these costs even if they cannot be accurately predicted. If they are not included now, they will show up later as cost overruns.

2. TEST FACILITIES AND INSTRUMENTATION

Before DSARC I, the test facilities and instrumentation requirements to conduct tests should be generally identified along with a tentative schedule of test activities.

The applicability of the test ranges, especially for attack aircraft, and the adequacy of the facilities and instrumentation should be verified; insofar as possible alternative approaches (different ranges, etc.) and instrumentation improvements needed should be specified. Funding for direct costs of range and instrumentation support must also be identified. Of prime importance are the constraints to be placed on the test because of the range and instrumentation. Factors such as available air-space, realism of the ground targets and the terrain surrounding the area of the instrumented range, etc. should not constrain the realism of testing. If range and instrumentation factors are found to cast significant doubt on the meaningfulness of the test data because of a lack of operational realism, the steps necessary to assure meaningful data should be identified and planned before the plans are included in the test concept.

Targets for air-to-air fighter aircraft warrant specific mention; some of the aircraft subsystems cannot be adequately tested without targets that realistically simulate the threat. In some cases, considerable lead time is required to provide the required target support; hence, target requirements to support the tests must be identified early.

## 3. TEST RESOURCES AND FAILURES

Ensure that there are adequate funds, reasonable time and an acceptable number of aircraft planned for the various test program phases and that these make provisions for the occurrence of failures.

Some major problems in test programs have been:

(a) Insufficient flying hours not only of the all up aircraft but also of subsystems and components to test all modes that stress the system throughout the performance envelope and to develop reliability. Circumstances have existed where, for various good reasons, the technology has had to be pushed rapidly, the higher risks involved have required more thorough testing and/or greater resources. These typically have taken a longer time to complete.

(b) Some significant problems found during development have not been adequately corrected prior to production. For example, a wing structure found to have inadequate structural life as a result of R&D fatigue tests should be corrected before production. Requalification of piece parts and assemblies has also frequently been required for many reasons. This results in a need for additional testing.

(c) The schedule was based on overall success and, among other things, did not provide for accidents. "Plan tests assuming some failures". A percentage of the total tests (sorties, runs, trials, experiments) should be allowed for retesting, over and above the basic number of successful runs required.

There must be sufficient time and resources put into the early planning for the operational tests, particularly the IOT&E phase, because the substantial production and deployment decision is planned to be made based upon IOT&E results. Further, test funds should not be postponed or reoriented to keep total program costs in line. In one program, it was found that testing time was arbitrarily decreased by 90 percent and the number of test aircraft reduced to 30 percent of the original forecast to compensate for the effect of the cost of development problems. One should not lose sight of the continuing need for adequate test articles. In the past, for example, there have been cases of new and unanticipated weapon launch requirements which necessitated additional testing.

4. SYSTEM INTERFACES

Consider all aircraft system interfaces, their test requirements and probable costs at the outset of the conceptual phase.

Ensure that the program plan assembled before DSARC I includes broad test plans for the entire program, and that these include scheduling time and costs required for testing system interfaces. The initial program plans sometimes have not anticipated the need for adequate interface testing. For example, if the system includes use of air-to-air or air-to-surface missiles, ensure that provisions are made for testing them in combination with avionics system tests. With the advent of the so-called smart weapons using E-O, IR or laser guidance systems, the interface with the aircraft is not only on the carriage stations and the fire control system but through the necessary displays. Tests need to be conducted to ensure that the planned displays do not limit the system performance. In one program, late selection of a new avionics suit for the aircraft made it impossible to define the missile/aircraft interface at the start of the fixed price contracts. This led to several design iterations to make the interface work correctly.

5. MAJOR WEAPON SUBSYSTEMS

If the aircraft system relies on the successful development of a specific and separately funded major weapon (such as a gun or missile) in order to accomplish its primary mission, this major subsystem should be developed and tested concurrently with or prior to the aircraft.

For example, if the major weapon is a gun, it should be R&D qualified in ground tests and then tested on the aircraft as early as practicable to develop satisfactory gun operation under aircraft G's and temperatures, to determine vibration effects, to investigate system integration problems, etc. Then, the aircraft system should be quickly subjected to a life-time of gun firing, e.g., simulated combat with the reasonable sorties and rounds expended.

There have been fighter programs where the gun tests were run late and problems were encountered with gun gas ingestion and link and case ejection damage.

## 6. PROPULSION SYSTEM

If the aircraft program is paced by the propulsion system development, an early advanced development project for the propulsion may be appropriate for a new concept.

The progress in the development of the propulsion system is normally a key factor in determining when full-scale aircraft development is warranted. However, when other subsystems such as the avionics, are also critical and when there is a time urgency to get the new system, there have been isolated examples where the aircraft system development program has been initiated with an interim power plant. This requires additional engineering and testing and can only be justified in unusual cases. Tests should be planned which use the substitute power plant and should be restricted to providing a platform for other subsystem flights tests. Full system tests should be planned only with the proposed power plant.

## 7. OPERATIONAL SCENARIO

A conceptual operational scenario for operation and use of the aircraft should be developed so that general test plans can be designed. This should include purpose, roles and missions, threats, operating environments, logistics and maintenance, and basing characteristics. The potential range of values on these aspects should be stated.

Whenever typical scenarios do not exist, one can expect problems in creating meaningful test plans. These should be developed as soon as practical, but in view of the long time interval between the pre-DSARC I period and OT&E it is essential that T&E plans make provision for reviews and changes of scenarios. This requirement will obviously have contractual implications but it is better to anticipate the inevitable necessity for change than pretending to be surprised by events that can be foreseen; changes will always be required in all systems but especially in aircraft mission scenarios. For example, the mission for a strategic bomber became that of a tactical support weapon for ground forces in SEA. Several aircraft developed during the 1960s required development and test changes to achieve a hot day performance for SEA operations. Development had been initially pursued based on standard day temperatures. The aircraft had to be modified to provide larger wings to achieve desired hot day performance.

## 8. EVALUATION CRITERIA

Develop evaluation criteria to be used for the selection of the final aircraft system design.

The evaluation criteria should be based on performance factors which are measurable through testing. For example, if the aircraft is designed to provide close air support under adverse weather conditions, these should be specified; if a helicopter is to be designed to provide nap of the earth, pop-up and hover capability, these performance factors should be specified. An evaluation plan should be developed which describes the range of acceptable performance for each factor. If competitive designs are under consideration, criteria for selection should be specified in advance, with critical issues identified for each design.

## 9. UNTRIED ELEMENTS

The aircraft development program should include conclusive testing to eliminate uncertainties of the untried elements.

Untried technology and its application must be backed by reasonable laboratory tests. Untried concepts have been incorporated in aircraft on the basis of paper studies and engineering analyses, and later the development or the production item tests indicated that the initial analyses were in error. Testing should be planned to verify the analysis on all critical items.

If the aircraft is intended to incorporate a large number of technology improvements designed to provide operational improvements over current systems, test milestones to demonstrate that the technology is in hand should exist for each of the improvements. Success should be proved for propulsion, fire control, advanced structural designs, etc. before the system is considered for engineering development. Be aware that, if there are a large number of relatively modest new technology applications in the new system, it may become difficult to conduct total system testing because of the high probability of failures brought about by the large number of new technology applications.

All of the untried elements of the proposed aircraft should be identified. Risks related to these and to alternative approaches should be evaluated and a test program should be conducted. Untried items can be made low risk even when failure potential is high if good alternatives exist. Other untried items which would appear technically to be of low risk can present a major problem if they later prove unworkable, and if alternatives do not exist. For example, in one program where the new rotor system feasibility had been based on tests in a smaller helicopter, the rotor system was considered as a low technical risk and testing was planned accordingly. However, the analysis of risk was wrong, major problems were encountered and the program was cancelled after major cost and schedule overruns.

## 10. BRASSBOARD AVIONICS TESTS

The use of brassboard or modified existing hardware to "prove" that the concept will work should be seriously scrutinized to ensure that the demonstrations and tests are applicable.

When tests are conducted on aircraft avionics that are in the brassboard stage or are modified existing hardware, the system should be evaluated with special attention to such as the following:

(a) Will the packaging of the hardware significantly affect the performance characteristics so that the suggested proof of validation is inconclusive?

(b) Will scaling laws invalidate the findings or introduce new technology problems? E.g., will scaling of the radar affect performance?

(c) Will the laboratory-type environment in which the hardware is tested preclude the generation of data needed to validate that the concept and technology approach will be applicable to an operational environment? Has the aircraft environment (e.g., vibrations from gun firing, sonic environment from engine noise, etc.) been taken into account?

(d) Do the tests include signals, noise, and vibrations (aerodynamic and gunfire) sources representative of those that might be expected in an operational environment? Has the likely EMI and ECM environment been accounted for?

11. NUCLEAR WEAPONS EFFECTS

The subject of nuclear weapons effects should be addressed in the test concept for all aircraft weapons systems where operational suitability dictates that survivable exposure to nuclear weapons effects is a requirement.

In most aircraft systems, inadequate attention has been given to the fact that they are intended for possible operation in a nuclear environment. Following early design for adequate nuclear hardness of subsystems and tests of the components and subsystems, an "all up" aircraft should be subjected to "threat level" EMP. A "pure" operational vehicle is required for EMP tests since special instrumentation and subsystem prototype peculiarities might significantly bias EMP tests. This use of a production aircraft must be weighed against the economics of early identification of modifications to improve survivability from nuclear weapons effects. Early planning must recognize that other agencies will be involved (i.e., DNA and AEC).

## II. VALIDATION PHASE

In the Validation Phase the issues raised by the DCP may be resolved by conducting tests on the system. The development and operational plans will be defined in considerable detail. The reader should review the Phase I checklist items since many of them will be appropriate to this phase. Additional test and evaluation checklist items are:

1. Test Plans and Criteria
2. Milestones and Goals
3. Operating Concepts and Environment
4. Priority of Requirements
5. Test Program Building Blocks
6. Technology Concepts
7. DT&E/IOT&E Plan
8. Test Failures
9. Joint Testing
10. Traceability
11. Competitive Prototype Tests
12. Prototype Similarity to Development and Production Aircraft
13. Prototype Tests
14. Inlet/Engine/Nozzle Match
15. Subsystem Tests
16. Propulsion System
17. EMI Testing
18. Parts Interchange
19. Human Factors Demonstration
20. Contract Form
21. Government Furnished Equipment
22. Military Preliminary Evaluation
23. User Participation
24. Maintenance and Training Publications
25. R&D Completion Prior to IOT&E

## 1. TEST PLANS AND CRITERIA

By the end of the validation phase, test and evaluation plans and test criteria should be established so there is no question as to what constitutes a successful test and what performance is required.

There are many examples where the objectives of a given test were not adequately defined or the criteria for success delineated clearly in advance. To a high degree, this reduces or even invalidates the value of the test process. Repeat testing necessitated by such actions is not uncommon.

The test plan must clearly define the primary and secondary objectives of each planned aircraft test. The test environment, the performance points to be tested, the instrumentation needs, the data collection plan, and the data reduction requirements must be generally stated sufficiently in advance of any test being made.

In summary, the test program for the aircraft should have the answers to the basic 7 "W's?"

What are you testing?
Why are you testing it?
When are you testing it?
Where are you testing it?
What do you expect to find out?
What will you do if test results meet, exceed, or fall short of goals?
What is the effect of test results on the program costs, schedules and the system capability?

Review of the above can assure that testing remains coupled to progress of the program and can prevent useless, inconsequential testing. A formal document which requires the answers to the above questions would change almost any test program ever prepared--and for the better.

## 2. MILESTONES AND GOALS

Assure an integrated system test plan that pre-establishes milestones and goals for easy measurement of program progress at a later time.

In an R&D program some failures may be expected, but the plan should be structured to generally ensure that:

(a) Repetitive failure will be held at an absolute minimum and each substantive failure will be analyzed and the cause corrected before subsequent flight tests.

(b) The schedule will accommodate problems.

(c) There is a clear statement of objectives for each test.

(d) The number of tests that are expected to yield an answer have been identified.

(e) Qualification testing of components and subsystems should occur at the earliest possible time in the program. Where existing technology is involved, qualification can usually occur prior to the onset of flight testing. Where advanced technology is involved, qualification should be introduced just as soon as practicable in the development flight test program--but in all cases before production of operational hardware is undertaken, provided that the prototype hardware represents the production hardware. Component or subsystem problems that are detected at the full system flight test level are extremely costly.

(f) Clear, well-defined milestones for review and commitment to the next test phase have been defined.

Almost without exception, every aircraft program has experienced flight test failures or anomalies. The degree to which corrective action has been taken prior to additional flight tests has varied extremely among various programs. The motivation for continuing flight test without adequate failure diagnosis and corrective action is associated with:

- The desire to claim that the program has completed its major milestones.
- Failure to clearly identify test objectives.
- A superficial conclusion that the failure was random.
- Flying of unqualified components which could have been qualified before flight.

Although milestones are normally shown on a time schedule, it must be understood that the date is a target and the milestone objectives must be accomplished before the milestone will be passed. Cost milestones have little meaning unless development and testing progress can be measured accurately, and this is extremely difficult because R&D is full of surprises and unfolding problems. In past aircraft programs that have been tied to fiscal or date milestones, there has been no practical way of readjustment of the program short of keep going, stop or renegotiate. Since the latter two alternatives are drastic measures, usually this situation led to placing production orders for aircraft in spite of development and test technical difficulties at the time.

## 3. OPERATING CONCEPTS AND ENVIRONMENT

The operational concepts and the environments in which the aircraft will be expected to operate and to be tested in OT&E should be specified.

The expected operational concepts and operating environment of the aircraft should be stated. Aircraft specifications should not be confined to technical items such as speed, weight, turn rate, G's, military specification compliance, etc., but also should provide environmental and operational information on such things as concepts for:

Operation: If the aircraft is to operate in the tropics or desert, this should be clearly stated and aircraft tests planned in that environment. If the aircraft is to operate off of sod runways, this should be stated and aircraft tests planned under these conditions.

Training and Personnel: Simple succinct statements as to the number and training of the personnel that are to be used in operations and test cycles may revise the design and sub-test philosophies and eliminate the wide disparities of results on aircraft programs where maintenance or other environmental considerations are major factors. Few, if any, aircraft systems that have been deployed have functioned to anywhere near the level of proficiency that is experienced when unlimited contractor maintenance is used.

Logistics: The maintenance and supply concept to be used should be specified. Such a thing as the type of maintenance support facilities planned can be an important design consideration.

Such environmental and operational information would have assisted in test planning in past programs and could have precluded major changes in some present aircraft systems and operational limitations in others. Without a positive guide to the likely concepts and environment--reliability, maintainability, availability and accuracy may not be interrelated in the design and test process.

Stress the conduct of the whole system test and particularly the avionics suite test in high temperature, high humidity operating conditions. Although new aircraft are subjected to all-weather testing, the adequacy of the test is dependent upon the actual weather experienced during the scheduled test period. In the past, subsequent operational use has exposed unsatisfactory conditions, particularly in hot, humid climates. For example, in one major aircraft program the hot weather tests were run in Panama and no great problems were encountered. When the airplane was deployed to SEA considerable avionics trouble was caused by condensation. In operations, the aircraft stayed at high altitude long enough to get the airframe cold soaked. After landing, the high humidity resulted in considerable condensation. In the inadequate tropic development testing, apparently the flight profiles had insufficient high altitude time to set up this condition.

## 4. PRIORITY OF REQUIREMENTS

The prime driving requirements for the aircraft mission should be stated and where possible priority and costs should be associated with each requirement.

Normal development requires many tradeoffs; therefore, priorities for various characteristics are necessary for guidance in this process. The contractual documents should state the relative importance of various requirements, e.g., ability to operate in stated environments, cost, speed, maintainability, etc. However, all the characteristics must be carefully considered in any compromises even though they may not be top priority. For example, a weight savings program on one aircraft resulted in reducing the structural life of the airframe by about 60 percent.

The priorities can serve as a basis for scheduling analyses, simulations and flight tests of the aircraft or its major subsystems and components. Because T&E is expensive, it is important that the elements critical to the decision to continue the program be tested as early as practical. For example, in developing a T&E plan for a new close air support aircraft designed to offer greater bombing accuracy than its predecessors, it is far more important to determine the actual bombing accuracy than to precisely determine expected combat radius.

## 5. TEST PROGRAM BUILDING BLOCKS

In the validation phase, demonstrate that the high risk technology is in hand and in planning the full-scale development test program ensure components and the subsystems are adequately qualified for incorporation into system tests.

In the validation phase, necessary testing should be done to demonstrate that the technology is in hand to justify full-scale development. For example, in a bomber program competitive system studies were conducted to adequately define the configuration. This work was done in coordination with competitive engine advanced developments. A sizing and cycle matching process was pursued to firm up on probable engine definition. At the same time, core engine advanced technology was used as a basis to proceed with design of hardware for test engines with the desired by-pass ratios, air flow, specific fuel consumption, thrust, thrust augmentation system, etc. In addition, challenging avionics areas were studied and hardware was built to investigate high risk problems.

In planning for the full-scale development test program, it is important that each component and then each subsystem, and finally the full system be tested in-turn as thoroughly as practical on the ground. Avoid including untested items in the system flight tests. In aircraft testing, normally there are a number of aircraft instrumented and specialized for testing in a given area. For example, the first airplane to fly is usually the stability and control-flight qualities aircraft. Other test aircraft may be dedicated to such things as ground static tests, engine/airframe (propulsion) tests, avionic tests, ordnance tests, post stall tests, and finally full-system tests. Some programs will have more than one test aircraft devoted to an area. The number of test aircraft in the program vary widely. In fighter and attack aircraft developments, the number of aircraft have recently varied from about six to eighteen test aircraft in the basic R&D program. A large cargo airplane program had five R&D aircraft and two heavy bomber developments have been structured around three test aircraft. Whatever the number of test aircraft, the flight test program should concentrate on developing a safe flying machine first and then selectively adding and proving the major subsystems. Finally, the whole system should be scheduled for the testing, debugging, retesting, and finally the demonstration phase.

## 6. TECHNOLOGY CONCEPTS

Each concept to be used in the aircraft system (e.g., aerodynamics, structures, propulsion) should be identified and coded according to prior application, prior or future research; tests for each of the concepts should be specified with the effect of failure identified.

A formal listing of all concepts planned for use in an aircraft system will provide understanding for all parties and enhance the use of experience from prior tests. Also the setting out of the basis for application of the concept can aid in eliminating wishful thinking related to new approaches and at the same time provide an index to the testing community of what needs to be tested in lieu of only documents of what is planned for test. For example, the application of a new rotor system concept led to serious technical problems in one program and eventual cancellation of the development. Since no prior similar (in scale) application existed for the rotor concept, the concept should have been coded for:

- Tests planned--subscale and full scale.
- Effect of failure--weight, cost, time, operational capability.
- Contractual arrangements to allow early and expeditious change of concept in the event of difficulty.
- Whether the customer set aside sufficient funds to match a reasonable percentage of failures or concept changes.

## 7. DT&E/IOT&E PLAN

<u>The aircraft DT&E/IOT&E test plan should be reviewed to ensure it includes ground and flight tests necessary to safely and efficiently develop the system.</u>

Desirable features to look for in the aircraft DT&E/IOT&E test plan include:

(a) Piece part, component, and subsystem development qualifications in that order before including them in the aircraft for system testing.

(b) Before the first flight structural tests of the major airframe assemblies are made, engine/inlet nozzle compatibility tests are conducted in wind tunnels, and the engine must be at least successful through the Preliminary Flight Rated Tests (PFRT).

(c) Continued airframe static testing of critical conditions are desirable to lead broader flight envelope exploration. Ground fatigue tests of the airframe should start as soon as the production airframe configuration is determined. There is considerable value in continuing these until destruction.

(d) Bench tests and system integration lab tests of the avionics and possibly mobile ground tests of the navigation gear and air tests of the prototype avionics gear are desirable before initial airborne avionics tests in the new aircraft.

(e) Ordnance ground testing should precede the ordnance flight testing.

(f) Military Preliminary Evaluations (MPEs) should be conducted as soon as practical so that user/evaluator inputs are available early and necessary corrections of deficiencies can be made during the R&D phase.

(g) All qualified systems, including airframe, engine, crew escape system, avionics and the ordnance system, are combined for final system tests and demonstrations.

(h) 2000-3000 hours of flight test on a sophisticated military airplane are usually necessary for the contractor to be adequately prepared to run a few-hundred-hour demonstration to satisfy the government that the basic R&D is complete.

(i) The test plan must also include scheduling of manning, training, and conduct of the IOT&E together with scheduling the required technical manuals, ground support equipment, test aircraft and test location facilities.

8. TEST FAILURES

Make T&E plans assuming failures--they are inevitable.

DT&E and OT&E test plans should include time and resources necessary for investigating test failures and making provisions for elimination of the cause before the next test of that failed system. Although there are some exceptions, the general rule that no additional major tests will proceed until a vital failure is understood and fixed, should be observed.

In some aircraft programs, failures have occurred which were not adequately diagnosed before further flight tests were made and the failures repeated. For example, if an air-to-air missile damages the airplane during launching, flight tests not involving missile launch could be continued, but if the flight control hydraulic systems failed, the aircraft would be subject to grounding for safety of flight reasons until fixes were made. In all instances of substantial failure, it is better to spend time in careful diagnosis and if necessary, in changing subsequent flight tests and their schedules than to assume the same failure will not recur.

There should be back-up tests planned so that failure of one item will not result in unproductive delay. The cost of test personnel and facilities, dedicated to a program, continues even though a specific test program, because of a failure, may be placed in a stand-by status.

In summary, experience has shown that there has been a marked tendency to be over optimistic in planning time and resources for test.

9. JOINT TESTING

When a new aircraft development program requires joint testing during OT&E, prior to DSARC II, the test plan should include the type of tests and resources required from other activities and services.

Several weapon systems designed for defense penetration or suppression have had inadequate testing and evaluation in relation to their mission objective.

In general, the T&E plan should, as far as possible, include offense/defense engagements representative of those in which the new system is expected to operate. Many programs have not given full attention to this. Offense/defense testing may be addressed in several phases, such as:

(a) Testing against the best simulation of the assumed threat which can be made available, either in the field or in a laboratory with variations in the threats, scenarios, and environment to cover the range expected in combat.

(b) Testing against advanced U.S. technology which may be representative of a potential threat.

(c) Testing against electronic countermeasures must be investigated. In the Conceptual Phase the matter of countermeasures must be considered to ensure that the development is sound. During the development, countermeasures are a secondary consideration; however, after the new system is developed, it is necessary to ensure that it can be used in the presence of countermeasures by the use of technical features of the hardware/software or by alternate operating modes or different tactics. Therefore, later phases of OT&E testing should include appropriate electronic countermeasure aspects.

In summary, there is considerable evidence that weapon systems have been less satisfactory under combat conditions than earlier testing promised. Had test plans been more realistic with better field simulations, the results would have been more meaningful. This in turn may demand joint Service involvements. For example, prototype tanks, armored personnel carriers and advanced anti-aircraft equipments and operators will be required for joint operational testing of a new close air support aircraft.

10. TRACEABILITY

The aircraft development and test program should be designed and scheduled in such a way that if trouble arises the source of the trouble can be traced back through the lab tests and the analytical studies.

The testing and instrumentation plans should be designed to allow correlation and correction of lab tests and analytical studies. Aircraft programs have been designed for success, therefore when a major variance was encountered, the level of ambiguities created by the test set-up and the instrumentation sometimes precluded a simple impact analysis. In many cases the analysis could not be corrected and improvement could not be made without additional testing or instrumentation. Thus, the scheduling of analyses, lab tests, hardware fabrication and full-scale tests should be such that the data from each activity can be constructively used in the next step and traced back through previous steps. If measurements are being made on static or fatigue tests, strain gauge the flight article in the same way and in the same locations, particularly on indeterminate structures. Also, the wind tunnel test points should include the ones that are needed to correlate with analyses and lab tests. As the aircraft system goes from the lab to full-scale, the instrumentation should provide for maximum practical traceability all the way back to the analytical studies.

## 11. COMPETITIVE PROTOTYPE TESTS

When a competitive prototype test program is used, the aircraft should be compared on the basis of the performance of critical missions using both test and operational crews.

The aircraft should be compared on carefully prepared criteria. It might include basing and runway requirements, maintenance efforts per flight hours, flight performance characteristics, survivability, ordnance carrying capability, weapon delivery accuracy, and cost. To the extent possible, aircrews for fly-offs should be a mix of operational and test pilots, and it would be desirable for some of the operational crews to have had experience with the aircraft that the prototype is designed to replace. In an attack aircraft prototype fly-off, tactical crews were used and their evaluations provided valuable inputs for the overall aircraft comparison.

## 12. PROTOTYPE SIMILARITY TO DEVELOPMENT AND PRODUCTION AIRCRAFT

A firm determination should be made of the degree of similarity of the winning prototype (in a competitive prototype program) to the development and production aircraft in order that test results derived from the prototype in the interim period prior to availability of the engineering development aircraft can be utilized most effectively.

In competitive prototype programs, the winning prototype will be used for tests for a period prior to the availability of engineering development aircraft. In order to assure the validity of tests in areas such as drag reduction, stall/post stall/spin and weapons compatibility on the prototype and the applicability of these results for the development and production aircraft, the differences of the aircraft must be understood. For example, in an attack aircraft program the engineering development model incorporated a repositioned landing gear and aerodynamic slats in place of fixed slats.

## 13. PROTOTYPE TESTS

The prototype aircraft test data should be used to determine where emphasis should be placed in the engineering development program.

Carefully review prototype test data to ensure full use is made of the data to plan the subsequent development and tests.

The prototype tests will undoubtedly show deficiencies which should be corrected. For example, one successful prototype showed that the engine inlet/wing arrangement resulted in an intake airflow reduction in a pull-out that tended to stall the engine. In the early prototype tests this undesirable characteristic was handled by a fuel control expedient. The fix later in the prototype test program consisted of a wing slat to restore proper intake air flow at the critical condition so that a power loss was not necessary. The prototype tests will be helpful in planning and conducting the full scale development.

If the level of flight safety risk is low, a sole prototype may be reasonable to demonstrate a system where, for example, the avionics tie-in might be the prime reason for prototyping. On the other hand, the risk may be high to prototype only one new concept V/STOL aircraft.

## 14. INLET/ENGINE/NOZZLE MATCH

The aircraft test program should provide for early and adequate inlet/engine/nozzle match through a well planned test program with time programmed for corrections.

The inlet/engine/nozzle match is the major match in aircraft and is often critical in obtaining the required aircraft performance. Most high performance jet fighter aircraft have experienced unsatisfactory inlet/engine/nozzle conditions during development; this resulted in engine stalls under some rapid throttle operation situations and high drag in some conditions. Full-scale inlet/engine/nozzle wind tunnel tests over the expected operational range of angle of attack, speed, and altitude have been useful in identifying problems and developing fixes so as to achieve low drag, stable, stall-free engine operation, both in steady state and transient conditions where rapid throttle bursts and chops and after-burner light offs and shutdowns were attempted throughout the performance envelope. Late changes of large magnitude in bleed air requirements for boundary layer control, air conditioning, and cabin pressurization can invalidate earlier inlet/engine/nozzle tests and should either be defined early or considered in the range of test conditions.

## 15. SUBSYSTEM TESTS

<u>There should be a balanced program for the aircraft subsystem tests</u>.

The test program for subsystems may be structured using working mock-ups for test of such items as flight control and landing gear and flying test beds for the fire control, engines and any special area of technology such as a super-critical wing. However, the cost of the subsystem test program has to be balanced against the possible cost you might incur if you did not do the testing and subsequently subsystems deficiencies show up in the full system tests.

For a subsystem such as an avionics package that may be available in prototype form well before a prototype aircraft is available, the subsystem may be flown in alternate aircraft (e.g., an avionics system mounted in an aircraft that will simulate the operating environment as closely as possible). Bench testing of avionics components and system integration laboratory testing of avionics are necessary, but results must be supported by data obtained under operational conditions in the flight environment. Subtleties often show up only in flight testing. The airframe should be flown at the earliest practical date and should not be held up awaiting avionics.

## 16. PROPULSION SYSTEM

If the aircraft program is paced by the propulsion system development, an early advanced development project for the propulsion may be appropriate for a new concept.

The progress in the development of the propulsion system is normally the key factor in determining when full-scale aircraft development is warranted. However, when other subsystems such as the avionics, are also critical and when there is a time urgency to get the new system, there have been isolated examples where the aircraft system development program has been initiated with an interim power plant. This requires additional engineering and testing and can only be justified in unusual cases. Tests which use the substitute power plant should be restricted to providing a platform for other subsystem flight tests. Full system tests should be planned only with the proposed power plant.

If the new aircraft is designed to use a new power plant, it is desirable, during the Validation Phase, at least to demonstrate successful operation of the core engine. The specific matching of the complete engine and the airframe and the resulting selection of by-pass ratio, augmentation, configuration, etc. should be expedited so that the engine can be configured and the propulsion engineering development initiated early.

## 17. EMI TESTING

Full-scale aircraft systems tests in an anechoic chamber are desirable for some aircraft.

E-type aircraft with sophisticated avionics and Electronic Warfare Systems (EWS) are prime candidates for EMI full-scale testing in an anechoic chamber. One program tested over 20,000 operating combinations in this manner and fixed 120 interferences. This kind of analysis would have been much more costly and time consuming in flight test.

EMI test plans for all aircraft, but particularly for EWS airplanes, should be reviewed to ensure that the anechoic chamber testing is being used where practical.

## 18. PARTS INTERCHANGE

Early plans should provide for tests where theoretically identical parts, particularly in the avionics, are interchanged to ensure that aircraft systems can be maintained in readiness.

Poorly designed gear or parts not fully developed can sometimes be made to operate properly by fine adjustment.

Test plans must ensure that poor design is not hidden by "fine tuning" or "tweaking" of parts and components of the aircraft and the avionics. If this is permitted, it is unavoidable that future redesign will be required. Furthermore, these tests should provide for the evaluation of time required to put the aircraft or subsystem in full-up readiness status using the planned size and skills of the field crew. These tests are particularly important in aircraft to (a) assess maintainability, (b) to determine if there are adequate interface space tolerances, and (c) to ensure EMI tolerance to maintenance and parts replacement.

## 19. HUMAN FACTORS DEMONSTRATIONS

Ensure adequate demonstration of human factors is considered in the test plan.

At an appropriate time in the concept definition or the development phase, T&E should ensure that the human factor concepts embodied in the proposed system design are tested. Questions of safety, comfort, appropriateness of man-machine interfaces, reaction time, performance under stress, fatigue, and number and skill levels of the personnel required and many other factors must be examined. Testing early versions in the "human acceptability and compatibility" environment is extremely important. This will not only result in better performance, but will also help to reduce (and validate) requirements.

For example, retargeting or selection of alternate weapons under battle conditions may be limited by human factors. Early test can bring out deficiencies which redesign can then correct. The maintainability of any system also is clearly of great importance. Testing to prove maintainability form the human standpoint is useful.

## 20. CONTRACT FORM

The contract form can be extremely important to the T&E aspects.

In fixed price aircraft development contracts there were pressures to force the contractors to obtain specified performance and characteristics regardless of what was learned as the developments progressed. Hindsight now indicates that this was not sensible in a number of cases.

In the Validation Phase the contracting strategy is usually established in the RFP and the subsequent evaluation and source selection process. From the T&E standpoint, the contract should:

(a) Permit early user and evaluator participation.

(b) Establish incentives only after careful consideration and resolution of possible undesirable aspects from the T&E standpoint. The incentives should not be based on extreme corners of the theoretical performance envelope unless there is a high operational payoff. On the other hand, the incentive should not constrain the developer from exploring the likely operational performance envelope.

(c) Facilitate engineering changes resulting from knowledge gained during the test program and from threat changes.

## 21. GOVERNMENT FURNISHED EQUIPMENT

If there are GFE and other government commitments in the proposed contract, there should be a clear statement of responsibility and liability of the interface of the GFE and the development aircraft because of the impact on test schedules and performance.

Relative to the impact on testing, special attention should be given to the following:

(a) Can the gear with required performance be available for test when required? The most prominent aircraft GFE items are engines and ECM.

(b) Can government-supported facilities provide the T&E assistance required at the time needed? If not, is it reasonable to construct the required facilities (test range, instrumentation, building, etc.)? If not, what alternatives are available?

(c) Avoid contract terms on fixed price contracts that vaguely commit the government. Do not include "government support as required" or "test facilities will be made available when needed."

The responsibility for the interface of GFE and development aircraft must be precisely structured. This interface agreement should not be merely in fixed terms. It should include a contractual mechanism to allow the movement of funds from contract to contract without time lag to allow the most cost effective solution to the interface problems.

22. MILITARY PRELIMINARY EVALUATION

Adequate resources should be scheduled for the aircraft Military Preliminary Evaluation (MPE) and a positive program should exist for the utilization of MPE information at the time of IOT&E.

The Military Preliminary Evaluations provide an opportunity for service crews to make an early evaluation of an airplane. Flights by military evaluation personnel early in DT&E may uncover deficiencies related to operational use of the system. These tests must be early so that there is time remaining in the development program to correct the problems discovered. Emphasis during MPEs should be on fundamentals (Is it safe? Does it show promise of providing improved capability? What are the gross deficiencies?) rather than on performance guarantee items (maximum speed, weapons delivery accuracy, etc.). For example, in one aircraft program, the MPE found that the aiming display on the windscreen was too narrow for operational use. During subsequent development, this deficiency was easily corrected and retested. If this deficiency had not been found until IOT&E, at the end of the basic R&D program, the correction could have delayed the initial production program or could have been a costly mod program. Consideration planning should be done to get the most out of the MPEs.

## 23. USER PARTICIPATION

It is imperative that the operational command actively participate in the DT&E phase to ensure that the user needs are represented in the development of the system.

Where user participation in DT&E has been inadequate, additional problems have been discovered when the program progressed to the operational test phase. Some deficiencies discovered late, such as human factors problems, technical manual errors, and design inadequacies, could have been much more easily corrected if they had been found early in the DT&E by user participants.

Initially, the operational test command should play an advisor role during the feasibility and engineering testing, and finally take over leadership in the conduct of the operational testing program. This user participation in DT&E should facilitate the necessary communication and interaction between the developing and operational commands--especially needed during the DT&E and IOT&E phases.

Some aircraft programs in the past have not provided for operators early in the program with the result that when the operators flew the aircraft, items such as bad displays, and poor handling characteristics had not been identified. In one program, the testing was conducted in such a way that testers and users were not permitted to communicate.

## 24. MAINTENANCE AND TRAINING PUBLICATIONS

The aircraft development program should provide for concurrent training of crews and for preparation of the draft technical manuals to be used by IOT&E maintenance and operating crews.

IOT&E should be conducted by maintenance and operating crews uitlizing as nearly as possible the type of materiel and information that will be available for the operational unit. Therefore a timely program should be provided to train maintenance and operating crews. Steps should be taken to ensure that the required materiel (ground support equipment, technical manuals, parts lists, etc.) will be available. Finally, the IOT&E program must be planned so that typical operations can be tested and sufficient data gathered to analyze the results. The main conclusions of the IOT&E will be important in determining the appropriateness of moving the programs into substantial production and deployment.

25. R&D COMPLETION PRIOR TO IOT&E

The testing plans should ensure that before an aircraft system is subjected to IOT&E, the sub-systems essential to the basic mission have completed basic R&D.

Development problems concerning computers and their software, for example, should be solved during DT&E. Development problems carried over into OT&E impede operational suitability testing. Further, development problems addressed under relatively austere field conditions, away from laboratory personnel and their test equipment, are more difficult to solve.

However, in parallel with the IOT&E, it is desirable to continue the R&D effort with the instrumented aircraft on alternate missions and degraded back-up mode testing. For example, in an attack fighter development, the problems that developed in the operational testing effort were quickly reflown on the instrumented R&D aircraft. The diagnosis was easy with the proper data from the instrumented aircraft.

## III. FULL SCALE ENGINEERING DEVELOPMENT PHASE

In this phase, the T&E plans developed in the Validation Phase will be refined and the development testing conducted. IOT&E plans will similarly be refined; personnel will be assigned and trained and the IOT&E conducted.

It is suggested that the checklists for the previous phases, particularly the Validation Phase, be reviewed by those interested in a checklist for full-scale development. The full-scale development checklist includes:

1. Test Design
2. Data for Alternate Scenarios
3. Test Milestones
4. Production Engineering Influence on R&D Hardware
5. Running Evaluation of Tests
6. Simulation
7. Software Tests
8. Avionics Mock-up
9. Escape System Testing
10. Structural Testing
11. Gun Firing Tests
12. Post Stall Characteristics
13. Special Attention Items
14. Sub-System Performance History
15. Flight Deficiency Reporting
16. Crew Limitations
17. Use of Operational Personnel
18. Role of the User
19. Crew Fatigue and System Effectiveness
20. Test Constraints on Crew
21. Complete Basic DT&E Before Starting IOT&E
22. Realism in Testing
23. Test All Planned Profiles and Modes

24. Update of Operational Test Plans
25. Conduct IOT&E Early
26. Missile Launch Tests
27. Operational Test Realism
28. Mission Completion Success Probability

## 1. TEST DESIGN

Test programs should be designed to have a high probability of identifying major deficiencies early, during DT&E and IOT&E.

T&E monitors should assure that testing is emphasized in those areas where major deficiencies are most likely to occur, such as where the state-of-the-art has been significantly advanced in propulsion or avionics.

Test programs should ideally provide time for fixes to be developed and engineering change proposal (ECP) action to be initiated in the R&D program when there is little hardware needing retrofit.

Later in system acquisition, when a substantial quantity of aircraft has been produced and delivered to the user, correction of major deficiencies and modifications becomes more difficult. These usually involve costly retrofit, in addition to interim operational limitations imposed on the user which can impede the performance of his mission. Further, these retrofit programs are funded by aircraft modification money. Modification funds are always in short supply with competition from other aircraft systems. Safety of flight items receive top priority.

There have been two examples of identifying deficiencies, one good and one bad, related to the head-up display (HUD). On one aircraft early MPEs recommended a broader field for the HUD. This change was easily made in the DT&E program. In another program, a desirable HUD change to display more information was not recommended until after deployment. At that point, the cost to change was high and the improvement in capability unsuccessfully competed for the limited aircraft modification funds against higher priority safety of flight items on other aircraft, as well as increased operational capability modification on other aircraft.

## 2. DATA FOR ALTERNATE SCENARIOS

Maximize the utility of the test data gathered by careful attention to testing techniques; aircraft instrumentation; range instrumentation; and data collection, reduction, and storage.

There are an infinite number of scenarios that may become of interest in the use of the systems and the operational testing can only be conducted on a few scenarios. The challenge to the test planners and conductors is to design the program, the instrumentation, and the data collection so that basic information gathered on the selected tests can also be used to reasonably estimate what the system would actually do on alternative missions. For example, a few of the many factors which might be of particular interest from the combined DT&E and OT&E testing are:

| | |
|---|---|
| Readiness | - Ability of airmen to maintain aircraft on alert under all weather, all climate conditions with minimum base support facilities as well as with normal base facilities and logistical support. |
| Performance | - Take-off characteristics from appropriate surfaces and engine out characteristics at various altitudes and temperatures with selected loads representing the allowable envelope. |
| | - Best miles/pound of fuel at different altitudes at various stores ranging from clean loads to high drag loads and without external loads. |
| Target Acquisition | - Ability to acquire representative classes of targets with a spread of acquisition assistance in varied weather and day/night conditions. |
| Survivability | - Ability to destroy or to survive typical classes of fighter and ground based defenses. This would include countermeasures considerations. |
| CEP | - Delivery accuracy, with representative items from various classes of ordnance, from typical attack conditions. |
| Destruction | - Measure kill potential on appropriate classes of targets with a variety of weapons and CEPs if it has not been done already. |
| Recocking | - Turn-around time with various loads, support, and weather. |

The OT&E tests should minimize repeats of DT&E tests, as has sometimes been done in the past, and should strive to expand the tactical and operational aspects to include other conditions and points within the operating capabilities of the system. These data would be used to provide a broad base of information to estimate system performance in alternate scenarios.

## 3. TEST MILESTONES

Development programs should be built around testing milestones, not calendar dates.

Testing milestones are more credible measures of progress of a development program than target dates. Where testing is to be serially accomplished, the completion of a critical phase is more meaningful than meeting an artifically-established calendar date. When a test plan is based on target dates, there is a tendency to compress the testing schedule should test slippage occur. This tends to compromise both quality and quantity of test results.

For example, a target date was specified for completion of the 150-hour qualification test (QT) for the power plant of a new aircraft weapon system. The date seemed to have been artificially selected to apply pressure to the contractor and the developer in the interest of early qualification, although it should be noted that the same engine core was to be used in another weapon system which had slipped its development schedule. The target date did apply pressure to the developer and the contractor, but when they were unable to qualify the engine by the established date, there was no apparent impact--only an extension to the target date for QT completion.

## 4. PRODUCTION ENGINEERING INFLUENCE ON R&D HARDWARE

Encourage that production philosophy and production techniques be brought into an early phase of the design process for R&D hardware to the maximum extent practical.

There have been aircraft programs in which major components have not been qualified until long after production was started. This situation led to an undersirable circumstance where operational suitability could not be determined until a large number of units were deployed.

An intimate interaction between production engineers and design engineers, including test personnel, should be established early in the program. This process will tend to minimize the changes between the R&D test hardware and the production units; hence, there is less probability that new problems will show up in the follow-on T&E tests of the produced system. Some programs have done this splendidly and saved much time and money in moving from development to production.

## 5. RUNNING EVALUATION OF TESTS

Assure that running evaluations of tests are conducted. If it becomes clear that test objectives are unattainable or that additional samples will not change the test outcome, ensure procedures are established for terminating the test.

In contemporary development flight testing, aircraft-to-ground telemetry and computerized data reduction provide real-time readout of test data, and make a running evaluation of the test results possible. This permits testers to identify and stop unproductive or unnecessary tests, or to modify the test as dictated by current data.

In an attack aircraft program, a considerable number of rocket launching missions were planned to demonstrate accuracy. After these tests were completed the data were analyzed and showed that little was learned beyond the first few missions; hence, many missions were wasted.

## 6. SIMULATION

Analysis and simulation should be conducted, where practicable, before each phase of development flight testing.

Analysis, simulation, and other ground testing should be used to predict test outcome and to establish test objectives. The flight test may then be accomplished to achieve the objectives. Comparison of simulation and flight test results provides better understanding of the system. In some cases, the analysis may predict dangerous situations where flight testing would be highly risky. In one instance, the contractor pointed this out and discouraged spin testing. The service decided to conduct the spin tests and lost the airplane.

## 7. SOFTWARE TESTS

Test and evaluation should ensure that software products are tested appropriately during each phase.

Software has often been developed more as an add-on than an integral part of the overall system. Software requirements need the same consideration as hardware requirements in the validation phases. Usual practices often do not sufficiently provide for testing the software subsystem concept. Often the facilities available to contractors for software development and verification are critical to schedule and cost.

## 8. AVIONICS MOCK-UP

Encourage use of a complete avionics system installed in a mock-up of the appropriate section or sections of the aircraft.

The avionics mock-up can be an important part of a system integration laboratory, the key functions of which are subsystem testing, systems integration testing and functional compatibility tests. The unit can be used to provide early crew training and support flight tests.

One typical fighter program used the avionics mock-up to solve airplane wiring and interface problems, to minimize airplane down time for system checkout, to provide a rapid solution to flight test problems, and to verify technical manual procedures.

## 9. ESCAPE SYSTEM TESTING

Ensure the aircrew escape system is thoroughly tested with particular attention to redundant features, such as pyrotechnic firing channels.

Loss of aircrews due to escape system faults has focused wide-spread attention to this system; its vital operation must be demonstrated as highly reliable during the development phase. Redundant systems must be instrumented so that even though the system functions satisfactorily in test, any failure of a redundant circuit will be detected. The failure can then be analyzed and fixed, reducing the possibility that redundant channels will fail at the same critical time.

Emergency egress from a first-line fighter aircraft system has been only 77 percent successful. A detailed investigation of the escape system disclosed sufficient failures of one of the redundant pyrotechnic channels in the escape actuation system so that failure of both channels was not as remote a possibility as thought.

## 10. STRUCTURAL TESTING

Assure that fatigue testing is conducted on early production airframes. Airframe production should be held to a low rate until satisfactory progress is shown in these tests.

Airframe fatigue test programs have identified serious structural problems. Early identification of unsatisfactory conditions has resulted in structural fixes or modified operations procedures so that unsafe flight conditions are obviated.

Fatigue testing should be accomplished on an early production airframe; testing a prototype or a limited production structural model may not yield data representative of the production configuration. Until the structural model survives critical testing, production should be held at a low rate to obviate an airframe modification program involving many delivered aircraft.

Major failure of a fatigue test article before test objectives have been met required redesign of the structure, fabrication of the newly designed article, and reinitiation of fatigue testing on the article. During the structural testing of an airlift aircraft, fatigue testing was begun on the critical section of any early limited production model. When it failed early, a model of the refined "production configuration" was fatigue tested and it, too, failed sooner than desired. Operational limitations were imposed on the aircraft and a third structure representative of the "limited use aircraft" was fabricated for test. The fatigue tests identified problems early; load limitations were placed on the airplane and fixes initiated so that it could be operated safely in peace time while maintaining a higher potential for wartime use.

After fatigue test objectives have been met, it is advantageous to continue testing the structural model until massive failure. This provides additional knowledge of the aircraft in test, as well as data which may be applicable to future design.

11. GUN FIRING TESTS

All forms of ordnance, and especially those which create gases must be fired from the aircraft for external effects (blast and debris), internal effects (shock), and effects on the propulsion (inlet composition or distortion).

Ordnance delivery considerations are extremely important in configuring the airplane. Ordnance tests should be run early in DT&E to ensure satisfactory operation. Tests have uncovered serious design problems resulting from the ordnance arrangement. For example, one interceptor configuration had to be changed because the gases from rockets launched from the fuselage stalled the engine. The redesign placed the rockets in wing pods. In another fighter, gun gas and link and cartridge ejection from a fuselage-mounted high rate of fire gun caused a propulsion problem. On a third fighter, debris resulting from dropping a banded bomb cluster damaged the horizontal tail in early tests.

12. POST STALL CHARACTERISTICS

Special attention is warranted on the post stall test plans for DT&E and OT&E.

The purpose of this testing is to determine aircraft controllability at high angles of attack, in stall and post-stall conditions. This is relatively hazardous; thus, only areas of the performance envelope where stalls are most likely to occur normally need to be investigated in flight. For example, fighter aircraft, designed for high-speed maneuvering flight, should be examined for high speed accelerated stall and post-stall characteristics. This type of testing should be avoided with aircraft designed for low "G" operation. Stall and post-stall characteristics of all types of aircraft should be checked in their approach and landing configurations.

To investigate other edges of the performance envelope and acquire data otherwise obtained by high risk to aircraft and crew, instrumented scale models can be dropped from aircraft, or spin tunnels and computerized simulations can provide other methods of investigating post stall characteristics.

Contractor demonstration of spin recovery is usually required of aircraft most likely to be spun, i.e., fighter, attack, and some trainer aircraft. Once spins are accomplished, duplication should not be attempted on high performance aircraft unless there is strong justification. Two major development programs in the early 70's lost test aircraft in the Services post stall testing.

## 13. SPECIAL ATTENTION ITEMS

<u>Selected hardware items sometimes warrant special attention by testing elements.</u>

There are a number of components and parts that often present significant recurring problems as a result of testing. Some of these are:

(a) <u>Connectors</u> - Connectors are a source of trouble. The major umbilical connectors, generally used as the electrical interface between ordnance and the launcher are particularly troublesome. It is advisable to do everything practicable to insure the continuity of the circuits by electrical checks, functional checks, direct viewing, or, in some cases, x-ray inspection. Bent pins, improper mating, and intermittent contacts on some pins have plagued major programs, both in development and the operational phases. When the circuits are related to warheads or range safety destruct gear, it usually is not practical to make final electrical continuity checks across the umbilical connector. Connector arrangements whereby the mating of the pins for these circuits could be visually inspected would be desirable, and this aspect should be stressed by T&E agencies at design review.

In addition to the test content for electrical continuity across the connectors, a logical operational suitability test would be one wherein the objective would be to show proneness of failure of a particular connector. For example, how easy is it to bend a pin so that the connector will mate but the bent pin will be open? Or, can adjacent umbilical connector sets be mismated?

(b) Lanyards - Lanyards and other safety devices which preclude inadvertent launches and operations, can also sometimes inadvertently preclude a successful launch. When a launch is commanded, the software should be scheduled so that safety pin extraction action operates over a sufficient time period so that variations can be accommodated in the time it takes the stores to go through the launch process.

(c) Safing, Arming and Fuzing - Laboratory devices which can simulate the environment that a fuze will experience during its captive, in-flight and impact phases should be liberally used. It is expensive and difficult to operationally test fuzes over the range of environments expected and often much of the testing can be done separately from the complete weapon system. Alternative safing, arming and fuzing (SAF) concepts can be evaluated inexpensively, with ease and safety through the use of such devices. However, finally the SAF should be included in all the full system tests and in as many other flight tests as practical to insure that subtle effects are not present in flight tests.

## 14. SUB-SYSTEM PERFORMANCE HISTORY

During DT&E and IOT&E of aircraft, ensure a performance history of each sub-system of the aircraft will be kept.

Development is an iterative process. Many pieces of equipment are run many hours in perfecting it or interconnected gear. When equipment is installed in the aircraft for systems tests, it is particularly desirable to maintain a performance history on each subsystem. Each component of the system should be identified and a performance history kept which allows an analysis of its performance with respect to reliability, maintainability, availability, etc. The record would be particularly helpful in analyzing avionics performance.

## 15. FLIGHT DEFICIENCY REPORTING

Composition of flight deficiencies reported by aircrews, particularly those pertaining to avionics, should be given special attention.

To compose meaningful "write-ups" (routine aircrew prepared deficiency reports after a flight) test aircrew members require system orientation and training; in the past they have often improperly written-up alleged malfunctions because they did not understand the operations or the function of a given avionics set. Sometimes the unsatisfactory operation resulted from the wrong switch being used. Write-ups caused by a lack of training and understanding result in wasted trouble shooting. Additional test time is then needed to repeat the test with the proper operator actions.

Also ensure that the test discrepancy reporting format throughout DT&E and OT&E phases provides a consistent basis for test evaluation during the program. It is important to clearly identify the cause of failure and to determine if it is random. This can best be accomplished if accurate correlation of the system deficiency history is possible.

## 16. CREW LIMITATIONS

Ensure aircrew limitations are included in the tests.

Most air launched tactical missiles, especially those used in close support, require visual acquisition of the target by the air crew and/or an air/ground controller. Thus, the system performance is very much dependent upon visual acquisition. The ability to acquire the target must not be assumed trivial and must be tested in operationally realistic conditions to determine to what extent this factor may limit the capability of the total system.

In a normal launch sequence of an electro-optical (E-O) type missile, the crew is required to (a) locate and acquire the target visually, (b) determine that what he sees is a real target, (c) decide whether it lies within the size, contrast, and range envelope of the weapon, (d) re-acquire the target on his cockpit display by means of the weapon's seeker, (e) verify that the seeker has "locked-on" the proper target, (f) launch the weapon, and (g) maneuver away from the target area. This sequence of activities must be conducted in a dynamic (and very likely hostile) environment; the effect is to make system performance very much dependent upon the operator's ability.

17. USE OF OPERATIONAL PERSONNEL

Recommend experienced operational personnel help in establishing measures of effectiveness and in other operational test planning. In conducting OT&E, use typical operational aircrews and support personnel.

Experienced operators should participate in developing measures of effectiveness and in planning the operational test so that results will be operationally significant. There was a tendency in the past for the initial operational command tests to be largely a repeat or extension of the DT&E activities. The result was that these tests were of little significance in determining operational adequacy.

Economical utilization of resources suggests that personnel gaining experience in planning and conducting IOT&E on an aircraft system should be utilized to plan the follow-on OT&E.

Typical operational unit personnel should conduct the operational test. The use of lead crews and highly experienced maintenance crews and specialists may bias the outcome of the evaluation by providing information which may later prove to be optimistic. For example, an aircrew which carries a lead navigator generally delivers weapons much more accurately than a recently-designated combat-ready aircrew with a relatively inexperienced navigator. Highly qualified operational evaluators should participate in planning operational tests, in evaluating results and in some cases in conducting the tests where the bias is understood.

18. ROLE OF THE USER

Ensure that users participate in the T&E phases so that their needs are represented in the development of the system concept and hardware.

Initially the operational command should play an advisory role during feasibility and development testing, and should play a more significant role in the conduct of the test program as it becomes operational.

In a case where the user was not active during the development of a tactical fighter system, the scope displays of the system were not fully satisfactory to the operational command.

## 19. CREW FATIGUE AND SYSTEM EFFECTIVENESS

In attack aircraft operational testing, and particularly in attack helicopter tests where vibration is a fatiguing factor, ascertain that the tests include a measure of degradation over time.

Short, few-per-day flights may not simulate the operational situation where many sorties in a hostile environment would be expected to take place at a high rate per day over a long period. Within the bounds of safety to the crews, they should perform in situations where data can be collected relative to weapon system effectiveness as a function of human fatigue.

## 20. TEST CONSTRAINTS ON CREW

Detailed operational test plans should be evaluated to determine that the test imposed conditions on the crew do not invalidate the applicability of the data so collected.

The evaluation of realistic performance must be a major objective in any OT&E. Constraints such as requiring the crew to perform atypical functions, or unrealistic test conditions may throw doubt on the validity of the data as it relates to weapon system effectiveness. Realistic combat operator task loading should be included to the extent possible.

One fighter program carried on OT&E in phases. Avionics testing was stressed during one period. Considerable care must be taken to insure that operational testing of this nature yields realistic results. For example, on this same fighter, during training and probably during the avionics operational test phase, the second crew man helped the pilot considerably by monitoring radar and other displays during low level penetration; however, in combat penetrations it was found that the pilot got much less help during this critical phase because the number two man was involved in electronic warfare matters.

## 21. COMPLETE BASIC DT&E BEFORE STARTING IOT&E

Before a weapon system is subjected to IOT&E, all critical subsystems should have completed basic DT&E with the significant problems solved.

Occasionally development deficiencies have been carried into IOT&E. This is undesirable as it impedes meaningful operational testing. Solutions to unsolved development problems are difficult to obtain under relatively austere field conditions of IOT&E away from laboratory personnel and their diagnostic equipment. Technical problems that surface in IOT&E can sometimes be most efficiently addressed by the contractor's use of an instrumented development test aircraft.

On a new fighter program development testing of digital avionics was carried over into initial operational testing. Test results provided little significant operational information.

## 22. REALISM IN TESTING

Ascertain that final DT&E system tests and IOT&E flight tests are representative of operational conditions.

An attack airplane successfully completed DT&E and OT&E type testing, but structural problems showed up in combat operations. All the testing was done from bases with good, smooth ramps, taxiways and runways. The combat airfields had much poorer ramps and taxiways which resulted in structural problems for the new airplane.

Operational testing must be planned and conducted as realistically as practicable so as to preclude operational deficiencies in combat and so as to minimize costly modifications of production aircraft.

23. TEST ALL PLANNED PROFILES AND MODES

Tests should be conducted to evaluate all planned operational flight profiles and all primary and back-up, degraded operating modes.

The flight profiles need to be evaluated to ensure that no unpredicted problems occur. In aircraft test programs the primary design profiles are generally well tested. The OT&E efforts re-test these design requirements to insure they can be satisfied in operational use. The testing should also cover those operational profiles which stress the system. In addition, the operational tests should exercise backup operating modes.

The backup operating modes need to be tested because aircraft avionics reliability problems and battle damage may cause the primary mode to fail. For instance, a carrier may have several navigation systems such as inertial, doppler, or bomb/nav radar to provide position data for air launched missile inputs. All systems might be used in the primary operating mode. In an operational environment, it is not unlikely that some launches might be made with only one of these systems remaining in operation. Therefore, these backup, degraded operating modes should be tested to determine their characteristics and capabilities.

24. UPDATE OF OPERATIONAL TEST PLANS

Ensure operational test plans are reviewed and updated as needed to make them relevant to evolving concepts.

Operational concepts on which aircraft design is predicated change as time passes. It is essential that operational test plans be based on the latest version of the operational concept. In one program if the helicopter had been tested on the basis of an OT&E plan prepared at initiation of the development contract, satisfactory results would not have proven anything because of changes in the concept of employment, environment, and tactics.

In another case, valid operational information relative to an airlift aircraft limited by structural problems was obtained from OT&E because the test plan was modified to accommodate major changes to the original operational concept.

25. CONDUCT IOT&E EARLY

Ensure operational suitability tests are planned to attempt to identify operational deficiencies of new systems quickly so that fixes can be developed and tested before large scale production.

Continually update OT&E plans so that testing can be expedited as soon as it is appropriate to start. Look at suspected problem areas early. For instance, operational tests should be used to identify problem areas associated with the tactics of delivering a missile in realistic combat conditions which may significantly degrade the operational effectiveness or utility of the weapon system. For example, an optically guided missile tracking subsystem may not function as desired for some sun angle conditions, or a semi-active laser seeker guided missile requires reflected energy from the target, thus imposing possible constraints on the geometry of the designator, the launch airplane and the target. Human factor problems associated with displays, task loading and weapons delivery functions may restrict total capability of the system.

These problem areas need to be identified early in the IOT&E phase so that possible engineering fixes can be studied, developed and tested prior to large scale production acquisition to allow for a more tactically usable missile. Problem areas associated with human factors can be examined to determine special training requirements or hardware and software modifications.

26. MISSILE LAUNCH TESTS

Review the final position fix planned before launching inertial guided air-to-surface missiles.

In operational tests of bomber/missile systems, there have been instances in which artificial position fixes were utilized just prior to missile launch. Optimistic missile accuracy data results, unless the position fixing test procedures are similar to those used for operational missiles. System accuracy for inertial guided air-launched missiles will be most dependent upon position, velocity, and heading data provided by the bomber. If the test program uses beacons, radar reflectors or other cooperative accurate fix features in the near vicinity of the target, the accuracy results will be better than could be expected on an operational mission. An operational bomber may have to plan to make the last fix on a prominent feature at a considerable distance from the target due to the possibility of battle damage or countermeasures near the target.

27. OPERATIONAL TEST REALISM

Ensure operational testing is realistic.

For example, in testing the operational navigational capability of an aircraft to reach a briefed target, the up-dating procedures used during the test should be those expected in actual employment. If the navigation system is up-dated in an unrealistic fashion, the operational effectiveness of the system in terms of the ability of the aircraft to acquire the enemy target may be biased towards a best possible condition. A recent operational test was conducted where the aircrew was advised of the amount of their navigation error and were asked to correct so that a target could be acquired. This compromised operational realism.

28. MISSION COMPLETION SUCCESS PROBABILITY

Mission completion success probability factors should be used to measure progress in the aircraft test program.

The test program should use mission completion success probability (MCSP) as a management tool to assess on a continuing basis the capability of the system to meet operational commitments. Standardized measures which evaluate overall system performance and are established as system development goals are more significant than non-standardized component bench test specifications and individual subsystem reliability predictions. For example, avionics MTBFs on bench qualification tests usually run some large factor better than the MTBF of the subsystem when it is installed in the aircraft. Aircraft peculiar environmental factors like actual temperatures experienced, vibration, and G's are difficult to adequately simulate in bench testing or system integration laboratory tests.

## IV. SUBSTANTIAL PRODUCTION/DEPLOYMENT PHASE

This phase occurs after the DSARC substantial production decision. Follow-on OT&E will be conducted with production hardware. The test and evaluation checklist includes:

1. Operational Test Realism
2. Design OT&E for Less than Optimal Conditions
3. New Threat
4. Certification of Ordnance
5. Test Fixes
6. Inadvertent Influence of Test
7. Deficiencies Discovered In-Service
8. Lead the Fleet
9. Direct Support Aircraft

The reader should also review the checklist items in the previous phases, especially the last phase, since many of these items will be applicable during this phase.

1. OPERATIONAL TEST REALISM

Ascertain operational testing is conducted under realistic combat conditions.

The offense/defense battle needs to be simulated before the evaluation of the weapon system can be considered completed. Whether this exercise is conducted within a single service (as in the test of an attack helicopter against tanks) or between services (as in the test of an attack aircraft system against tanks with anti-aircraft protection), the plans for such testing should be formulated as part of the system development plan.

Special attention should be placed on the realistic environment to be used in the operational test, on the vulnerability of the various elements of the system (FAC, platform, target designator, etc.) and on the use of models and simulators to evaluate the post launch activities affecting target kills (probability of break lock of missiles, reliability, invalid launches, etc.) when the ordnance is not launched during tests.

Similarly, the OT&E offense/defense tests should be performed in appropriate weather. The practicality of finding the right conditions for some of these tests during a reasonable IOT&E may require some conditions to be simulated and possibly some to be deferred as goals for the follow-on OT&E. In summary, the goal is that the full production equipment should be tested under appropriate offense/defense, day/night, weather conditions.

2. DESIGN OT&E FOR LESS THAN OPTIMAL CONDITIONS

Structure the OT&E logistical support for simulated combat conditions.

In operationally testing tactical fighter aircraft, the aircraft should be operated from minimal basing facilities--relatively unimproved runways, taxiways, and ramps, mobile maintenance shelters, and substandard administrative and living accommodations. Planning for support of the aircraft under these conditions should be exercised.

Although these conditions may seem overdemanding, bare base conditions should be anticipated.

## 3. NEW THREAT

Be alert to the need to extend the OT&E if a new threat shows up.

It is important to ensure that adequate testing of the aircraft system is carried out against current threats and that the T&E be responsive to new threats, should they be identified later.

The operational test should be re-instituted to evaluate system adequacy in the face of new threats encountered after the system is operational and the first follow-on OT&E phase is complete. The continuing training activities that usually generate reliability and CEP data for war plan purposes, should be considered also as an additional means for testing responses to new threats.

## 4. CERTIFICATION OF ORDNANCE

Assure that ordnance to be delivered by an aircraft system is certified for that aircraft.

Most military aircraft systems are flexible enough to carry a considerable spread of ordnance. Sometimes the arrangements to qualify the many ordnance options on the aircraft are loosely planned; the contractor does some of the work and the Service does part. In addition, there are new munitions being developed, some which become available may not have been included in the initial test plans; hence, certification of ordnance may be required during the production and deployment phase.

## 5. TEST FIXES

Test fixes resulting from earlier operational testing.

Following initial operational tests which identify problem areas, follow-on OT&E should investigate the adequacy of the fixes incorporated, particularly if the IOT&E did not run long enough to test the fixes.

For example, on one bomber missile program a rocket nozzle deficiency showed up in a ground qualification test of a motor just at the end of the equivalent of IOT&E testing. Fixes were developed and ground tested, but extensive full system flight tests with the fixed nozzle had to await follow-on OT&E.

6. INADVERTENT INFLUENCE OF TEST

OT&E plans should provide measures for insuring that actions by observers and umpires do not unwittingly influence trial outcomes.

Observers and umpires can provide important clues to the participants of operational suitability offense/defense testing, and in that way, may lessen the validity of the test. For example, in a recent test program where air/ground duels were being conducted, observers looked in the direction from which they had been told that the aircraft would approach. This inadvertently disclosed the direction of approach to the ground party in the duel. Similarly, concentrations of observers at a certain location may clue the air crews where to search first for the ground targets.

Plans should obviate compromising the test in this manner by prescribing necessary observer and umpire discipline.

7. DEFICIENCIES DISCOVERED IN-SERVICE

Be aware that in-service operations of an aircraft system will surface deficiencies which extensive follow-on OT&E probably would not uncover.

Formally conducted OT&E is expensive, time-consuming, and should be stopped when the basic test objectives have been met. In-service operation of an aircraft system provides rapid accrual of flight and maintenance experience. Routine operations and training will serve to identify design and operational deficiencies not found in OT&E. Operational organizations often have maintenance data analysis units, and they recognize a significant problem from periodic maintenance inspections or from aircrew reported discrepancies. Serious problems may require diagnostic testing, development of a fix, and even additional OT&E.

After many years in the inventory, a strategic bomber system experienced major structural fatigue problems. This necessitated a major modification program preceded by structural testing and development of the fix. A good fatigue test program during the R&D might have identified this problem before all the aircraft were produced. On the other hand, there are some items which can only be economically tested in-service. For example, it may be very costly to attempt to test all combinations and permutations of a complex avionics digital program in OT&E. It may be more reasonable to plan for in-service correction of a reasonable number of things that can only be adequately tested in the fleet environment over a relatively long period of use. Contractors may be required to provide in-service correction of some things where the cost of specialist support in the field is economical compared to the extensive DT&E and OT&E otherwise required.

8. LEAD THE FLEET

Accelerated service test of a small quantity of early production aircraft is advisable during follow-on OT&E and thereafter.

These accelerated test aircraft which are flown to accumulate flying hours much faster than normal may disclose major airframe and engine deficiencies which the entire fleet might be expected to experience should early corrective action not be taken. Early discovery of any service induced deficiency provides more time to develop a fix, test it, and start modification of the fleet.

A trainer aircraft used in combat as a forward air control aircraft and as a fighter-bomber was subjected to early accelerated service test. A major propulsion problem was surfaced and fixed before large quantities of these aircraft were delivered.

9. DIRECT SUPPORT AIRCRAFT

OT&E for close support fixed-wing aircraft and fire suppression helicopter systems should emphasize system ordnance delivery accuracy and system survivability.

Where an aircraft has been designed for close air support under low ceilings and poor visibility, it should be tested in OT&E under these conditions with live ordnance to evaluate its unique capability. In the close air support role, accuracy is of primary importance--accuracy in the sense of a tight cluster of bomb impacts around the target. Accuracy should be determined as precisely as possible with particular attention to the gross errors, as ground commanders are wary of air-dropped "short rounds"--inadvertent delivery of ordnance by friendly aircraft on friendly ground troops.

The determination of survivability should also receive high interest. Offense/defense tests should be conducted to measure significant parameters related to vulnerability, such as the following:

- Exposure time as the aircraft penetrates hostile defenses, maneuvers for ordnance delivery, and withdraws.
- Ranges and angles from the defense while the aircraft is observed.
- Sun angle as it relates to detectability (glint off the aircraft).
- Background when the aircraft pops up to acquire the target (e.g., sky versus terrain).
- Aircraft noise as a function of wind direction, weather, clouds, and battlefield noise.

These data can be used in estimating the probability of survival for the aircraft.