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AGARD Flight Test Techniques Series

Volume 7

on

Airborne Radar Flight Testing

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARDograph No.300 Vol.7

AIR-TO-AIR RADAR FLIGHT TESTING

by

R.E.Scott

A Volume of the

AGARD FLIGHT TEST TECHNIQUES SERIES

Edited by

R.K.Bogue

This AGARDograph has been sponsored by the Flight Mechanics Panel of AGARD.

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PREFACE

Since its founding in 1952, the Advisory Group for Aerospace Research and Development has published, through the Flight Mechanics Panel, a number of standard texts in the field of flight testing. The original Flight Test Manual was published in the years 1954 to 1956. The Manual was divided into four volumes: I. Performance, II. Stability and Control, III. Instrumentation Catalog, and IV. Instrumentation Systems.

As a result of developments in the field of flight test instrumentation, the Flight Test Instrumentation Group of the Flight Mechanics Panel was established in 1968 to update Volumes III and IV of the Flight Test Manual by the publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, the Flight Mechanics Panel decided that further specialist monographs should be published covering aspects of Volume I and II of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group was established to carry out this task. The monographs of this Series (with the exception of AG 237 which was separately numbered) are being published as individually numbered volumes of AGARDograph 300. At the end of each volume of AGARDograph 300 two general Annexes are printed; Annex 1 provides a list of the volumes published in the Flight Test Instrumentation Series and in the Flight Test Techniques Series. Annex 2 contains a list of handbooks that are available on a variety of flight test subjects, not necessarily related to the contents of the volume concerned.

Special thanks and appreciation are extended to Mr F.N.Stoliker (US), who chaired the Group for two years from its inception in 1981 and established the ground rules for the operation of the Group.

The Group wishes to acknowledge the many contributions of E.J.(Ted) Bull (UK), who passed away in January 1987.

In the preparation of the present volume the members of the Flight Test Techniques Group listed below have taken an active part. AGARD has been most fortunate in finding these competent people willing to contribute their knowledge and time in the preparation of this volume.

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ABSTRACT

This volume in the AGARD Flight Test Techniques Series describes flight test techniques, flight test instrumentation, ground simulation, data reduction and analysis methods used to determine the performance characteristics of a modern air-to-air (a/a) radar system. Following a general coverage of specification requirements, test plans, support requirements, development and operational testing, and management information systems, the report goes into more detailed flight test techniques covering a/a radar capabilities of: detection, manual acquisition, automatic acquisition, tracking a single target, and detection and tracking of multiple targets. There follows a section on additional flight test considerations such as electromagnetic compatibility, electronic counter-countermeasures, displays and controls, degraded and backup modes, radome effects, environmental considerations, and use of testbeds. Other sections cover ground simulation, flight test instrumentation, and data reduction and analysis. The final sections deal with reporting and a discussion of considerations for the future and how they may impact radar flight testing.

* * *

Le présent volume AGARD sur les techniques d'essai en vol décrit les différentes techniques d'essai en vol, l'instrumentation d'essai en vol, la simulation au sol, la réduction de données et des méthodes d'analyse employées afin de définir les caractéristiques d'un système radar air-air moderne. Après la description générale des spécifications requises, des batteries de test, des besoins en matière de support, des essais de développement, des essais opérationnels et des systèmes intégrés de gestion, le rapport donne une description plus détaillée des techniques d'essai en vol, qui couvre les capacités d'un système radar air-air en: détection, acquisition manuelle ou automatique de la cible, poursuite de cible unique et détection et poursuite de cibles multiples.

L'autre volet du rapport concerne d'autres aspects des essais en vol tels que la compatibilité électromagnétique, les contre-contremesures électroniques, les commandes et les visualisations, les modes dégradé et de secours, les effets radome, les conditions d'environnement et de mise en oeuvre des bancs d'essai.

Les autres sections traitent de la simulation au sol, l'instrumentation d'essai en vol, la réduction des données et l'analyse. La section finale du rapport concerne la rédaction des comptes-rendus, des discussions et des considérations pour l'avenir et leur incidence éventuelle sur les essais en vol des radars.

ACKNOWLEDGEMENT

The author wishes to acknowledge the invaluable assistance from many colleagues in the preparation and review of this volume. Without the time, information and advice freely provided by them, plus their encouragement in its preparation, this volume would not have been possible. Special thanks go to representatives of Boeing Military Aircraft Co., Kansas; General Dynamics Corp. and Texas Instruments Corp., Texas; Aeritalia, Reparto Sperimentale di Volo and Fabrica Italiana Apparecchiature Radioelettriche S.p.A., Italy; Messerschmitt-Bölkow-Blohm, Germany; Centre d'Essais en Vol, France; British Aerospace, GEC Avionics Ltd. and Aeroplane and Armament Experimental Establishment, United Kingdom; US Naval Air Test Center and Westinghouse Electric Corp., Maryland; 3246 Test Wing Eglin AFB and ITT Corp., Florida; 4950 Test Wing, Aeronautical Systems Division and US Air Force Wright Aeronautical Laboratory, Wright Patterson AFB, Ohio; 57th Fighter Weapons Wing Detachment, Luke AFB, Arizona; Lockheed-Georgia Co., Georgia; Martin Marietta Corp., Florida; and US Air Force Operational Test and Evaluation Center Detachment and US Air Force Flight Test Center, Edwards AFB, California.

CONTENTS

LIST OF ABBREVIATIONS

a/a	Air-to-air
a/g	Air-to-ground
ACM	Air combat maneuvering
ACMI	Air Combat Maneuvering Instrumentation
ACMR	Air Combat Maneuvering Range
AGC	Automatic gain control
AGL	Above ground level
AR	As required
AS	Air superiority
ATE	Automatic test equipment
BET	Best estimate of trajectory
CCB	Configuration Control Board
CFAR	Constant false alarm rate
CM	Configuration management
COMSEC	Communications security
CRT	Cathode-ray tube
dB	Decibels
deg	Degrees
DT&E	Development test and evaluation
ECCM	Electronic counter-countermeasures
ECM	Electronic countermeasures
ECS	Environmental control system
EED	Electro-explosive device
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ESM	Electronic support measures
FA	False alarm
FAR	False alarm rate
FCC	Fire control computer
FCR	Fire control radar
FFT	Fast Fourier transform
FM	Frequency modulation
FOT&E	Follow-On Operational Test and Evaluation
FOV	Field-of-view
FP	Force protection
FPS	Feet per second
ft	Feet
FTR	Fighter
g	Acceleration due to gravity
GL	Gimbal limits
GMT	Ground moving target
GMTR	Ground moving target rejection
GPS	Global Positioning System
GS	Ground speed
HUD	Head-up display
IF	Intermediate frequency
IFF	Identification friend or foe
INS	Inertial navigation system
IOT&E	Initial Operational Test and Evaluation
LOS	Line-of-sight
LRS	Long range search
LRU	Line replaceable unit
M	Number of ST/BIT failures
MFD	Multifunction display
MIS	Management information system
MSL	Mean sea level
MUXBUS	Multiplex bus
N	Number of ST/BIT tests
N/A	Not applicable
nm	Nautical miles
O&S	Operation and support
OFP	Operational flight program
OPSEC	Operations security
OT&E	Operational Test and Evaluation
P^3I	Pre-planned product improvement
P_{CUM}	Cumulative probability of detection
P_D	Probability of detection
PAD	Point area defense
PI	Pure intercept
PRF	Pulse repetition frequency
R	Range to target
RAM	Raid assessment mode
RCR	Raid cluster resolution
RCS	Radar cross-section
REF	Reference
RF	Radio frequency
RTS	Return to search
RV	Reject velocity
RWS	Range while search

SMS	Stores management subsystem
SRB	Safety review board
SS	Supersearch
ST/BIT	Self-test/built-in-test
STE	Special test equipment
STT	Single target track
SWT	Search-while-track
T/M	Telemetry
TD	Target designator
TGT	Target
TRB	Technical review board
TSPI	Time space position information
TWS	Track-while-scan
VS	Velocity search
VSWR	Voltage standing wave ratio
WOW	Weight-on-wheels

Air-to-Air Radar Flight Testing

by

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SUMMARY

This AGARDograph describes flight test techniques, flight test instrumentation, ground simulation, data reduction and analysis methods used to determine the performance characteristics of a modern air-to-air (a/a) radar system. Included is a general coverage of specification requirements, test plans, support requirements, development and operational testing, and management information systems. Detailed flight test techniques cover a/a radar capabilities of: detection, manual acquisition, automatic acquisition, tracking a single target, and detection and tracking of multiple targets. For each mode, there is an explanation of what to evaluate plus conditions and factors to consider. Following is a section on additional flight test considerations: self-test and built-in-test, electromagnetic compatibility, electronic counter-countermeasures, displays and controls, degraded and backup modes, mode mechanisation alternatives, radome effects, radar processing, environmental considerations, interfaces, configuration management, operator knowledge, and use of testbeds. The section on ground simulation and test covers lab uses, limitations, requirements, test methods, instrumentation and data, data processing and data analysis. The flight test instrumentation and data section includes the use of video tape, internal radar data, avionics interfaces, telemetry, on-board special controls and reference data. The section on data reduction and analysis addresses video, first and second generation, data merging and analysis techniques. Additional sections cover reporting and a discussion of considerations for the future and how they may impact radar flight testing.

1 INTRODUCTION

This volume deals with the flight test and evaluation of modern multimode air-to-air radar systems. These systems are normally pulse doppler, characterised as having a synthetic display, i.e., displaying what the system determines is a target as a small symbol (such as a square) with no operator interpretation involved. The radar is normally highly integrated with other on-board systems such as multifunction/purpose displays, a head-up display, navigation systems, weapons control and delivery systems, electronic warfare/countermeasures systems, other sensor systems, and even with the aircraft steering and flight controls. Increasingly complex computational capabilities are allowing the implementation of more radar modes, submodes and achievement of greater accuracies. This has simultaneously put greater demands on the flight test instrumentation and analysis capabilities, and the accuracies of the ground-based reference systems. At the same time, more limits are being placed on available test time and funding, necessitating more efficient testing and further usage of ground test facilities when available and applicable. In order to fully cover the subject of a/a radar flight testing, this volume also addresses related topics such as: specifications, test plans, ground simulation and reporting. While a volume could be written for each of these general subjects alone, this document includes only those portions which apply to a/a radar testing.

This volume is intended to be a "menu" of what to test and suggestions on how to do it. Since a/a radars vary considerably in what modes they contain, the intent of this volume is for the reader to choose whatever mode is appropriate, and then to choose from the suggested evaluation criteria and factors as best befits the implementation and intended usage of that mode. While the most typical installation of this type of a/a radar is in a fighter aircraft, the objectives and methods of tests described herein do not preclude their use for other applications such as in airborne early warning or tail warning systems. This volume is organised by radar capability, such that it should be possible to use the described test methods for these other applications. The results of lessons learned have been incorporated throughout this volume under the appropriate subject for better continuity.

The use of specific references has been intentionally minimised, not as an attempt by the author to take credit where credit is not due, but to make this volume applicable to the widest variety of radar systems. The intent is to have this volume address a generic radar rather than to imply the test requirements or techniques are applicable to only one specific system. This approach also lessens the possibility of including any proprietary, sensitive or classified information.

2 RADAR SYSTEM

The purpose of this section is to provide an explanation and baseline for the type of radar that is addressed in this volume on testing, and to explain the terminology used throughout.

2.1 Typical System Description and Capabilities

One of the most common uses of airborne radar is to detect the presence of other airborne vehicles. This can be for the purpose of providing information for overall situational awareness, to avoid collision, or it may be to accomplish an intercept and attack. The radar is usually designed not only to detect airborne targets but also to track and provide accurate target information for gunfire or missile launch solutions. Some a/a missiles may have a passive radar receiver which uses the aircraft fire control radar for illumination of the target, or a seeker that also uses target data telemetered to it from the fighter aircraft radar. The a/a radar may also have the capability to detect storms and turbulence, either through specifically designed modes or through the use of modes originally designed for other purposes. Some aircraft may also have an a/a

Identification Friend or Foe (IFF) interrogator mounted on the radar antenna, with the IFF responses integrated with the radar display to give pointing commands and/or confirmation of target presence. Additionally, many a/a radars have the added capability of air-to-ground (a/g) modes such as sea search and ship detection, ground moving target indication, ground moving target track, fixed target track, real-beam ground map, doppler beam sharpening, high resolution ground map, and terrain following/terrain avoidance. However, air-to-ground modes are not a subject of this volume.

The radar must provide rapid and accurate long range detection and tracking capability in order that the aircrew may react and the fire control system has enough time for weapon delivery in very dynamic situations. For close-in engagements, the radar system must provide automatic lock-on for guns and short range missile weapon delivery. Radar systems are required to meet these performance standards in concert with standards of reliability, maintainability, electromagnetic compatibility, environmental tolerance, hardware constraints, and life-cycle costs.

2.1.1 Radar Units

A typical radar is packaged in several separate line replaceable units (LRUs) depending on its size, and the size and layout of the host aircraft. The radar LRUs usually include: antenna, receiver, transmitter, radar signal processor, and radar computer. Brief descriptions of each typical LRU are contained below to further orient the reader to the type of radar being addressed in this volume on testing.

ANTENNA
The radar antenna is normally a high gain, vertically polarized, flat plate, slotted planar array. It may be driven by electromechanical servos or by a hydraulic drive system. It is normally gimballed in two axes to provide 120-degree coverage in azimuth and elevation. Some type of relative phase shift among the four quadrants of the antenna array is usually employed in order to cause the main antenna beam to be directed at various angles (lobes) for target tracking modes. The selection of antenna scan patterns and their location in azimuth and elevation can be manually or automatically selected depending on the radar mode. Antenna movement is usually controlled by the radar computer.

RECEIVER
The radar receiver receives the return signals, and in conjunction with the radar signal processor, determines the presence of a target. When a beacon interrogation mode is included in the radar, a separate path from normal signal processing is usually provided.

TRANSMITTER
The transmitter provides high power radio frequency (RF) input to the antenna. Radars will generally have several (four to six) in-flight selectable frequencies within a given operating band. The LRU which controls the operating frequency may have several (three or four) configurations, each with its own set of the four to six operating frequencies. This overall frequency mechanization is primarily intended to minimize interference between radars on aircraft in the same vicinity. To meet the size, weight and power limitations of many current aircraft, short wavelength based systems are required, causing most a/a radars to be operated in the frequency band of 8 to 12.5 GHz.

RADAR SIGNAL PROCESSOR
The signal processor extracts the required target information from the returned signals, and then uses that information to generate range and angle data for target tracking. Digital data is transferred between the signal processor and the radar computer over a dedicated radar digital multiplex bus (MUXBUS).

RADAR COMPUTER
The computer contains and runs the radar Operational Flight Program (OFP) - the software which controls the radar system operation. The extensive use of digitally configured and controlled systems has several advantages compared to older analog systems: 1) provides flexible signal processing, 2) allows the system to more easily and quickly be updated with newer mechanizations and to address new threats, 3) accommodates hardware changes during the system life cycle, 4) presents a consistent user interface, and 5) lowers the probability of unintended production differences. Major radar performance changes can be made by modification of the software within the constraints of memory availability and throughput of the computer system. Most radar OFPs are structured in a

module form, based on functional divisions of the tasks to be performed by the radar system. The radar computer sets up the radar system in its operating modes, directs the display symbology, and routes data to the aircraft fire control computer (FCC) via the aircraft avionics MUXBUS. In addition to controlling the basic radar modes, the radar computer also provides the capability to perform continuous performance monitoring (self-test) or interruptive performance monitoring (built-in-test) of the radar hardware to detect, identify, and isolate malfunctions. Missile seeker pointing signals or telemetry data for radar missiles are provided by the computer. Configuration control of all the on-board computers is extremely important, since the radar OFP configuration may be compatible with only certain combinations of other systems. The radar system may have one or more internal busses to allow the LRUs to communicate, including a serial digital multiplex bus tying all LRUs together, and a dedicated high speed bus between the radar signal processor and the radar computer.

2.1.2 Other Features

DISPLAYS
The radar LRUs may include a dedicated radar control panel and a dedicated radar display. However, many of the latest radar systems do not have either, as they instead employ Multifunction Displays (MFDs) which can display information from any sensor (including the radar), and which have programmable controls around their periphery to control the radar. Depending on the mechanisation and cockpit layout, radar data may be displayed and controlled on any one of several MFDs. The displayed radar information is generally the same for all air-to-air search modes and may include: 1) minimum and maximum altitude coverage of the selected scan pattern, 2) range scale (velocity scale in velocity search), 3) current antenna elevation bar of the selected scan pattern, 4) pulse repetition frequency (PRF), 5) aircraft ground speed, true airspeed, heading and altitude, 6) antenna azimuth and elevation position carets, 7) target acquisition (cursor) symbol, 8) grid lines and, 9) the horizon line. Radar detected targets may be displayed as solid rectangles and tracked targets as solid diamonds. The acquisition cursor can be a set of two short, parallel lines displayed in a search mode. The display may also contain additional data, such as IFF-detected targets, or target information datalinked from other detection sources, depending on the aircraft application. The display is usually in a raster scan format. Radar targets are most commonly displayed using a range versus azimuth display (B-Scan) or target velocity versus azimuth. The displayed range scale is manually selectable or may be automatically changed by moving the acquisition symbol beyond 95 percent of the current displayed range to increase the displayed range scale, or under 5 percent of the current displayed range to decrease the displayed range scale. The radar may detect and display many (60 or more) targets at any given time.

Several radar or radar-derived parameters are displayed on the aircraft Head-Up Display (HUD). One of the primary symbols is a Target Designator (TD) box. The TD box may be a small hollow square which identifies the line of sight to the target whenever the radar is tracking a target. The TD box position is computed from the azimuth and elevation angles of the radar antenna. Information concerning target range, closing velocity and g's may also be displayed on the HUD.

CONTROLS
The appropriate radar operating modes and mode parameters can be selected by activation of switches located on a radar control panel or push buttons on the MFD, in conjunction with switches located on the throttle grip and flight control stick. The stick and throttle controls are designed so that, in a visual situation, the pilot need not look in the cockpit. The throttle grip switch functions that affect radar operation can include: control of antenna elevation, positioning of target symbols on the radar display and action commands such as calling for an air combat mode. Radar commands that may be initiated through switches located on the flight control stick include: radar boresight commands, target track commands and mode change/rejection commands. The push-buttons located around the MFD can allow execution of data entries, change of radar modes, and change of MFD displays.

PULSE REPETITION FREQUENCY
Air-to-air radars use a number of different PRFs, categorized as high, medium and low. High PRF is primarily used to detect long range head-on aspect targets in velocity only, although some implementations do use frequency modulation (FM) techniques to determine target range in high PRF. Medium PRF is most commonly used for target detection and is also the most common PRF set used in tracking. Low PRF is used for longer detection ranges under look up conditions when no ground clutter returns are present. Interleaving high and medium PRFs is often used to obtain longer range detection performance under many operating conditions.

SCAN
In the search modes, the radar uses a bar raster scan technique. The antenna sweeps in azimuth using various patterns and widths with fixed separations between bars in elevation. The scan center for the +/- 10 and 30-degree scans is the azimuth of the pilot positionable acquisition symbol on the display. The +/- 60-degree scan covers the full gimbal limits in azimuth. The antenna elevation angle is operator positionable over the entire +/- 60-degree range. The typical operator selectable air-to-air radar parameters are:

Range Scales: 10, 20, 40, 80, 160 nautical miles (nm)
Scan Volume: +/- 60 degrees azimuth and elevation

Azimuth Scan Width: +/- 60 degrees (wide), +/- 30 degrees (medium), +/- 10 degrees (narrow)
Elevation Scan: 1, 2 or 4 bars
Target History: 1, 2, 3, or 4 (present targets and up to 3 additional frames of target history, variable in intensity)

2.2 Typical Modes

To perform in the air-to-air arena, most radars have several primary modes for search, acquisition and track designed to fit a particular environment for airborne target detection and acquisition. Mode control may either be "manual" (selectable by the operator) or "auto" (automatically selected by the FCC depending on the scenario). In auto, whenever the operator selects any one of several weapons modes, the radar operating mode, display range scale, and the azimuth and elevation scans are initialized to the parameters programmed in the FCC. For example, the selection of medium range missile may automatically command the 80-nm range scale, 120-degree azimuth scan, and 2-bar elevation pattern in the search mode. The operator may be able to manually override any of the initialized conditions, if desired. Some modes, such as auto-acquisition, may only be commanded automatically with no provision for manual selection. The logic and equations to achieve these modes will vary among radars due to differences in specifications and the particular approach taken by the radar designer. More emphasis is now put on hands-on, heads-up radar operation to reduce pilot workload and improve cockpit visibility. This means the primary radar controls are mounted on the stick and throttle to reduce the need for the operator to remove his hands and distract his attention to controls located throughout the cockpit.

Typical a/a radar modes are listed and explained below in order to acquaint the reader with the types of testing addressed in this volume. Not all radars will contain all of the modes described. The specific mode terminology is not the same for all a/a radars, however the terminology listed below will be used consistently throughout this volume, and a sufficient description is given such that the reader should be able to determine the equivalent mode in any system of interest.

2.2.1 Mode Descriptions

The a/a radar modes described are:
- Long Range Search (LRS)
- Range While Search (RWS)
- Velocity Search (VS)
- Manual Acquisition
- Auto-Acquisition
- Single Target Track (STT)
- Raid Assessment Mode (RAM)
- Track-While-Scan (TWS)
- Self-Test/Built-in-Test (ST/BIT)
- Electronic Counter-countermeasures (ECCM)
- Degraded and Backup modes

LONG RANGE SEARCH (LRS)
In the LRS mode, both high and medium PRFs are employed on an interleaved basis. On one antenna azimuth scan, transmissions are at a high PRF; on the next azimuth scan, medium PRF is used. If a multiple elevation bar scan is selected, the PRF sequencing is alternated at the start of each frame to achieve both high and medium PRF coverage at all altitudes. The radar uses FM techniques on the transmitted pulse to determine target range when in high PRF. At ranges greater than those practical for detection in medium PRF (more than 80 nm), an all high PRF FM waveform is used, and at very short ranges (10 nm or less), an all medium PRF waveform is used. The LRS display is a B-scan, range versus azimuth presentation. All antenna, azimuth and elevation scan patterns, and range scales are selectable.

RANGE WHILE SEARCH (RWS)
Range while search mode is designed to perform against targets in either look-up or look-down profiles. Medium PRF can be used for both look-up and look-down conditions, although it is normally used for look-down situations, and low PRF is used for look-up (low clutter environments) for somewhat longer detection ranges. A selection can be made for "normal" PRF, which will allow the radar to automatically select between low and medium PRF based on clutter levels and/or antenna elevation angle. This may allow alternating operation in low PRF and medium PRF in a multiple bar scan pattern, where the upper bar(s) are in low PRF and the lower bar(s) are in medium PRF. The radar may have an Altitude Line Tracker/Blanker to provide an indication of aircraft altitude above terrain and blank target returns at this range. This function can be automatically enabled upon entering an air-to-air mode, and manually disabled or reenabled by the operator. The radar will have a preset main lobe clutter notch to filter out ground clutter returns which will also delete any ground or airborne targets with a radial velocity at or below the notch speed. This notch velocity (sometimes termed the Reject Velocity (RV) or Ground Moving Target Rejection (GMTR) velocity) is often set between 50 to 60 knots, but may be selectable by the operator to any one of several speeds as low as 25 or as high as 110 knots, depending on the situation.

VELOCITY SEARCH (VS)
Velocity search uses high PRF to provide detection of high closing velocity, head-on targets in look-up and look-down situations. The VS mode has the potential to detect high closing rate targets at greater ranges than the LRS mode by using only high PRF

waveforms with no FM ranging. All antenna azimuth and elevation scan patterns are selectable. VS mode has a velocity versus azimuth B-scan type display. The displayed symbols are the same as for LRS, except the target symbol position represents the target's relative closing velocity versus range, and the VS cue is displayed instead of a range scale cue. The VS display may also indicate the target velocity relative to the radar equipped aircraft velocity, and may have a limited capability to display relative target range if VS includes ranging techniques.

MANUAL ACQUISITION

Once a target is detected, the pilot can acquire (lock on to) the target (cause the radar to go into single target track (STT) on that target) by bracketing the displayed target return with the acquisition cursor and activating a designate switch (usually located on the control stick). The detection files are then searched for the presence of this target. If the target is found, the antenna slews to the azimuth and elevation of the target detection, and may be put into a small rapid acquisition scan to confirm the presence of the target. At designation, all target symbols are blanked from the display. The radar operates in medium PRF during the acquisition sequence.

AUTOMATIC ACQUISITION

The radar automatic acquisition modes usually are not directly selectable by the operator, but rather are automatically selected by the weapons system (to override any other mode) when required to support short range detection and automatic acquisition of a target. The most common types of automatic acquisition modes, called air combat maneuvering (ACM) modes, are: supersearch (SS), vertical scan, slewable scan, and boresight. The ACM modes are mechanized to automatically lock on to the first target which appears in the field of view of the selected scan pattern, and are usually limited to a maximum range of 10 nm. If more than one target is detected in the same beamwidth, the closest target in range is the one selected by the radar for lock-on. The modes are optimized for high maneuvering, head-up attack situations. Tracking is accomplished in medium PRF and uses the same track mechanization as in single target track.

The supersearch scan pattern covers the HUD field of view (an area approximately 20 by 20 degrees). The radar uses a multiple bar (typically 4 or 6 bars) overlapping scan pattern, starting at the bottom and working towards the top, to search for targets within the 10 nm range window. Vertical scan is a 3-bar pattern that covers a 10 by 40 degree pattern centered 10 degrees above the aircraft water line at 0 degrees azimuth. The bottom of the pattern extends down to approximately the center of the HUD field of view. The slewable scan pattern is initially centered at 0 degrees azimuth and elevation when selected. The pattern size is typically 40 degrees azimuth by 20 degrees elevation. The center may be manually relocated by the operator within the radar gimbal limits by means of the radar cursor control. In boresight, the radar is caged to the aircraft armament reference line. The radar will then lock on to the first detected target within 10 nm. If several targets exist within the beamwidth, the radar will lock on to the nearest one. The fighter can be maneuvered to place the desired target within the boresight in order to achieve lock-on.

Except for slewable scan, the scan patterns are all aircraft stabilized, i.e., they stay in the same relationship with respect to the aircraft fuselage during maneuvering. In some mechanizations slewable scan is space stabilized, i.e., it is roll and pitch stabilized with respect to the ground regardless of aircraft maneuvers. Once lock-on is achieved from any of the scan patterns, the target can be tracked throughout the full field of view of the radar. Altitude line tracker/blanker software permits the elimination of altitude line false alarms in search modes and false lock-on to large ground discretes or water in the ACM mode.

The ACM displays are similar to the normal air-to-air track displays except the range scale is automatically selected to 10 nm, and the mode indicated is ACM. No acquisition symbol is displayed, and no target symbols are displayed prior to lock-on. In order to prevent the radar from locking on to the altitude return, some systems keep track of the location of the altitude line and can display it as a part of the ACM mode display. If enabled while in ACM, it will appear at a range equal to either the altitude line (if the altitude line is being tracked) or the system altitude above sea level (if the altitude line is not being tracked).

When the radar is commanded to enter an ACM mode, it typically goes into the SS pattern first, with the operator able to select any other pattern using the Return-to-Search (RTS) switch prior to the radar locking on to a target. This selects the next scan pattern, such as vertical scan, then slewable scan, then boresight, then back to SS, etc. The pilot can reject a target that the system has acquired and is tracking by selecting RTS, and the radar will search further out in range at that beam position, then continue the ACM scan pattern. However, once a target has been acquired and is being tracked, selection of RTS causes the radar to break lock on that target, but does not cause a change in the scan pattern. The scan pattern can only be changed if the system is not tracking a target at the time of receipt of the RTS command. When the pilot rejects a target by depressing the RTS switch, or when track is lost for any other reason, the radar returns to the ACM scan pattern from which the target was acquired.

SINGLE TARGET TRACK (STT)

When a track is established, the target symbol typically becomes diamond shaped and the acquisition symbol disappears from the display. The target symbol may have an attached vector line with its length proportional to target speed, and its direction representing target direction relative to the fighter. During STT, a considerable amount of data is available on the target, some of which is displayed and much of which is transmitted to the other aircraft avionics subsystems via a MUXBUS. Some of the information is calculated by the FCC based on the target track provided by the radar. Typical information displayed on the radar display, in addition to the target symbol indicating target range and bearing, is target altitude, closure rate, magnetic ground track, calibrated airspeed and aspect angle. The FCC also can compute and display a horizontal intercept steering angle to the target. The STT display may have an automatic range scale switching feature. This automatically switches the display to the next higher range when the target range is 95 percent of the present maximum range scale, and switches automatically to the next lower value when target range is 45 percent of the present maximum range scale.

Single target track is normally accomplished using medium PRF, to track the target in angle, velocity and range. However, some radars have the capability to track in high PRF, wherein the target is tracked in angle and velocity, with FM ranging to periodically approximate target range. Once the target is acquired in high PRF, the radar will attempt to switch to medium PRF as soon as it can. Medium PRF ranging is more accurate than the FM ranging used in high PRF. If the radar senses that it is about to lose track on the target, it may enter into a reacquisition sequence using a small scan pattern in an attempt to re-establish track. If track is lost, the radar will revert to search mode. The pilot can intentionally break lock by selecting RTS.

RAID ASSESSMENT MODE (RAM)

The raid assessment mode (sometimes named the raid cluster resolution (RCR) mode) is a high resolution mode which expands a cluster of targets normally displayed as one target in STT, and displays them as individual targets. This enables the pilot to assess a multi-target environment. A medium PRF waveform is transmitted and alternates between a search and spotlight phase to provide a track file on several more targets in addition to the original tracked target. RAM is selectable in all ranges but is usually limited to 40 nm for operation.

TRACK-WHILE-SCAN (TWS)

The TWS mode is designed to provide simultaneous multiple target detection and tracking, generally of up to 10 targets. When the radar detects a target a number of times (as a function of range) in successive scans, it may automatically establish a radar track file in the radar computer. Or, the radar may be commanded by the operator to establish a track file on a specific target. The primary difference between this mode and STT is that the antenna continues to scan in TWS, with the target detections on each scan used by the radar computer to compute target tracking information. With a TWS track file established, the radar can display target range, azimuth, and aspect angle. The operator has the capability to prioritize the targets depending on the situation, such as time to intercept. For the highest priority target, the radar will display additional tracking information such as target Mach and altitude. The radar has the capability (if so directed by the operator) to transition from TWS to STT on the highest priority target without breaking lock. TWS normally operates in medium PRF, at all selectable range scales, but at reduced azimuth coverage (typically up to +/- 30 deg).

SELF-TEST/BUILT-IN-TEST (ST/BIT)

Self-test (ST) is a non-interruptive capability that continuously monitors radar performance during normal operation, with many of the tests being performed at the end of a bar (sometimes called off-bar) during the time the antenna is transitioning from one scan direction to another. Also, other checks can be performed, such as: scanning system transducers for evidence of arcing, and monitoring peak power, voltage standing wave ratios (VSWR) and over-temperature. When abnormal or fault conditions exist, the radar system can indicate the fault, may be able to indicate the severity of it to the operator, and may shut itself down to prevent damage if a severe fault exists.

Built-in-test (BIT) is operator initiated. It is the capability to further test and isolate failures, generally at least to the line replaceable unit level, in order to give the operator additional information on the system's status and to allow maintenance personnel to fix it. In most instances, initiation of BIT removes the radar from normal operation for several minutes. The display for a detected ST or BIT fault is usually separate from the main radar display, although short messages or annunciations may be inserted on the radar display to call the operator's attention to another area.

ELECTRONIC COUNTER-COUNTERMEASURES (ECCM)

Requirements are normally imposed on a radar system for ECCM to prevent an adversary from jamming or deceiving the radar system. These can be inherent ECCM capabilities due to the design of the radar (such as that of a pulse doppler radar versus a pulse radar) or active measures the radar may take in the event it senses it is being jammed. Specific ECCM measures and techniques used will not be discussed in this volume, as they vary considerably from radar to radar, and are also highly dependent on the threat. However, general guidelines for testing are included in Section 5.3.

DEGRADED AND BACKUP MODES

Radar systems usually have provisions for backup or degraded modes of operation depending on the particular aircraft and radar system design. For instance, if the inertial navigation system (INS) were to fail, the attitude data which it normally provides to the radar to maintain antenna stabilization would be lost. In this case, the data can be obtained from the HUD rate sensors, but the radar mode is degraded and space-stabilization is not as effective. In another case, if the FCC were to fail, the INS would take over as the aircraft avionics MUXBUS controller, but the radar STT display would not have all the normal target data on it since some of it was computed in the FCC.

Examples of backup radar modes are pulse search, manual track and flood. These are modes which allow some radar capabilities when a radar failure has occurred. Pulse search is a backup air-to-air mode that employs a low PRF pulse waveform, and is therefore only effective in look-up situations. All antenna scan patterns and range scales are selectable, and the display is the normal range versus azimuth. Targets are displayed according to the amplitude of the return. Since ground clutter obscures airborne target returns in look-down situations, radar returns are blanked in this mode when the antenna is tilted down. Pulse search can be used in all of the radar automatic acquisition modes except supersearch. The track displays are the same as in STT.

Manual track provides a backup angle tracking mode in the event the normal automatic angle tracking capability is inoperable. When manual track is selected by the operator, the antenna is placed in a two-bar, narrow acquisition scan pattern. The target is tracked by placing and maintaining the acquisition cursor on the target symbol and adjusting the antenna elevation control to maintain illumination of the target. The display is similar to a search display except that only a small area is scanned.

Flood mode may be selected as a last resort backup ranging mode for air-to-air gunnery. It is used when radar track cannot be established in the normal modes. When flood is manually selected, the radar switches to a separate flood antenna and is commanded to high PRF. Target ranging is manually initiated by the operator and the radar automatically acquires the nearest target within a two mile range limit. Targets are acquired in range only, not angle. The closest target may be manually rejected and the next target out in range acquired, if so desired. Target information is displayed by the range bar on the HUD. No display of radar information is provided in this mode.

2.2.2 Radar Integration

In order to accomplish the necessary mission tasks, the radar is integrated with the other avionic systems, usually by means of one or more aircraft avionics Multiplex Busses. A common type is the MIL-STD 1553 data bus that has a data rate of one megabit per second and uses Manchester II biphase level codes. Numerous aircraft subsystems may be connected to the MUXBUS. A dual redundant bus is often used, with one subsystem (such as the fire control or central computer) as the bus controller, and another subsystem (such as the inertial navigation system) serves as the backup bus controller. All transfers of data are controlled by the bus controller. For example, the bus controller causes aircraft pitch, roll and heading information to be sent from the INS to the HUD, radar (for antenna stabilization and clutter rejection), and displays. The radar sends target data via the MUXBUS to the fire control system which uses this information to compute and display weapon delivery selections.

Also, there are discrete signals (usually to and from the radar controls on the stick and throttle), analog signals (such as attitude information from the navigation system) and video sent from the radar to the displays. An interface control document contains a description of all interconnections between the radar and the other avionics systems, controls and displays. Figures 1(a) and 1(b) are typical radar interface diagrams--Figure 1(a) shows typical discrete and analog interfaces, Figure 1(b) shows typical MUXBUS interfaces, and Table 1 is a list of typical data communicated between the radar and other systems. Radar integration may include the use of telemetered data transmissions to exchange target information with other detecting and tracking systems, such as ground or airborne early warning platforms, or other fighters and interceptors.

2.3 Typical Terms

In addition to the terms described so far, several others are used in this volume. Ground tests refer to testing on the ground with the radar installed in the aircraft, while lab or ground lab tests refer to those accomplished in a laboratory setting usually with a considerable amount of external simulation and stimulation equipment required. References to the fighter, the aircraft or the production aircraft are intended to address the radar-equipped aircraft with the radar as installed in its intended use vehicle (as contrasted with installation in a testbed). Targets refers to airborne single and multiple flying vehicles (usually another aircraft, but also could be something such as a cruise missile) which can be similar or dissimilar to the radar-equipped aircraft. Ground moving targets are normally vehicles on the ground which form a part of the background when the radar is in an a/a mode looking down towards the ground.

In a single-seat aircraft, the terms operator and pilot are used interchangeably since the pilot is the radar operator (as well as the operator of many other systems), whereas a two-seat or more aircraft may have a separate radar operator. In either case, there should be little difference as far as testing is concerned.

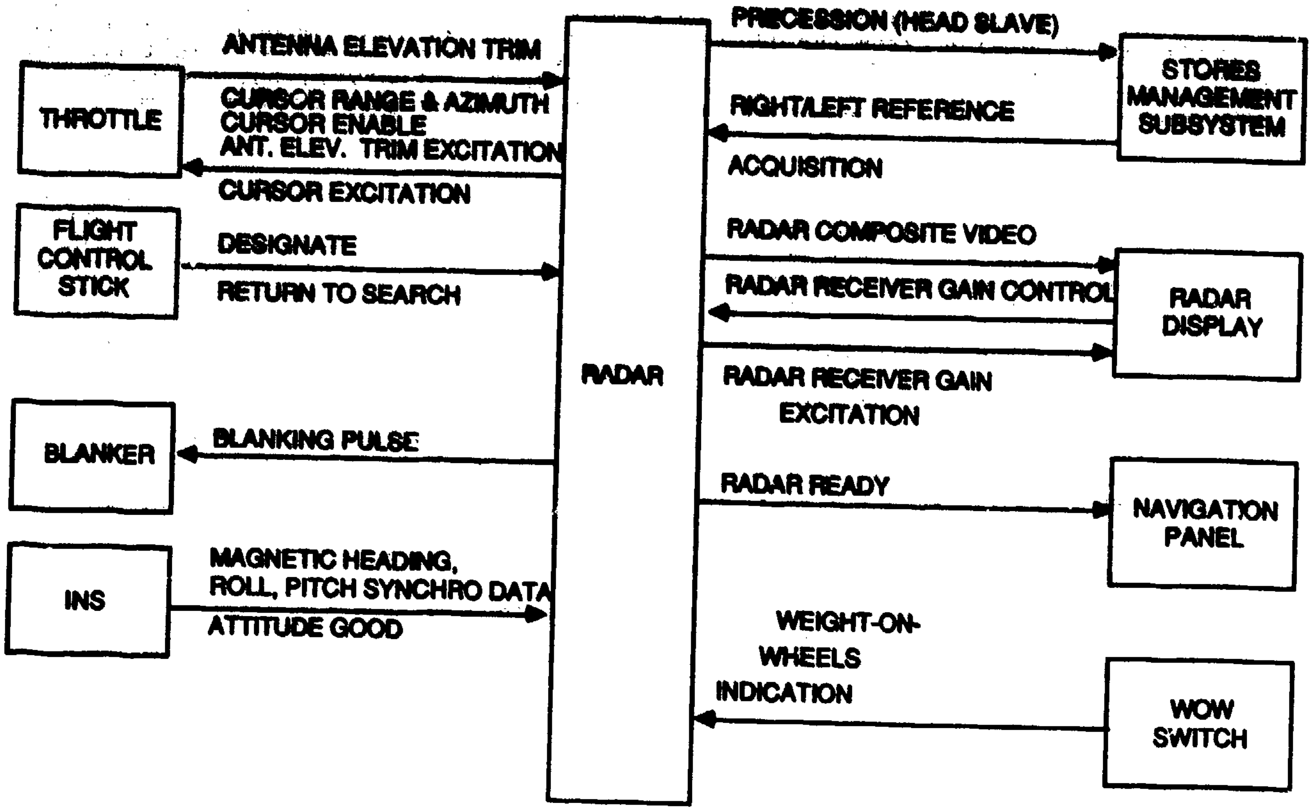


Figure 1(a) Typical Radar Discrete and Analog Signal Interfaces

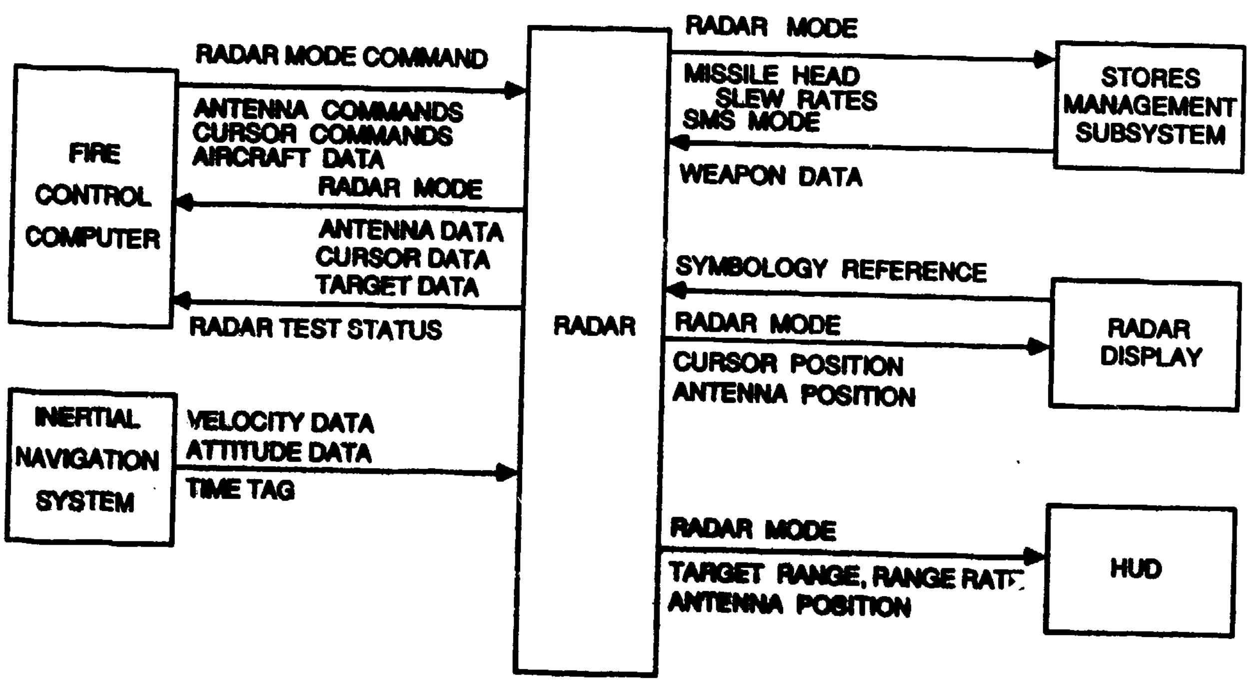


Figure 1(b) Typical Radar MUXBUS Interfaces

Table 1   Typical Communicated Radar Data

From FCC to Radar

Radar Mode Command
Azimuth Angle Command
Elevation Angle Command
Total Cursor X, Y, Z
Cursor Correction X, Y
Cursor Reference Update
Drift Angle
Roll, Pitch, Yaw Corrections
Auto Tilt Angle
True Airspeed
True Angle of Attack
Roll Rate
Pitch Rate
Yaw Rate
Normal Acceleration
Data Validity
Aircraft Symbol Range and Bearing
Elevation Symbol Range and Bearing
FCC to Radar Roll Calibration
System Altitude

From Radar to HUD

Radar Mode Word
Slant Range
Range Rate
Antenna Azimuth
Antenna Elevation
Relative Target Velocity X, Y, Z
Fore/aft Cursor Movement
Left/right Cursor Movement
Target Acceleration X, Y, Z
Relative Target Range X, Y, Z
Antenna Tilt Angle
Radar Test Status
Kalman Clock
Antenna Azimuth Center

From Radar to FCC

Radar Mode Word
Slant Range
Range Rate
Antenna Azimuth, Elevation
Radar Mode Word 1
Radar Mode Word 2
Relative Target Velocity X, Y, Z
Fore/aft Cursor Movement
Left/right Cursor Movement
Target Acceleration X, Y, Z
Relative Target Range X, Y, Z
Antenna Tilt Angle
Radar Test Status
Kalman Clock
Antenna Azimuth Scan Center
Radar-FCC Roll Calibration

From Radar to Stores Management Subsystem

Radar Mode
Weapon Azimuth Slew
Weapon Elevation Slew
Precession (Head Slave)

From Stores Management Subsystem to Radar

SMS Mode Word
Delivery Mode
Weapon Identification
Rounds Remaining
Right/Left Reference
Acquisition

From INS to Radar

INS Mode Word
Time Tag
Velocity X, Y, Z
Platform Azimuth
Roll
Pitch
True Heading
Magnetic Heading
Roll Synchro
Pitch Synchro
Platform Heading Synchro
Attitude Good Indicator

From Throttle to Radar

Antenna Elevation Trim
Cursor X/Y, Range/Azimuth
Cursor Enable

From Radar to Throttle

Cursor Excitation
Antenna Elevation Trim Exciaation

From Flight Control Stick to Radar

Designate
Return to Search

From Radar to Blanker

Blanking Pulse

From WOW Switch to Radar

WOW Indication

From Radar to Display

Radar Mode Word
Cursor Azimuth
Cursor Range
Antenna Azimuth
Antenna Elevation
Radar Video
Gain Excitation

From Display to Radar

Symbology Reference
Gain Control

From Radar to Navigation Panel

Radar Ready

3 FLIGHT TEST TECHNIQUES - GENERAL

Test and evaluation is an important part of the development, production, and deployment of a radar system. Air-to-air radar system tests are performed in the laboratory, in the aircraft on the ground, and in flight--usually in that order. Tests performed on the bench in the laboratory are normally the most convenient, quickest, least expensive, and safest. Flight tests are the least convenient, take the longest time, are most costly, and present the greatest danger to personnel and equipment. They also are most susceptible to uncertainties in the weather and availability of equipment. Radar evaluations should be performed in the laboratory before installation in the aircraft, when feasible. Some tests that can only be performed with the radar installed in the aircraft may be performed on the ground. Flight tests should be performed only when necessary and only when laboratory and ground tests have reduced the uncertainties to the greatest extent feasible, i.e., maximized the potential for success. Some tests can be performed only in flight; and, in any event, flight performance eventually must be demonstrated.

The best sequence for an a/a radar evaluation is as follows: 1) test individual radar system units on a bench (simulating the presence and function of other radar units), 2) test the full-up system in a lab with all the radar units operating together, 3) test the radar in an anechoic chamber where the external environment can be well controlled, 4) evaluate the radar on an antenna range with and without the radome installed, 5) perform ground and flight tests in a testbed aircraft, and 6) perform ground and flight tests in the production aircraft.

The actual process of defining test requirements may be initiated by determining what is needed in the final report/assessment by the "customer" (i.e., what must be known about the system to make necessary decisions such as proceeding to the next development or production phase). This can continue through definition of data, analysis and instrumentation requirements, and lead to the definition of test conditions. Other major factors which should be included in the test definition process are: the kind of testing to be accomplished--diagnostic/research, development or operational, and the radar status--whether it is in development, production or modification.

The kind of testing to be accomplished has a major impact on the test plan. Diagnostic or research type testing is concerned with the evaluation of features for the purpose of design development. The end result of this testing can be a "go/no-go" decision for continued development or a recommendation for the proposed final design. The intent is to acquire data on the radar under test. Usually, no established criteria are imposed for performance acceptance or rejection, rather the objective is to determine whether the radar system design has the potential to do the job for which it was conceived. Development Test and Evaluation (DT&E) is concerned with the performance evaluation of the final radar system design. The principal method of evaluation is the quantitative measurement of the radar's ability to perform its intended functions. DT&E is primarily intended to evaluate radar specification compliance. Operational Test and Evaluation (OT&E) is conducted using the production version of the radar to assess its ability to accomplish the intended operational mission and to establish operational procedures. Operational testing is primarily concerned with mission performance. While some specific, quantitative requirements are imposed, test criteria for operational testing often are of a qualitative nature. More details on DT&E and OT&E are contained in sections 3.1 and 3.2, respectively. It should be recognized that research, DT&E and OT&E are not mutually exclusive, rather that the differences are primarily ones of emphasis. For example, research testing often produces data that result in a major design change. However, DT&E may also result in changes, requiring testing to a depth sufficient to allow engineering analysis of the problem. A "go" or "no-go" answer often is not sufficient. On the other hand, DT&E cannot ignore mission suitability when evaluating a new design. Compliance with published specifications is not sufficient if DT&E reveals an operational problem. DT&E should reflect mission requirements when appropriate. Most test programs are bounded by time and resources constraints. One method of staying within these limits during a test program is to combine DT&E and portions of OT&E testing, using the same data for independent evaluations.

A test plan ties together test objectives, priorities, milestones, test and engineering interfaces and responsibilities, development and operational test requirements, and the flow and structure of the tests to be performed. A review of any previous analyses, modeling or tests on the system should be made to help determine what to test and for the establishment of test priorities. Detailed, prioritized, and structured test objectives must be laid out in advance and then systematically accomplished. It should be recognized, and the planning should accommodate, changing system performance requirements due to threat changes, technology changes, mission changes, supportability problems, and changes in the operational concept. Section 3.5 contains further information on radar test plans.

Radar specifications form the "contract" which defines what the system is supposed to do, and may also state how that performance will be measured and evaluated. A specification has its limitations, especially if it fails to convert the operational performance requirements into the appropriate set of technical terms. It should define the test strategy explicitly, including test requirements, and define what management structure is needed for timely feedback to manage the test program and support program decisions. More information on radar specifications is contained in section 3.3.

Flight test and evaluation personnel should participate in design reviews to gather information on how the radar system is intended to perform, what should be tested, and to determine the effects of any system configuration changes on the test program. They should also monitor the progress of modeling, simulation and lab tests to better decide what to flight test. This is a critical activity since the latest weapons systems are so highly integrated, with multiple shared controls and displays, that the testing may not break out radar-only errors but will only give an indication of the overall capability.

3.1 Development Test and Evaluation

Development Test and Evaluation is defined as that testing and evaluation used to measure system development progress, verify accomplishment of development objectives, and to determine if theories, techniques, and material are practicable; and if systems or items under development are technically sound, reliable, safe, and satisfy specifications (Ref 1). The major objectives of DT&E are to:

- Assess the critical issues, as specified in program documents
- Determine how well the contract specifications have been met
- Identify and report system deficiencies
- Determine system compatibility and interoperability with existing and planned equipment or systems
- Report reliability in relation to the approved reliability growth plan, and to estimate maintainability, availability, and logistics supportability of the system at maturity
- Verify that the system is safe and ready for OT&E
- Validate any configuration changes caused by correcting deficiencies, modifications, or product improvements
- Assess human factors and identify limiting factors
- Assess the technical risk and evaluate compliance with the specifications, in relation to operational requirements (including reliability, maintainability, and availability), lifecycle costs, and program schedules
- Determine system response or hardness to the nuclear and conventional environments in order to support system survivability assessment as directed, and assess system vulnerability, including hardness features and radioelectronic combat vulnerability
- Verify the accuracy and completeness of the technical orders developed to maintain and operate the weapon system
- Gather information for training programs and technical training materials needed to support the weapon system
- Provide information on environmental issues to be used in preparing environmental impact statements
- Determine system performance limitations and safe operating parameters

As stated previously, DT&E cannot ignore the system's operational requirements, and therefore should not be so limited in scope that it is designed to only test within the specification. Some operational "flavor" should be given to planning the DT&E test conditions. It is helpful to have pilots with operational experience participating in DT&E, (simulation as well as flight test) as it is still early enough in the life of the radar system to make changes. However, the intent of DT&E is to get multiple, repeatable samples using specific dedicated test conditions. DT&E is sometimes used for verification that the radar subcontractor met the requirements of the aircraft prime contractor, who in turn must meet the overall weapons system requirements of the customer. It can also be used to obtain a certificate of airworthiness, if required.

3.2 Operational Test and Evaluation

Operational Test and Evaluation is defined as testing and evaluation conducted in as realistic an operational environment as possible to estimate the prospective system's military utility, operational effectiveness, and operational suitability (Ref 1). In addition, operational test and evaluation provides information on organizational and personnel requirements, doctrine, and tactics. Also, it should provide data to support or verify material in operating instructions, publications, and handbooks. The major objectives of OT&E are to:

- Evaluate the operational effectiveness and operational suitability of the system
- Answer unresolved critical operational issues
- Identify and report operational deficiencies
- Recommend and evaluate changes in system configuration
- Provide information for developing and refining:
    - Logistics and software support requirements for the system
    - Training, tactics, techniques, and doctrine throughout the life of the system
- Provide information to refine operation and support (O&S) cost estimates and identify system characteristics or deficiencies that can significantly affect O&S costs
- Determine if the technical publications and support equipment are adequate
- Assess the survivability of the system in the operational environment

OT&E usually will be conducted in two phases, Initial Operational Test and Evaluation (IOT&E) and Follow-on Operational Test and Evaluation (FOT&E), each keyed to an appropriate program decision point or milestone. OT&E can be continued as necessary during and after the production period to refine estimates, to evaluate changes, and to reevaluate the system to ensure that it continues to meet operational needs and retains its effectiveness in a new environment or against a new threat.

IOT&E is normally accomplished prior to the first major production decision to support the acquisition objectives. Planning for IOT&E should begin as early as possible in the acquisition process. IOT&E is usually conducted using preproduction items, prototypes, or pilot production items due to the timing of testing with respect to the production decision. However, these items must be sufficiently representative of the production article to provide a valid estimate of the operational effectiveness and suitability of the production system. During IOT&E, operational deficiencies and proposed configuration changes should be identified as early as possible. It is especially important to provide as realistic as possible an operational environment for IOT&E in order to assure that performance, safety, maintainability, reliability, human factors, and logistics supportability criteria can be evaluated under conditions similar to those that will exist when the system is put into operation.

FOT&E is conducted to refine the initial estimates made during IOT&E and to ensure that production article performance and operational effectiveness/suitability is equal to or greater than the preproduction article. FOT&E is used to verify that deficiencies previously identified have been remedied and any new deficiencies are identified and corrected. FOT&E also evaluates organizational and personnel requirements, logistics support, doctrine and tactics for employment of the system. Tests will be conducted to evaluate system configuration changes and recommend release prior to production incorporation. Completion of the FOT&E objectives should provide sufficient operational data to support introduction of the radar system into the active inventory.

When combined DT&E and OT&E is conducted, the necessary test conditions and test data required by both test types must be achieved and acquired. The DT&E and OT&E agencies must insure that the combined test is planned and executed to provide the necessary development and operational test information. It is important that both agencies participate actively in the test and provide independent evaluations of the results. The philosophy to be used is that OT&E is a logical extension of DT&E, and that a single integrated test plan can be written to incorporate all the objectives and test conditions. Tests of a function will usually be accomplished first as a part of DT&E prior to using the function during an operational assessment. This serves to minimize the occurrence of "surprises" in OT&E.

OT&E should use an operationally configured radar system, maintained in an operational environment, especially since the DT&E program may have a highly modified avionics suite and/or have the system maintained by engineers not representative of the normal field maintenance skills. OT&E should be accomplished by operational and support personnel of the type and qualifications of those expected to use and maintain the system when deployed. Even so, the failure data gathered (such as Mean Time Between Failure - MTBF) should still be looked upon as preliminary since: 1) the maintenance concepts used in DT&E and early OT&E may be different; 2) the only technical orders available may be preliminary; and 3) special test equipment (STE) is often used since the production automatic test equipment (ATE) is usually not available at that point in the program.

A good cross-section of pilots/operators should be used, with varying backgrounds (such as bomber/attack and fighter/interceptor), and different experience levels. In fact, it may be found that it is more difficult for more experienced personnel to transition from another system (such as a previous generation radar) than it is for those with little or no prior experience to become proficient in system operation. Also to be noted, is that if the same pilots do OT&E as do DT&E, they may have too much familiarity with the system to make accurate operational assessments. The OT&E pilot does need to have some experience with similar types of radars, otherwise very important qualitative comments on controls and displays and system mechanizations will not be as useful or as relevant with respect to the operational environment. The pilot may not put the emphasis on problems or evaluation in the correct area. For example, the inexperienced pilot may not have the background to determine which modes are operationally critical (something not contained in a specification), and therefore where to place the correct test emphasis in a time and funding constrained test program.

Typically, there are three levels of OT&E evaluation criteria: thresholds, standards and goals. Thresholds are quantitative or qualitative minimum essential levels of performance/capability that permit mission accomplishment. Standards are quantitative or qualitative levels of performance/capability that will satisfy the operational requirements established for a fully operational system. Goals are quantitative or qualitative levels of performance/capability that will enhance the system.

OT&E radar test objectives may cross several mode bounds (i.e., detect, acquire and track a target) where a DT&E objective may only be accomplished by keeping the radar in one mode for the length of the run. OT&E tests may also use a mode not originally designed or tested as such in DT&E to evaluate its operational usefulness--for example using a ground map mode to look up and try to detect weather or targets, or an a/a low PRF mode for detection of weather. The operational environment should also have some influence on DT&E since it should have influenced the specification requirements. For example, the specified radar minimum range detection should not be based solely on the achievable signal characteristics but on the minimum operationally useful range given the weapons and tactics to be employed. OT&E testing may even find modes that are in the specification and implemented in the radar (and may even meet the specification requirements as determined in DT&E) that aren't really useful operationally. For example, a low PRF/uplook search mode may not really add much in detection range versus the increase in displayed clutter given the limited operating envelope. Also, the usefulness of a mode versus the mechanization complexity and operator time required to obtain it may dictate that the mode be eliminated, and this fact may not be discovered until the radar is placed in an OT&E operating environment. Any discrepancies between the radar specification and actual system utilization should be identified as soon as possible. Usually, the sooner these discrepancies are defined, the cheaper and easier it is to get them resolved.

Representative starting conditions should be specified for the OT&E tests by involving the operator and conducting the tests in an operationally realistic environment. The objective is often not just radar-only but involves overall weapon system performance, i.e., a mission objective. For example, an objective of intercepting and shooting down a target requires the pilot to use his own experience and techniques as well as the capabilities of the radar coupled with the aircraft weapons system. OT&E testing may use ground controllers and target data handoffs from other aircraft (such as other longer range fighters/interceptors or airborne early warning aircraft) to generally locate targets and help identify them in concert with the a/a aircraft radar system under evaluation. There still exists a requirement for some well-defined, repeatable OT&E scenarios which are operationally acceptable. These should be based on operational mission profiles and will help determine what the pilot can expect to consistently see under these conditions.

OT&E tactics development takes into account what the radar system can and cannot do, and also takes advantage of other aircraft in operational scenarios since a fighter is not always by itself in the arena. Tactics evolve from answers to questions such as: what is the best way to use the system? and what makes it most useful? Test conditions may involve numerous aircraft, including 1v1 (one radar test aircraft versus 1 target), 2v1, 1v2, 2v2, 2v4, 4v4, and 4 versus many. This larger number of aircraft can also be used to evaluate areas such as co-channel interference between like and unlike aircraft radars.

There can be several limiting factors to the successful accomplishment of OT&E. The number of test radar-equipped aircraft may be limited, and the availability of interfacing subsystems may be limited (especially if the radar is part of a whole new avionics suite). There may be an initial lack of production support equipment, limited munitions capability, limited test range airspace, and limited capability to deploy to remote sites which then delays or precludes specialized tests and limits others to only one environment.

The detailed test techniques sections of this volume incorporate both DT&E and OT&E radar test objectives. Since various testers may have different dividing lines, definitions and requirements for DT&E and OT&E (or may not make any distinction at all), the test techniques sections are organised such that they can be used regardless of the DT&E/OT&E definitions used.

3.3 Specification Requirements

The specification is the starting point for planning the evaluation of either a newly developed radar or modifications to an existing system. It is based on an error budget for the overall weapon system given the user requirements, and is a part of the contract between the user and the radar manufacturer. The specification defines the system performance requirements and may also define the verification requirements. It defines which modes the system will contain, mode priorities and interfaces with other avionics systems (such as data transfer, commands and displays). It normally describes what the modes and submodes will accomplish, but not the detailed methods of implementation. The specification will define system capabilities and accuracies such as an overall radar system operating envelope (e.g., altitude and velocity limits), an envelope for each mode (e.g., opening/closing velocities and maneuvering limits), capabilities (for example, to detect, acquire and track an airborne target) and accuracies (such as the mean and standard deviation of target range-rate error under non-maneuvering versus maneuvering conditions).

The specification will define which radar capabilities must be demonstrated by flight test and which ones by other methods (such as analysis or laboratory demonstration). However, just because the specification does not require a flight test, this does not mean that one cannot or should not be performed. The verification section may define actual flight test conditions, but if not, it identifies the accuracies which will have to be demonstrated under a variety of flight test conditions. This will influence: 1) the types of test conditions; 2) the sample sizes required based on available test time, comparisons with other modes, and desired confidence levels and intervals; 3) the type and amount of instrumentation and data - both qualitative (such as operator comments) or quantitative from a variety of sources; and 4) the analysis techniques, formats and presentation of results. The required flight testing may be put in terms of verifying the ground computer simulation of radar performance in order that the entire performance envelope can be extrapolated from fewer flight conditions. If so, the flight test conditions must duplicate those simulation points to be used in order to best determine if the results do properly compare.

The specification is an interpretation of the operational need and must contain inputs from the operational users and testers. For example, the radar specification detection range may be based on a 30 second pilot interpretation time (which includes lock-on, identification of the tracked target as the correct one, missile lock-on and launch). The specification verification requirements need to be realistic, and the testers should be involved in writing and reviewing it early in the process in order to revise it if necessary. Too often, the testing community ends up in the role of interpreting what the specification writer meant when covering a particular subject, and can guess wrong. The verification section must be realistic and demonstrable for it to be of any use. It is important to clearly state what is to be measured in unambiguous terms to avoid misinterpretation. Sometimes the specification definition is so poorly stated that it cannot be verified. For example, time to stable track may be called out as a measurement, but if the start and stop times are not defined, it cannot be measured or evaluated. This requirement could be stated such that the start time is when the pilot initiates lock-on (designates) and ends when the track accuracy parameters (target range, range rate and angle) come within the two sigma values of steady-state accuracy requirements. When the specification defines a parameter accuracy in terms of a standard deviation, not only should the mean be defined (to eliminate the use of closely grouped but biased data to meet the requirement), but it should also define over what sample size the definition is appropriate. This concentration on the clarity of the specification definitions is partly due to the modern economic environment, i.e., a radar manufacturer cannot afford to overbuild the system relative to the requirements, therefore the performance of modern radar systems is much closer to possibly not meeting the specification. This requires very exacting test planning, conditions and procedures for evaluation.

The test program must also ensure that the radar was not designed to meet only the specification verification test conditions. For example, if the radar is required to detect targets of a wide variety of radar cross-sections (RCS), but the verification section calls out the flight tests be conducted with a five square meter target, flight tests should also use other size targets to ensure the radar design was not optimized for one size target and performance suffers when using others. The design assumption of target RCS affects scan rate and refresh rate (especially for very short range targets), which can then affect situational awareness in the tradeoff with detection performance. Also important is the knowledge of the RCS of the targets that are used for detection range testing and whether they are operationally representative. If the RCS of the target used for testing differs from that required in the specification, the specification should define the method for extrapolating the measured radar performance to that which would have been achieved using the specified target RCS. This extrapolation method is very important and may only be correct for a limited target RCS envelope, particularly with respect to scaling the results to a considerably smaller target, since the terrain background has a large impact on detection performance. This also points out the need for accurate and consistent data on target RCS and terrain backscatter coefficient (gamma).

The specification may also be written to include a requirement that the final production configuration for some radar capabilities be based on flight test results. Examples include: target track coast time through the doppler notch, ACM mode scan pattern size and direction, and target prioritization for track-while-scan mode. Flight tests may also be set up to determine radar performance limits or to provide sufficient data to extrapolate performance to greater limits. If a specification flight test condition is not practical or achievable during the test program (such as specific weather conditions), the testers/users/program managers may have to collectively decide whether the specification is sufficiently met. This may be based on analysis and any similar tests which have been accomplished that indicate specification performance would have been successfully achieved.

For a radar which is designed to interface with other elements of the avionics suite, the specification should also include a definition of the data and data rates required to support the other systems and weapons. Also, the latency of the data on the MUXBUS to and from the radar, the time-tagging of the data, the interleaving of modes, and the method of sharing displays all need to be well defined. This definition is also a necessity for the best selection of instrumentation systems for flight testing. Any acceptable degraded capabilities should be defined, as well as the pilot/vehicle interface. This includes the switchology and the requirement that the display be easily interpreted. As a part of the detection performance requirements, the clutter background and multipath environment should be defined as long as the definition incorporates that which is available at the actual test sites.

Some radar flight test programs, such as those for research, may not have a specification, but may instead have objectives for what the system should do. This type of test program may be set up to evaluate whether the technology is at the point to support a radar mode or capability, and determine if it worked in the laboratory--will it work in flight? This may include the use of mission scenarios and an operational requirements team to develop some measures of performance. These can then be used to judge if system development should continue, and what performance the radar must have in order to be competitive.

3.4 Test Requirements

Flight testing in addition to that explicitly called out in the radar specification will most likely be required to determine the overall performance, functional adequacy and operational effectiveness of the radar system. A specification verification is not all-encompassing since it is often accomplished only at a few points within the system operating envelope and may not realistically represent the conditions under which the system will actually be operated. Also, a radar mode or capability may meet specification requirements but be operationally unacceptable, or conversely, may be operationally acceptable even though it does not meet the system specification. If too much emphasis is put on only specification testing, the true capabilities or shortcomings of the system may not be determined--only whether or not it meets a particular specification requirement. For example, if the radar system's air-to-air specification detection range was 50 nm and the test was initiated only just outside that range, the evaluation may show that the specification number was met, but the system's true detection range could actually be considerably greater if the test had been set up to fully exercise the capability. To be considered is the possibility that the test points called out in the specification may no longer be appropriate since the operational arena, the threats and approaches to the threats may have changed since the specification was originally conceived. Also, if the specification calls out too specific a test condition (such as what aircraft types to use for targets), problems may arise when test support is no longer available (such as when the specified target aircraft are retired).

Some additional topics should be considered when planning or conducting a/a radar flight tests. The flight test engineers should participate in the radar preliminary and critical design reviews (the ones covering software are usually more relevant than those on hardware since they cover the system operating modes) with the design and operational personnel. These reviews are quite helpful in giving an early indication of how the system will operate and can provide valuable information on how to best plan the system evaluation. The radar flight test engineers should also observe and participate in ground laboratory tests which use the radar alone, and those which integrate the radar with the remainder of the avionics suite. This will allow them to better assess what flight testing should be accomplished and how it should be done to help ensure more efficient and productive flight time. Further detail on ground simulation and test can be found in section 6. Test plan working groups should be formed and meet regularly to discuss and agree on issues (such as test objectives, test conditions, support requirements, data processing and analysis) among all the test participants. This is also a good forum to include any test issues or concerns from other agencies, such as test data requirements to construct operational trainers and simulators, and data to perform survivability/vulnerability analyses.

In order to make better use of the available test time, it is most helpful to have the weapons system Concept of Operations in order to prioritize the DT&E test conditions, and best plan for OT&E. This will tend to keep the test conditions at least somewhat realistic. The test planning process should incorporate time and funding provisions for retesting--either when critical test parameters have not been satisfied during the test and it was therefore unsuccessful, or when changes/fixes/updates are made to the radar. Retesting due to system configuration changes is often termed "functional" testing. Section 4.2.1 contains further details and suggested functional flight test conditions. While no exact figures are universally applicable, some experienced testers have used figures of 20 to 30 percent to be added to the required evaluation schedule to accommodate retesting requirements. When revisions to the radar system are made (such as through engineering change proposals), the flight test engineers must be allowed to participate in the planning and approval process to insure that the flight test requirements are incorporated for each proposed system change.

The test requirements definition should determine the required radar instrumentation capabilities and accuracies, as well as the reference systems to be used and their associated accuracies, tracking capability and area of coverage. If the test aircraft is not dedicated to radar testing, the instrumentation may have to be optimized for each test type, and the priorities and prerequisites for radar tests determined. The test planning may have a provision that flight testing for radar ECCM capabilities be open-ended, i.e., that testing continue when new threats are defined and updates are made to the radar to counter them. If the radar test program is research oriented, the test planning may evolve as the program progresses to further explore areas of success or failure.

The test program should include a decision on how many radar systems to test. Tests which use only one production representative system may not be the best indication of the performance that can be expected from all radars coming off the production line. The overall weapons system error budget should have accounted for the allowed performance statistically, but the argument could be made that every N'th system be put through an in-depth test (to include ground lab and flight testing) to insure it is still up to the performance standards. Unfortunately, this could get very expensive and time consuming, with the resulting substantial addition to the instrumentation, data processing and analysis requirements. A compromise may be to periodically take a production line radar system, conduct extensive ground lab tests, and then run it through a limited flight test program to get better confidence in its performance.

3.5 Test Plans

This section on test plans is applicable not only to a/a radar testing, but has been tailored to those areas required to address all facets of the subject of a/a radar testing. Test plans are key documents that describe the tests to be accomplished and how they will be conducted. Typically, there are several levels of test plans: a System Test Plan (STP), a detailed test plan known as a Test Information Sheet (TIS), and Run Cards. The plans are jointly prepared by all test participants, with a goal of having one set of plans which covers the requirements of all participants (contractors and government). The STP is the management plan for an entire program and contains flight test management concepts, the general objectives and types of tests to be covered, a description of the overall responsibilities of the participants, and a general description of how the program will be conducted. This may cover a number of disciplines (such as the complete test and evaluation of a new aircraft) or one major discipline (such as the evaluation of the entire avionics suite).

A TIS includes sufficiently detailed test information, clearly stated, to allow management and the technical community to review it for adequacy, and the flight test engineer to provide run cards based on the included information. The TIS normally contains detailed test objectives, aircraft and system configuration requirements, general procedures, instrumentation requirements, detailed test conditions (number of samples, radar mode, fighter and target speeds/altitudes/initial conditions and a description of how the run will be conducted), data analysis requirements, and reporting and safety procedures.

Individual runs from the radar TIS (and other avionics test information sheets as applicable) are translated into a set of pilot run cards which make up the flight plan for each mission. These run cards further define each test run with regard to the set-up of the radar and other avionics systems, all the run conditions, the sequence of events to be followed, and any significant test limitations. The cards may include test conditions which are "piggy-backed" onto the ones of prime concern, i.e., conditions which do not require a dedicated flight or run, but which can be accomplished concurrently. The run cards are reviewed at a preflight meeting with all parties involved in the test. Two typical a/a radar run cards are shown in Figure 2. Backup run cards are often prepared, briefed and carried in the event of an in-flight circumstance (e.g., a radar failure in one mode only, or a loss of target aircraft or range support) which precludes accomplishing the primary tests but still allows some useful testing to be completed.

To minimize confusion, the remainder of this volume will use the term "test plan" rather than differentiate between STP, TIS and run cards. The elements described herein as necessary for a radar test plan can be put in a general test plan, a detailed test plan, a general TIS, or a detailed TIS as the reader sees fit. Test plans need to be completed in time to allow adequate review and coordination by management personnel, technical and safety reviews, scheduling of support, definition, design and checkout of instrumentation and data processing systems, and assessment of the data analysis schemes. The timing of test plan development can become critical when system development and production schedules overlap. It should be recognized, and so stated in the test plan, that it is a changeable document depending on the progress of the test program. Most modern radar systems do not have all the planned modes operable and ready for test at the beginning of development, therefore the test plan should either be written in stages which parallel the development or written to include all modes with the understanding that it may have numerous changes as the modes develop. The coordination procedure for reviewing and approving test plan changes should be identified well in advance. Minor changes are usually handled at the local level, while major changes (changes affecting the scope, resources or schedule) usually require approval at higher levels. The most dangerous situation to prevent is in-flight, spur-of-the-moment flight planning--the test plan must be followed at all times. A well-written test plan can also be used to provide the building blocks for the final technical report.

3.5.1 Test Plan Description

A complete a/a radar test plan should include the topics described below. They need not be in the exact order shown, but each should be addressed at some point in the document. A brief explanation of what each test plan topic should cover is included here.

Introduction
- Background information such as the purpose of the test, the scope of the testing (i.e., whether it is to develop or evaluate a minor system change versus a major evaluation of an entire new radar system)
- Critical issues and questions to be addressed
- Who authorized the program and what priority has been assigned
- Test location(s), the overall schedule, and any related tests

Test Objectives
- Clear definition of general and specific objectives. A typical general radar test objective is: "Evaluate the capability of the radar to detect airborne targets" while a specific radar objective is: "Evaluate the radar range-rate accuracy in single target track mode"
- Assurance that the objectives cover critical development, evaluation and operational concerns
- Requirements in applicable management directives and plans (e.g., regulations, Test and Evaluation Master Plan and System Test Plan)
- Prioritize objectives

Success Criteria
- Confirmation that the test has been properly performed and sufficient data collected, to determine if the tests have been satisfactorily accomplished to evaluate the specific objectives
- May include measures of effectiveness (the performance expected to be seen) in terms of thresholds and goals

TITLE: SINGLE TARGET TRACK

RUN:

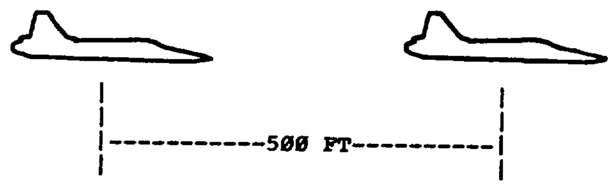
MASTER MODE____ MASTER ARM__AR__ RADAR MODE__RWS__

GMTR________ EL BAR________ SCALE___AR______

HISTORIES______ TILT__________ SCAN__________

SET-UP ----FTR---- ------TGT------

250 KNOTS/5K AGL 250 KNOTS/5K AGL



1. DATA ON: MUXBUS, VIDEO AND RADAR INTERNAL.
2. ACQUIRE TARGET.
3. TARGET ACCELERATES TO 400 KNOTS AND DESCENDS TO 500 FT AGL.
4. MAKE MULTIPLE ACQUISITIONS WHEN TARGET IS BEYOND 2 NM. USE BORESIGHT FOR SOME ACQUISITIONS.
5. TARGET SLOWS TO 200 KNOTS WHILE PERFORMING 180 DEGREE 2g TURN AT 10NM. TRACK TRROUGH TURN.
6. MAKE MULTIPLE ACQUISITIONS ON CLOSING TARGET.
7. TRACK TO GIMBAL LIMIT WHEN WITHIN 2NM.
8. DATA OFF: AT GIMBAL LIMIT.

DATE__________FLT. NO.______

RUN NO. TIS NO.

TRACK THROUGH THE NOTCH
LOOK DOWN/MOUNTAINS

FTR 270 KNOTS/7K AGL
TGT 310 KNOTS/6.5K AGL

AZIMUTH-______RANGE 10
HISTORIES_____PRF MED
CHANNEL_______MODE AIR
BAR___________TILT AR

- SET UP 1 NM TAIL CHASE, ACQUIRE TGT.
- DATA ON: MUXBUS, VIDEO, AND RADAR INTERNAL
- COMMENCE DATA RUN:

CHECKPOINT	TARGET MANEUVER
0	RAPID ROLL TO 45° LEFT BANK. HOLD FOR 15 SECONDS (50° HEADING CHANGE).
1	RAPID ROLL TO 45° RIGHT BANK. HOLD FOR 30 SECONDS (10° HEADING CHANGE).
3	RAPID ROLL TO 45° LEFT BANK. HOLD FOR 15 SECONDS (50° HEADING CHANGE).
4	END OF ONE CYCLE.

- DATA OFF AND RE-POSITION OR CONTINUE S-TURN UNTIL REQUIRED RUNS COMPLETED.

Figure 2 Typical A/A Radar Run Cards

References
- Other test plans
- Other test reports
- Specifications and test requirements document,
- Aircraft modification and configuration documentation
- Operating limitation documents

Test Schedule
- Any limitations imposed by test sites, test agencies, production decisions, or deployments
- Estimate of required flight time and number of sorties

Participating Organizations and Responsibilities
- Including areas of administration, support, maintenance, logistics, data reduction, photo coverage, scheduling, briefing, debriefing, and reporting
- Definition of the lead organization responsible for coordinating each effort
- Agreements (Memos of Understanding or Agreement) which have been reached with the required organizations

Aircraft Configuration
- Definition of any requirement for a particular aircraft configuration (such as external fuel tanks, missiles, or jamming equipment) or particular configurations of the other avionics/fire control systems (such as specific interfacing avionics systems OFPs and/or hardware), or a requirement that specific systems be operating during radar testing (such as other avionics systems, ECM equipment, or specific environmental control system configurations) especially to determine electromagnetic compatibility
- Brief description of the configuration control program and participants

Test Radar Description
- Brief description of the radar system, the controls and displays, and the relevant interfacing avionics systems (such as the HUD, fire control computer, weapons, and electronic countermeasures (ECM) systems)
- Definition of peculiar/particular radar software and hardware configurations required (specify serial number if a particular one is required), and a short explanation of the differences from a standard production unit (or reference another document where a description can be found)
- Assurance that the specific radar test items are clearly defined and understandable

Test Methodology (Conditions, Procedures and Techniques)
- Detailed test objectives and conditions/procedures/techniques organized by radar mode
- Ground and preflight testing requirements such as: EMC tests; ST/BIT completion (prior to each flight); harmonization/boresighting of radar, HUD and INS; preflight radar operating mode checks during taxi prior to take off (if ground operation is allowed)
- Any required pre- and post-calibrations of the radar system, ECM equipment, and/or reference data equipment
- Detailed description of tests, including test and target aircraft parameters (such as configuration, altitudes, airspeeds, heading, and maneuvering requirements) and environment (such as electromagnetic, weather, ground moving targets, or clutter background)
- Number of test conditions, sample sizes, flights and flight time required, with each sample of each condition uniquely numbered in order to track test accomplishment and traceability of requirements to testing
- Description of retest (regression) conditions to be accomplished if changes are made to the radar (sometimes called functional tests). These can be detailed to the point of defining what runs will be accomplished for each type of system change
- Definition of test condition tolerances to allow the test conductor the flexibility to accommodate variables encountered during the test (such as weather or other conflicting aircraft traffic), also to define to the crew the critical parameters which must be followed or which could be substituted for others which are less critical
- Usually written in the form of tables which describe the run in detail, the instrumentation requirements (the required recording systems and their configurations, whether analog, digital, and what video sources--radar, HUD or both), the resources required, the maneuvers to be accomplished, the start and stop conditions and initial points/conditions/ranges
- Written to ensure a logical technical sequence of planned testing
- Identification of the critical limits and the protection required to ensure they are not exceeded
- Description of the interrelationship between various tests (i.e., establishment of priorities and prerequisite tests) including ground tests, milestones and production deadlines
- The sequence of modeling, simulation, lab, integration, EMC and ground tests to be accomplished prior to both initial testing and testing after significant system changes
- Rules and criteria for decisions whether or not to proceed with testing
- The criteria or philosophy used to determine the sample size and the required confidence levels
- Requirement that the test conditions be controlled and the procedures designed to ensure repeatability and attainment of results comparable with previous tests, as applicable

- A matrix showing each test objective versus the specification requirement, also the test objective versus runs (at least for those runs which satisfy more than one objective, or objectives which are satisfied by more than one type of run)

Limitations/Constraints
- The limits within which the aircraft will be operated. Typical flight limits for an a/a radar test are: Altitude 500 ft above ground level (AGL) to 50,000 ft mean sea level (MSL), dive angle 0 to 60 degrees, airspeed and g's (all types of maneuvering) within flight manual limits. Also, typical flight rules for test conditions which include other aircraft are: altitude separation without visual contact will be maintained at greater than 1000 ft within 5 nm when the closure rate is less than 1000 knots and will be maintained at greater than 2000 ft within 10 nm when the closure rate is greater than 1000 knots or when Mach number of either aircraft is greater than 0.95
- Any unusual limitations imposed by weather or by external stores such as an instrumentation pod or external tanks

Instrumentation
- Description which includes the number and types of systems and recorders, available recording times, locations, sources of data (i.e., which systems are instrumented), how in-flight operation is controlled and monitored (i.e., by the pilot or on the ground)
- Telemetry requirements such as pilot audio, time, status indicators, event indicators, analog and digital data
- Parameter lists
- Checkout and calibration procedures
- Special instrumentation requirements and/or limitations (such as the use of commercial equipment not certified for all flight regimes)
- Requirement that adequate time be made available to thoroughly exercise the instrumentation and data reduction cycle prior to the first flight
- Definition of which parameters are go/no-go (i.e., the aircraft will not take off or will abort the test condition if a no-go parameter is unavailable), both from a technical and safety viewpoint. The measurands and parameters could be categorized as: Category 1 - mandatory for safe conduct of the test (if not available, the test flight will be aborted until repairs are made), Category 2 - required to meet a specific test objective (if not available, those tests will be aborted and others substituted in their place), Category 3 - desirable to accomplish the objective and support data analysis, however other alternate means of assessment can be substituted
- Required instrumentation system accuracies (as appropriate)
- Any requirements to have a transponder beacon installed for ground-based tracking reference systems, or a Global Positioning System (GPS) receiving system installed, time code generator or receiver, and audio tone generator for time correlation with other data sources
- Requirement for spare video cassettes or film cartridges to be carried
- On-board and/or postflight hand-recorded data requirements (pilot/operator comments)
- Weather data requirements

Support Requirements
- Range support to include a geographic area with specified terrain backgrounds, airspace, and electromagnetic environment
- Equipment
- Manpower
- Test facilities such as Time Space Position Information (TSPI) data sources (tracking radars, tracking cinetheodolite cameras, GPS), mission control rooms, vectoring/flight test control, real-time readouts of aircraft speeds or closure rates, and time correlation capability between airborne and ground sources
- Other aircraft such as radar targets, instrumented targets, beacon-equipped aircraft or air-to-air refueling tanker (including details on target RCS, type of beacon and settings)
- Target aircraft systems to be instrumented (such as the Inertial Navigation System (INS) and TACAN)
- ECM equipment on test aircraft, target(s), or standoff aircraft (including details on jammer signals--or reference another document where they are contained)
- Training
- Unique technical support requirements
- Key test personnel and their responsibilities

Data Processing Requirements
- Definition of real-time displays for telemetered data (strip charts, discrete lights, CRT display)
- Quick-look postflight data requirements
- Detailed postflight data requirements
- Data distribution plan
- Data reduction plan
- Data processing responsibilities
- Turnaround time requirements for quick look, detailed data and range data
- Definition of the data which must be processed before the next flight can be planned or accomplished
- Requirement that sufficient time be allowed between tests for applicable data turnaround and analysis
- Requirements for encrypted data

- Data analysis plan which is sufficiently detailed to the point of stating methodologies, equations, types of output (such as listings or plots) and formats (if not included in the basic test plan, the data analysis plan should be referenced and written concurrently)
- Analysis responsibilities

Reporting Requirements
- Periodic status reports
- Service reporting
- Preliminary report of results
- Final technical report
- Reporting frequency, milestones and responsibilities

Safety
- Safety planning in accordance with the applicable regulations and requirements
- Requirement that the test program be accomplished under the least hazardous conditions consistent with the test objectives
- Description of any peculiar operating hazards envisioned during the conduct of the tests

Security
- Operations Security (OPSEC) requirements
- Communications Security (COMSEC) requirements
- Requirement that all activities are in accordance with the program security guide
- Any special or unusual problems concerning the safeguarding or transporting of documents or equipment

Appendices (containing detailed explanations and drawings of test conditions and flight profiles)
List of Abbreviations

One of the areas often overlooked in test planning is that of defining tolerances (also called trial/no-trial criteria) for the radar test conditions. A run may be deemed an invalid test of the radar system if a test parameter (target relative speed or aspect angle, for example) was not within certain bounds. For those conditions which are critical to the test success, tolerances should be specified in the test plan and included in the run cards (usually in the form of target aircraft speed +/- XX knots or aspect angle within +/- XX deg). This not only will help to ensure more efficient use of the limited test time, but will identify to the test card writer, range support personnel and aircraft crewmembers, the criticality of some parameters and others of lesser importance.

Another area which requires considerable attention during the test planning stage is that of defining test condition sample sizes--the number of successful runs of each condition required for an adequate statistical evaluation. This involves a considerable tradeoff between huge matrices which result from a multiplication of all modes, conditions and variables, versus limited and expensive test time. Specifications will often have a mean and standard deviation requirement, sometimes required sample sizes, but rarely a required confidence limit or interval. Radar test planning usually assumes a normal distribution of the results with a sample size based on the confidence level desired. This may be per mode or to make comparisons of variables within a mode (such as the effects of various terrain backgrounds on detection capability). The use of interval statistics during the conduct of the test program is encouraged to possibly decrease the required sample sizes if the results are well grouped and appear to be representative of true system performance within agreed upon reasonable confidence and risk limits.

3.5.2 Technical Review

In order to ensure proper and adequate preparation and planning, a thorough technical review of the test plan should be accomplished, and any major test plan changes made during the course of the test program. The intent of the Technical Review Board (TRB) (also termed an Operational Review Board) is to establish a committee of experienced personnel not directly associated with the test program to provide an independent technical assessment of the test plan. The board is usually made up of operations and engineering personnel, chosen based on their experience in the areas covered by the test plan. The review will cover the entire test plan in detail, to include the test objectives, the status of preparation and planning, the technical adequacy of test conditions to satisfy the objectives, any prerequisites to accomplishing the tests, and any unique training which may be required (Ref 2). The TRB will also cover general information such as:

- Background information, purpose of test, type of test (i.e., Research, Development Test and Evaluation, or Operational Test and Evaluation), and previous related tests
- Critical technical issues
- Areas of project management emphasis
- Primary responsible test agency, other participating test organizations and their responsibilities
- Program authority and priority
- Security classification
- Test location

- The use of past experience with similar testing in preparation of the test plan
- Criteria for ending the test (e.g., when all test points have been flown or when the system or component works as advertised)
- Review of appropriate lessons learned and any resulting test modifications which have been incorporated in the test plan
- Review of technical risks (i.e., is something being done for the first time that may require unique talent or resources?)
- Review of what production decisions may depend on the test results and the schedule for those decisions
- The extent of government and contractor participation

3.5.3 Safety Review

A safety review of the test plan and any major revisions should also be accomplished, in order to identify any potential hazards, their possible causes and effects, and what minimizing procedures will be followed. Both technical and safety reviews must be completed prior to initiation of testing. Typically, these reviews are completed one month prior to the start of testing. The main topics considered by the Safety Review Board should be (Ref 3):

- The necessity of the test, the requestor, and the documentation requiring the test
- Mishap prevention responsibility, mishap procedures, accident accountability, and aircrew and test conductor responsibilities
- Use of previous safety lessons learned
- Adequate definition of test conditions in order to determine any potential hazards or critical areas
- The adequacy of the system safety analysis and the results
- The adequacy of the operating hazard analysis and the results
- Safety of flight prerequisite tests (modeling, simulation, lab, integration and/or ground tests) which have been accomplished prior to both initial testing and testing after significant system changes, and the test results
- EMC lab, ground and flight tests which have been accomplished prior to radar testing, and the test results
- The presence of sufficient buildup in the sequence of test conditions (i.e., testing at less hazardous conditions before proceeding to more hazardous conditions)
- Air-to-air radar testing specifics such as: separation altitudes, closing speeds, maneuvering limitations, the terminology to be used to initiate and abort maneuvers and runs
- Policy to brief all participants (including test aircraft crew, target aircraft crew(s), and support/range personnel)

3.6 Support Requirements

A wide variety of support is required to conduct an a/a radar flight test program. The specific support requirements and necessary accuracies must be determined and well defined early in the planning process, since there can be long lead times to obtain items such as an instrumented target, high accuracy reference systems, and COMSEC equipment. The test planners need to understand the ramifications of specifying a support item, and be ready to justify or substitute accuracy or capability versus cost and availability. Support includes a mission control capability, Time Space Position Information (TSPI), and targets. Mission control usually includes sufficient personnel to direct and monitor the test conduct, monitor the available real-time test data and have a test conductor in charge who is in contact with the test aircraft. Mission control room requirements such as communications links, telemetry sources and reception, displays and/or strip chart formats, and room layout all need to be specified early in the planning process. During the test, mission control room discipline is critical. It must be stressed that the test conductor is in charge at all times, and that there should be only one individual who is designated to communicate with the test aircraft. TSPI can be provided by ground-based reference systems such as radar for aircraft skin or aircraft transponder beacon tracking, or the more accurate cinetheodolites or laser trackers. These systems track both the fighter and airborne targets, but have limitations as to area of coverage, number of targets tracked (usually only one target per tracker), accuracies obtainable, and operating meteorological conditions. The "rule of thumb" that the reference system accuracy be well known and that it be 10 times more accurate than the radar system under test is getting more difficult to achieve with today's advanced a/a radar systems. Best estimate of trajectory processing of multiple source tracking information is being applied to obtain better aircraft position and velocity data with the limited existing resources. Future radar testing will need to incorporate the use of the Global Positioning System (GPS) as part of the TSPI reference systems. While GPS gives a significant increase in the number of targets tracked (if they are instrumented), it doesn't provide aircraft attitude which is important with a maneuvering test aircraft or target.

The TSPI systems also provide flight vectoring information which is vitally important to achieve the proper setup for fighter and target(s), and to notify the aircrews of other aircraft in the vicinity. Additionally, reference system data is used in real time to obtain aircraft X-Y position data, altitude and airspeed when critical to the mission. After the flight, the data is used in the form of position plots, data tapes and printouts for analysis. In order to achieve best results, preflight coordination and briefing of all range support personnel (especially the controllers) is required, as well as having some radar test program personnel at the range site during the flight to help coordinate the mission. The test conditions and profiles, terrain and airspace requirements must be identified. One way of doing this is to write a range specification or test plan which incorporates all range support requirements for the a/a radar flight test conditions. In addition to the high accuracy tracking range, a test arena such as an Air Combat Maneuvering Instrumentation (ACMI) range should be used for operational testing. This allows both real-time and postflight analysis of the aircraft radar capability using multiple targets in concert with an operational intercept controller.

Other sources of TSPI, while less accurate, may be sufficient for some test conditions such as a/a detection range. Air-to-air TACAN/DME can be used for the test conditions when aircraft positioning and data requirements are less stringent, for initiating the run, and for helping to identify which displayed targets are actually detections of the subject target aircraft. The accuracy of a/a TACAN has been estimated to be as good as 0.1 nm based on comparisons with other available tracking systems. The best approach to its use, would be to set up a small flight test of the a/a TACAN system to be used and measure its performance under flight conditions similar to the radar conditions. For the most utility, the a/a TACAN/DME data should be instrumented and recorded on-board the radar test aircraft. Loran C has been successfully used in the calibrate mode when no aircraft maneuvering is involved to obtain an estimated 60-foot accuracy, although the accuracy has degraded to 160 feet under some circumstances. Coupled with TACAN/VOR and on-board INS data, this could be sufficient to satisfy aircraft relative data requirements, especially during system development. Of course, use of LORAN constrains the geographic location of the testing. Some programs have used a pod mounted on the test aircraft containing a small radar which can provide relative position information between the fighter and a target. Further coverage of a/a radar reference data requirements is contained in section 7.6.

Numerous airborne targets will be used throughout an a/a radar test program. The test planning process needs to identify the required types and number of targets, flight hours and sorties, target speed, altitude and maneuvering performance, transponder beacon requirements, and target instrumentation parameters. These targets should: 1) have similar and dissimilar flight capabilities and radar systems (for EMC testing), 2) have a variety of known radar cross-sections, 3) represent "friendly" and "unfriendly" situations, 4) be in single and multiple formations, 5) be capable of the maneuvers required to evaluate the radar at all points within its operating envelope, and 6) be equipped with electronic countermeasures (ECM) systems and radar missile telemetry receivers when required. The RCS of each target used for detection range testing must be accurately known, and preferably be close to that of the types expected to be encountered in operation. A target with a radar reflector installed (or mounted in a pod) can be used to better know and control the RCS, but carries with it the disadvantage that it may be much less representative of a true target in terms of scintillation effects. There may be a requirement for the target to have a cockpit readout of some flight data (such as angle of attack, or g's) to best attain the test condition. Helicopters may be needed to evaluate the effects of the rotating blades on the radar. Some a/a radar testing will need a target with realistic emanations of other on-board systems as well as a representative RCS.

The use of targets and their associated systems causes the need for other support equipment. On-aircraft pods need ground support equipment and personnel for loading and programming of jammers, checklists for their use, logistics for support at deployed locations, and special handling equipment. The radar-equipped test aircraft will also require support equipment and personnel for on-board pods, jammer programming, missiles and launchers. Also, significant numbers of ground support equipment and personnel may be required for the likely long periods of time the a/a radar will be operated on the ground in the test aircraft for development and checkout.

Ground targets and a known terrain background are important for a/a radar testing in look-down conditions. Various terrains should be used and radar reflectors may also be used to simulate terrain types and/or large stationary discrete targets. Moving ground targets will be required and may have to be instrumented for speed and relative position to evaluate the radar's ground moving target rejection capability. Ground-based ECM systems will be required in order to determine effects on the a/a radar look-down modes. The operational evaluation will need multiple airborne jammers in concert with ground-based jammers to obtain a realistic battlefield signal environment.

Ground telemetry receiving sites will be required to support real-time data reception and processing. There may have to be ground or airborne repeaters to relay the data when the test aircraft is operating at low altitudes, over rough terrain or at longer distances from the mission control site. A portable telemetry receiving capability, possibly mounted in a self-propelled vehicle, can be of great value. It is even more valuable for deployed location testing when it also includes some radar data processing systems.

Correlation of the time systems used by all test participants (using a time standard such as IRIG B) is extremely important for a/a radar evaluations. Usually some event marker will be recorded on all systems which will allow a postflight check to identify any time deltas to be applied to the data. The aircraft speeds combined with the radar system accuracies being evaluated quite often require that all data times be correlated to within 10 milliseconds.

3.7 Management Information System

The term management information system (MIS) used herein refers to a system containing a large data base of information for the a/a radar test program, with an easily accessible interactive means of retrieving the information by multiple users at various locations, and the ability to manipulate it according to the users' desires. This system can be used for radar data generated by the tests, and program data which includes information on objectives, schedules, conditions, and problems. The system should be "user-friendly," i.e., require very little detailed training to operate it and provide the user with simple plain-language commands. It should also easily and quickly accept input data, as that is usually the most labor intensive and time-consuming part of the process.

For all radar tests there should be one controlled set of data, that is, all evaluators should start with the same acquired data and can then go on and analyze it as each sees fit. The MIS should contain the radar and aircraft avionics suite configuration (software and hardware) for each condition flown, pilot and engineer comments for each test condition flown, and should be organized such that all information on any particular radar subject (such as a specific mode, or a specific problem area) can be obtained. This will allow indications of trends in radar performance from multiple flights, and will help in documenting and reporting on radar performance. The system configuration information should be formatted and stored so it can also indicate which conditions need to be reflown when a configuration change is made. The MIS can also be used to help construct quick-look and final radar performance analysis reports and standardize their appearance.

The system should be sized to incorporate radar performance data from all types of tests including simulator, integration lab, ground and flight tests. It also needs to be able to accommodate data from instrumented targets, reference tracking systems and ECM ranges. The system may contain a library of data formatting and merging routines, variables, and analysis algorithms that enable the radar analyst to rapidly determine radar performance.

Once properly configured, the MIS can be used to prioritize radar test conditions, and reprioritize them during the course of the program as changes take place. It can construct a schedule of tests and include the prerequisite radar test points (those points or modes which must be successfully accomplished prior to others). These prerequisites may also address other on-board aircraft systems which are dependent on radar operation or which provide information to the radar. The MIS should have a capability to cross-reference radar specification requirements with test objectives, include information on each test condition for each radar mode, and include requirements for support (e.g., TSPI, targets and ranges), instrumentation and data processing. This can then allow the MIS to select test points to be accomplished for a flight (logically grouped together most efficiently considering fuel, support and other constraints), and to prepare instrumentation lists, support requirements and schedules, flight cards and data processing requests. It could be used to indicate to the radar flight test engineer that the setup for one radar test point (A) is the same as for another (B) and they can be satisfied simultaneously, or that they are so close that a minor change would allow their simultaneous accomplishment. If only certain types of support were available for a given test period, the MIS could identify all tests that can still be accomplished within that (or any other) constraint. It can also be used to track status of each test condition (e.g., number of times it has been attempted, whether it was satisfactorily flown, aircraft and support data acquired, and analysis completed) and provide current overall program status and management indicators of test progression versus the planned schedule, cost and significant program milestones.

4 FLIGHT TEST TECHNIQUES - SPECIFIC

4.1 General

This section is organized to include some general (non-mode specific) test considerations, with section 4.2 and beyond going into detail on testing of specific radar modes. In general, the a/a radar evaluation should be constructed to fly to the performance boundaries of the radar and/or aircraft operating envelopes to determine if any limitations exist. Knowledge of the radar system, as well as the intended operational usage, should be considered when determining what tests to accomplish and must accommodate applicable safety constraints.

In many radar test programs, most or all of the tests are accomplished with one set of radar hardware and one avionics suite. Although during a development effort there may be some LRU changes, the question may remain as to how representative of the entire production run was the one radar tested. Often, a radar specification requirement is intentionally written such that, if the tested radar meets it, the rest of the production run will be within a reasonable range of the specification and still meet the operational requirement. Production radar systems may be periodically evaluated (both in a ground lab and by flight test) to ensure the average performance has not fallen and that the test results are still representative of those systems installed in the fleet.

While antenna beam patterns and sidelobes are primarily measured in a laboratory, some in-flight testing should be performed to fully evaluate the installed performance to include all effects of the antenna installation, interface with the radome, and effects of aircraft motion and vibration. This testing would require flying a prescribed flight path with respect to a ground receiving station while transmitting with the radar beam set to continuously point at the same angle and sweeping it past the ground station. This beam configuration may be available as the ACM boresight mode, or it may require a modification to the radar to achieve it. The fighter will be maneuvered to cover the required azimuth and elevation angles, and the radar antenna beam signal strength will be measured by the ground receiving station instrumentation. The evaluation will need to take into account the fighter position relative to the ground receiver and the attitude of the fighter at all times.

The geographical area used to accomplish radar performance evaluations is usually more dependent on the locations of the reference instrumentation, the flight test facilities and the airspace availability rather than a specification terrain reflectivity coefficient. Therefore, some extrapolation may be required between the conditions actually encountered and those required for each mode. Not to be forgotten, however, is the necessity to also test the radar in the "real world" where other factors, such as signal multipath, are present from varying terrains.

With the more highly integrated aircraft avionics suites being built, it is difficult to evaluate the radar only since the other avionics systems (or their functional equivalents) are required to be installed in order to even turn on the radar and cause it to perform. Further, if the radar interleaves a/a with a/g modes, the best approach is to test the a/a modes first alone to determine a performance baseline, then allow the modes to operate interlaced and see if the a/a performance degrades. Other examples of the appropriateness of establishing a performance baseline are: adding more multiple target tracking capability--possibly in conjunction with the addition of more data-linked a/a missiles; the addition of data-linked missiles with other missiles requiring radar guidance transmissions and radar pointing--especially since it may require radar reconfiguration times from one mode to another; integration with an IFF interrogator; and any future modifications. Also, radar tests should be performed in a clear environment (no ECM present) to establish a baseline, and then run with ECM present. Sections 4.3 to 4.7 of this volume contain details on a/a radar evaluation in a clear environment, and section 5.3 covers evaluation in an ECM environment.

The effects of weather on radar operation are difficult to measure, since it is very formidable and expensive to accurately determine exact weather parameters (e.g., cloud moisture content, and rainfall rate) all along the route of a moving fighter and target. Also, scheduling a mission in advance to include weather is far from an exact science. If the radar is installed on a new (still in development) fighter aircraft, the aircraft may not be cleared for operation in weather at the time the radar is being tested; therefore the use of a radar testbed aircraft may be essential.

4.2 Operational Evaluation

4.2.1 What to Evaluate

An overall operational evaluation of the radar system should be conducted based on both the testing described for the detailed mode evaluations in sections 4 and 5 of this volume, as well as additional dedicated testing to accomplish the following types of objectives:

- Evaluate, during routine a/a flight operations, the operational effectiveness of the radar, and its suitability for single-ship and formation operations
- Evaluate the operational effectiveness of the radar during air-to-air combat operations and weapons employment
- Identify pilot training requirements to achieve effective radar use

- Evaluate actual and potential radar hazards which could cause equipment damage or injury to personnel
- Determine any tactical limitations associated with the radar
- Identify and assess aircraft tactics with respect to radar operation
- Assess the pilot performance/workload
- Determine if the radar can be supported by personnel in the field
- Assess the effect of the radar on the aircraft reliability and maintainability
- Assess the effect of radar system reliability on the availability of the aircraft under peacetime, surge, and sustained operating conditions
- Assess the logistics supportability of the radar system
- Determine the percent of engagements in which the aircraft: 1) starts from an offensive setup and achieves first weapon employment, 2) starts from a neutral setup and achieves first weapon employment, and 3) starts from a defensive setup and achieves a separation or first weapon employment
- Evaluate the capability of the radar while performing: 1) a trail departure, 2) a tanker rejoin, and 3) high speed intercepts
- Perform pilot subjective evaluation of radar performance in all modes

Functional test conditions will be required each time a significant change is made to the radar. These conditions are intended to determine if the radar still adequately functions in the modes which should not have been affected by the change, and that the changed modes function and are ready for evaluation. These runs may be modified as desired to accomplish the functional test requirements. The requirements for reference data, on-board instrumentation, specific target size and maneuvering capability will likely be less stringent. Table 2 identifies typical test conditions which may be utilized for mode functional checks.

4.2.2 Conditions and Factors for Evaluation

Operational testing will use operational profiles and will require some dedicated missions to accomplish. Routine operations are common to most missions and for the most part can be evaluated in conjunction with other testing. Some dedicated sorties may be required to focus on specific tasks or mission segments. Organizational and intermediate support equipment, military support personnel, and production technical data (as available) should be used. Data will also be gathered from any training missions accomplished.

Various force sizes of test aircraft will perform radar intercepts and attacks against simulated adversary force aircraft. When appropriate, other "friendly" aircraft will be integrated into the force mix. Missions should be structured to assess offensive, defensive and neutral initial conditions. Emphasis is placed on determining the capabilities of the radar and (when applicable) the integration with the weapons system. Tactical missions are typically planned for two to four "friendly" aircraft and from one to eight adversaries. The initial aircraft set-ups are co-altitude, look-up, and look-down, with low, medium, and high initial target altitudes. Scenarios are designed to engage the targets from various aspects. Although the majority of sorties will normally be conducted during daylight hours, a small sample of night missions should be conducted to investigate any effects of the night environment on the ability of the pilot to effectively employ the radar system.

4.3 Detection

4.3.1 What to Evaluate

The primary evaluation for an air-to-air radar is that of determining its capability to detect an airborne target. The full operating envelope of radar detection capabilities needs to be determined in all search modes (RWS medium and low PRF, and VS) including minimum and maximum detection ranges. In addition to the statistical measures of radar detection performance, the pilots should make a subjective evaluation of detection performance in operational scenarios and the utility of various features such as false alarm rate, low versus medium PRF, VS, and GMTR.

There are several ways of expressing the detection range of an a/a radar: P_D, P_{CUM}, and what might be termed the "pilot" detection range. These are all directly related to the RCS of the target and will change based on different aspect angles with respect to the same target, or different size targets. The terms presented in this volume are also applicable to radar systems which do not have a synthetic display, with the added requirement that the evaluation also include display interpretation to define the criteria for saying that a target detection is present.

The single scan probability of detection, P_D (also termed the blip-scan ratio), is the ratio of the number of target detections (hits) to opportunities (usually based on one opportunity per scan). The detection range is specified as the range at which P_D reaches a certain percent of target detections versus opportunities--usually either 50 or 90 percent. The cumulative probability of detection, P_{CUM}, is the cumulative probability of the first target detection based on a number of similar runs, and is usually specified as the range at which P_{CUM} is either 85 or 90 percent. An example of a way of expressing P_{CUM} is as R_{85} - which would be defined as the range beyond which 85 percent of the first target detections occurred.

TABLE 2 TYPICAL FUNCTIONAL FLIGHT TEST CONDITIONS

RUN #	CONDITION	FIGHTER SPEED KNOTS	FIGHTER ALT (FT)	FIGHTER BARS/ SCAN	TARGET ASPECT (DEG)	TARGET SPEED KNOTS	TARGET ALT (FT)	BEGIN RUN	END RUN	REMARKS
1	LOW ALT. LOOK DOWN HEAD-ON	475	5K	2 +/- 60°	180 +/- 5	385	500	20NM	GL	CLUTTER REJECTION (RWS). DETECTION @ +/- 60°. ALTITUDE LINE TRACKER. NOTES: 1, 3, 5
2	LOW ALT. MOVING TGT. REJECTION	475	5K	2 +/- 30°	N/A	N/A	N/A			GMTR SELECTION (RWS) FLY PARALLEL TO A HIGHWAY AT 800 FPS GROUND SPEED. SELECT LOW/HIGH NOTCH WHILE PAINTING THE TARGET AREA. NOTES: 1, 3
3	LOW ALT. LOOK DOWN HEAD-ON	400	5K	SPOT	180 +/- 5	350	500	20NM	AR	SPOTLIGHT (RWS) DETECTION RANGE. NOTES: 1, 3, 5
4	MED. ALT.	500	10K	N/A	180 +/- 5	445	6K	12NM	AR	SCAN PATTERNS. (ACM) 30 X 20) AUTO ACQUITION. ALTITUDE LINE TRACKER. GMTR SELECTION.
5	MED. ALT.	295	10K	N/A	180 +/- 5	295	6K	12	AR	SCAN PATTERNS. (ACM SLEWABLE) AUTO ACQUISITION. ALTITUDE LINE TRACKER. GMTR SELECTION.
6	MED. ALT.	350	12K	N/A	180 +/- 5	350	15K	5NM	1000'	SCAN PATTERNS. (ACM 10X40) AUTO ACQUISITION. ALTITUDE LINE TRACKER. TARGET MAKES LEVEL TURN, FIGHTER FOLLOWS MAKING REPEATED ACQUISITIONS. NOTE: 4
7	MED. ALT.	350	15K	N/A	0 +/- 5	350	15K	2000'	1000'	SCAN PATTERNS. (ACM BORESIGHT)AUTO ACQUISITION. ALTITUDE LINE TRACKER. GMTR SELECTION. TARGET PERFORMS SPLIT-S, FIGHTER FOLLOWS MAKING REPEATED ACQUISITIONS. NOTE: 4
8	HIGH ALT. HEAD-ON	300	20K	AR	180 +/- 5	300	25K	40NM	AR	PROCESSING TIME (RCR) INITIATE RCR SEVERAL TIMES. NOTES: 2, 4, 5
9	LOW ALT HEAD-ON	300	5K	AR	180 +/- 5	300	500	AR	AR	CLUTTER REJECTION (VS). DETECTION @ +/- 60°. MAKE SEVERAL ACQUISITIONS. NOTES: 1, 4
10	MED. ALT. LOOK UP HEAD-ON	475	13K	1 +/- 30°	180 +/- 5	445	35K	20NM	AR	ALTITUDE LINE TRACKER SPOTLIGHT ACQUISITION DESINGNATE. OBSERVE THAT THE TRACKER/ BLANKER IS DISABLED NOTES: 2, 4

TABLE 2. (CONCLUDED)

RUN #	CONDITION	FIGHTER SPEED KNOTS	FIGHTER ALT (FT)	FIGHTER BARS/ SCAN	TARGET ASPECT (DEG)	TARGET SPEED KNOTS	TARGET ALT (FT)	BEGIN RUN	END RUN	REMARKS
11	MED. ALT.	250	15K	N/A	0 +/- 5	355	17K	500'	GL	SPOTLIGHT (STT) TRACK THRU NOTCH. AUTO RANGE SWITCHING. ENTRY INTO RCR. ACQUISITION WITH MANEUVERING TARGET. ACQUISITION WITH HIGH CLOSURE. HAVE TARGET START AT 500' RANGE AND INCREASE RANGE SEPARATION. TARGET PERFORMS 180° TURN PERFORM RCR AS TARGET CLOSES. NOTES: 2, 3
12	LOW ALT.	250	5K	N/A	0 +/- 90	355	500'	5	AR	SAME AS RUN 11 EXCEPT LOW ALTITUDE. NOTES: 1, 3
13	HIGH ALT. ALL ASPECTS	250	20K	3 +/- 25°	MULTIPLE TARGETS			AR	AR	AZIMUTH AND ELEVATION COVERAGE. TARGET PRIORITIES. PILOT PRIORITY OVERRIDE. EXPANDED DISPLAY. MANUAL/AUTO TWS. MULTITARGET TRACK. TRACK TRANSFER. TRACK TARGETS OF OPPORTUNITY.

NOTES:
1. ALTITUDES ARE AGL.
2. ALTITUDES ARE MSL.
3. SPEEDS ARE GROUND SPEEDS.
4. A FIGHTER-SIZED TARGET IS REQUIRED.
5. AR IS AS REQUIRED.
6. GL IS GIMBAL LIMITS.

The "pilot" detection range can be defined as that range at which the pilot is able to determine there is truly a target present. With a synthetic display radar, this is dependent on the system false alarm rate, operator experience and faith in the system, and the flight scenario. Normally the "pilot" detection range would be greater than the P_D range but less than the P_{CUM} first hit range under the same conditions.

In an operational sense, there can also be a "useful" contact range, especially since it may well be dependent on the tactical situation (during which the pilot may not have the opportunity to be continuously observing the radar display) and the weapons to be employed. The number of target detections required to declare a "useful" target detection range could range from as low as one (if the target location is well known by another source such as an early warning system and transmitted to the fighter pilot to have him search a small specific area) to several if in a multi-target environment. In that case, the criteria to declare a detection could vary; for example it could be defined as using a scan pattern to cover an area for a target as reported by another source, receiving two closely spaced hits on the the suspected target, and then an attempted lock-on to confirm the target is present.

One other exception to the detection definitions previously stated is that of a/a beacon mode. The display of a beacon return normally consists of a set of characters or lines which indicates the beacon range and the beacon code. Since there is no interpretation required and the mode usually includes a capability to freeze the display to better identify the return location, the first hit would be sufficient to describe the detection range and a blip-scan ratio would not be not required. The evaluation should note, however, the consistency of the presence and location of the returns from scan to scan with respect to range and azimuth.

Evaluation of the radar detection capability will also include a determination of the existence of any detection holes ("blind zones") in velocity or range using the results from a number of runs to correlate any holes with target range or combinations of fighter and target velocities. This relationship will likely change with respect to RWS versus VS modes, long range search options which interleave medium and high PRF on a scan-to-scan basis, and may also be dependent on what ground moving target rejection (GMTR) velocity is selected. Also, the adequacy and usability of the displayed minimum/maximum search altitude (the spatial coverage of the antenna pattern at the cursor range) should be evaluated by the pilot with respect to how well he can use the information to help locate the scan pattern to detect a target.

In a synthetic display radar, the false alarm rate (FAR) must be very low (typically no more than one false alarm per minute) in order to recognize the presence of true targets. In a look-down radar mode, ground clutter is the main contributor to false alarms, so the evaluation must determine if the system properly rejects (notches out) the clutter return presented by the terrain. False alarm rate should be evaluated on every detection run since a tradeoff exists between FAR and detection range sensitivity. The look-down detection modes may have an operator-selectable GMTR velocity in order to distinguish and eliminate the display of relatively slow moving ground targets and enhance the pilot observation of the desired airborne target. The evaluation should include an assessment of the effects of each selectable GMTR velocity on the detection range and FAR. Velocity search mode is also more susceptible to false alarms being generated by multiple velocity returns from sources such as jet engine modulation, aircraft propellers, and helicopter rotors.

The accuracy of the target information on the radar display should be evaluated, especially if the operator or radar system is exchanging target information with another airborne or ground-based source. For a B-scan display, this would be the accuracy of the target range and azimuth in RWS, and target velocity and azimuth in VS. If the fighter is equipped with an on-board IFF interrogator, the correlation of the radar-detected targets with the IFF-detected targets should be evaluated.

Evaluation of the scan-to-scan azimuth and range correlation (target centroiding) should determine if any changes occur in the displayed target azimuth or range when displayed from left-to-right or right-to-left scans in each mode. This is a more likely occurrence if the radar has a long range search option (which interleaves high and medium PRF in alternate scans) due to the differences in range resolution and accuracy. If present, these displayed target position shifts could confuse the true target position or mislead the pilot into believing more than one target was being detected.

Determination of the radar capability for multiple target range, azimuth and elevation resolution (elevation resolution is a function of the elevation bar overlap in other than one-bar scan) is the measurement of its ability to distinguish between two or more airborne targets. Tests will determine the minimum separation for which two targets can be distinguished and displayed. In VS, resolution is the minimum doppler velocity separation required to distinguish and display multiple targets.

The effects of several different radar operating variables should also be evaluated: scan width, pattern, speed and elevation coverage; operating frequency; the presence of weather; the detection of weather; changes in radar system sensitivity; and non-clutter rejection mode operating envelope. A number of operator-selectable combinations of radar scan width, pattern, speed and elevation coverage is usually available, as well as those that are preset. The use of one versus another can impact detection range, and should be compared to an established detection performance baseline to measure any effects. If the radar has more than one selectable operating frequency (most do), any effects of changing the operating frequency--given all other conditions are the same--should be determined for target detection and false alarm rate. If test conditions allow the fighter and target to be separated by weather, any effects on detection range or false alarm rate should be evaluated. Some air-to-air radar non-clutter rejection modes (such as LPRF) may allow detection of areas of large weather buildups. If conditions permit, an evaluation should be made of the radar effectiveness in detecting the presence of weather and identification of associated characteristics. The adequacy of the system to compensate for changes in sensitivity (usually a factor of the mechanization of the automatic gain control (AGC)) should be assessed with respect to any effects of fighter altitude changes, or the proximity of a radar-equipped wingman. It is possible that the proximity of a wingman could drive the AGC up (and therefore lower the radar system sensitivity) which would decrease the radar detection range. This is a potentially serious impact, particularly since there would likely be no indication to the pilot of a decrease in radar capability. The operating envelope of non-clutter rejection modes such as LPRF and VS (primarily a function of antenna tilt angles and clutter conditions) should be explored and identified during the test program. LPRF is typically limited to antenna tilt angles of greater than about +5 degrees, depending on the fighter altitude and the surrounding terrain, since lower angles result in an excessively high false alarm rate.

4.3.2 Conditions and Factors for Evaluation

Evaluation of the radar a/a detection capabilities involves a substantial number of test conditions and factors. These include both look-up and look-down runs in the presence of different clutter backgrounds and at a variety of tilt angles, combinations of fighter/target altitudes (such as low/low, low/medium, low/high, medium/low, medium/high, high/low, and high/high) and detection through different portions of the radome. Also used should be head-on, tail-on and off-angle (such as 45 degrees) fighter/target flight patterns to obtain a variety of closure rates, different clutter relative speeds off-angle, and to detect the existence of reflection lobes, different false alarm rates or radome effects. Terrain background has the most effect on a/a radar look-down modes, but can also affect look-up modes when flown at lower altitudes with shallow look-up antenna tilt angles. Tests at different elevation and azimuth angles are especially important if the radar antenna is a non-scanning phased array, since it will likely have a different detection range off-angle versus head-on due to the pattern forming characteristics. A range of various fighter and target speeds will investigate if there are any detection holes or significant changes in detection probabilities when in different regions of visible PRFs. Typically, 6 to 10 samples of each detection test condition are required to provide statistically meaningful results.

The effect of terrain background on detection capability is measured by making comparisons of measured detection ranges over different terrains while holding all other conditions constant. The types of clutter/terrain/backscatter coefficient used may have a substantial effect on the system false alarm rate and detection sensitivity. It may impose a distinct altitude line in the radar (worst case being a calm sea) and present large discrete ground targets (especially terrain such as steep-sided ice-covered cliffs). The radar performance requirements may include a specific backscatter coefficient to be used, but it may not be available at the test site during the test program. Commonly, radar system performance is evaluated over desert, mountainous, urban and sea terrains, but the true terrain reflectivity coefficients for the actual test areas may not be known. There are several factors to consider in this situation. While the backscatter coefficient may be known for another area further away from the test facility, the tests may be constrained by the availability of ground-based references, or telemetry receivers in that area. This situation may result in changes such as the use of a non ground-based reference system such as the Global Positioning System, or by accepting less accuracy through the use of a/a TACAN. Another solution for the lack of backscatter coefficient for the test area has been to implement a scan down capability in the radar which, when calibrated properly before the flight, will gather data in the detection modes to make a judgement on the relative amount of clutter presented to the radar. The most expensive solution is to use an airborne system to make thorough measurements of the backscatter coefficient for the test area to be used.

Detailed knowledge of the target radar cross-section (RCS) is extremely important and must be known for all aspect angles to be used, since considerable changes occur on most targets with changes in aspect angle and angle-of-attack. To preserve a consistent target RCS during detection testing, it is important to establish test condition tolerances in order to maintain the target aspect angle within a fairly small range. Often, the RCS of the target used is different from that called for in the specification. It would be helpful if the specification were written with the actual available targets in mind, and even better if a standard target was defined. However, if the target RCS is different from that in the specification, the measured detection range can be normalized using the $1/R^4$ (R is range to the target) relationship from the radar equation. Also, knowing the RCS of the target used will allow extrapolating the test results to any target of interest. A note of caution is appropriate since this extrapolation cannot be applied universally for several reasons: 1) very small targets in a look-down situation will have to compete with large clutter returns and may fall below system thresholds thereby changing the detection range significantly, 2) very small targets also require a lower tilt angle (the antenna pointed further down) to detect the smaller target at a shorter range which can cause the radar to pull in more clutter AGC, 3) very large targets may pose such a large signal return that the system sensitivity and false alarm mechanizations will not adequately compensate, and 4) other factors associated with targets, such as the rotors on a helicopter, may alter the extrapolated detection range. If test time and resources permit, a further check of the detection range extrapolation based on target RCS can be accomplished by tests using several different sizes of targets and thereby checking several points on the extrapolation "curve" with respect to target size and clutter background.

Detection runs should be accomplished with the radar antenna set at a constant tilt angle throughout the run and for all similar runs, otherwise the detection probabilities can change significantly if the target does not enter the radar beam at the same range each time. Most detection runs are in a two-bar scan pattern with the tilt angle set to cover the target at the predicted detection range. This should produce proper P_D curves, but if not (the P_D curves do not rise to the required percentage before the target exits the beam or rise immediately as soon as it enters the beam), a different tilt angle should be used. The emphasis on setting the tilt angle may require a non-standard high accuracy tilt angle readout on the radar display (to a tenth of a degree) during the test program to achieve repeatable results. During detection test conditions, target history (the number of frames during which the detection symbol remains on the display) should be selected for the lowest setting (preferably one) to minimize confusion of actual target detections with the presence of false alarms.

The target must be flying straight and level at the start of each detection run, otherwise unrealistic detection ranges will result against a target still maneuvering to achieve the run conditions. Maximum target detection range runs normally start with a separation between the fighter and the target well beyond the estimated maximum detection range, and are set up in either a tail-chase or head-on configuration to close in separation until the target is out of the radar beam. If the run is started with the target at short range already being detected, and then increasing target separation until it is no longer detected, it is more a test of the retention of detecting a target rather than the maximum detection range.

A major source of target false alarms can be the presence of very large radar cross-section discrete targets (on the order of 100,000 square meters) in the antenna sidelobe and radome reflection lobes. Look-down tests should be conducted in an area with low backscatter coefficient terrain on one side of the ground track and large discrete targets on the other side of the ground track. Testing should include rolling maneuvers which cause the beam to illuminate many radome locations to note any false alarms caused by antenna sidelobes and radome reflection lobes. The shape of the radome will dictate how much testing and how many angles should be observed. If the radome is symmetrical, it is unlikely any change in FAR would result. However, if it is not symmetrical, differences in reflection lobe characteristics may exist and cause a FAR change. Section 5.7 of this volume contains a further discussion on radome evaluation.

Multiple target azimuth, range and velocity resolution can be accomplished by varying the separation of two targets (using only one separation type at a time) and requiring continuous TSPI on the fighter and targets to correlate their actual separation with the number of targets shown on the radar display. The most advantageous method of conducting the range and azimuth resolution tests is to set the aircraft up in a tail-chase aspect in order to better control the test conditions and achieve many separations and closures in a shorter period of time. The nature of the velocity search mode will require the targets be set up in a tail chase with respect to each other, but head-on to the fighter.

Tests involving weather are difficult to "schedule" in advance and are therefore accomplished as time and weather permits. It is also difficult to quantify the weather when encountered, resulting in only a qualitative analysis of its effects on radar capabilities. Therefore this test is of a lower priority, yet is still a worthwhile evaluation to conduct. There is no necessity to actually penetrate the weather, only to have it in the vicinity between the fighter and the target. Table 3 contains typical test conditions for a/a detection testing.

4.4 Manual Acquisition

4.4.1 What to Evaluate

Manual acquisition is defined as the process wherein the operator identifies a target of interest (usually through moving a cursor over the target on the radar display) and designates (commands the radar system to initiate a track/lock on to) that target. The adequacy of the size of the cursor "window" which defines the area of interest must be determined. The important aspect is the range interval that the cursor represents--its defined internal range dimension is a tradeoff between the system ability to resolve and lock on to the desired target in a formation of closely spaced targets (using a narrow cursor range interval), versus the capability to lock on to a single high closure rate target (using a wide cursor range interval to accommodate the rapid change in target range). It is probable that there may be different window sizes mechanized for various stages of the acquisition cycle such as designate, confirm, mini-scan and reacquisition. The evaluation of the cursor size will also involve an operational assessment of the precision required of the pilot to place the cursor in order to achieve a high rate of lock-on success. The acquisition cursor movement--both the rate of movement and sensitivity to pilot inputs--will be qualitatively evaluated. The movement is usually determined by the radar software and will vary with the amount of control deflection and whether the mechanization represents a position or a rate command.

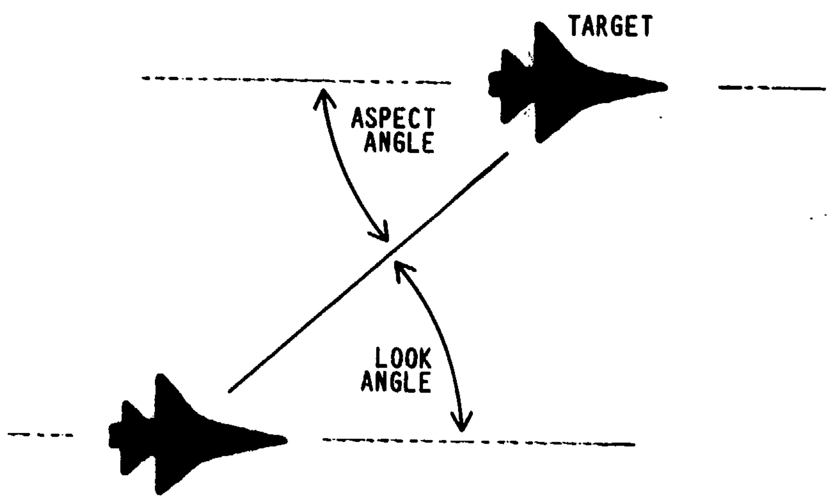
RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER ALT (FT)	LOOK ANGLE (DEG)	TGT ASPECT	TARGET SPEED (KNOTS)	TARGET ALT (FT)	TERRAIN	REMARKS
1	LOW ALT, LOOK-DOWN, HEAD-ON	474 GS	5K AGL	0 +/- 5	HEAD	340 GS	500 AGL	D	CLUTTER DETECT, BLIP-SCAN RATIO, FAR.
2	LOW ALT, LOOK-DOWN, TAIL	474 GS	5K AGL	0 +/- 5	TAIL	340 GS	500 AGL	D	CLUTTER DETECT, BLIP-SCAN RATIO, FAR.
3	MED ALT, LOOK-UP HEAD-ON	700 GS	30K AGL	0 +/- 5	HEAD	432 GS	33K AGL	D	BLIP-SCAN RATIO, FAR.
4	MED ALT, LOOK-UP, TAIL	700 GS	30K AGL	0 +/- 5	TAIL	432 GS	33K AGL	D	
5	LOW ALT, LOOK-DOWN CLOSING	320 GS	5K AGL	45 +/- 5	45°	320 GS	500 AGL	D	CLUTTER DETECT, BLIP-SCAN RATIO, FAR.
6	LOOK DOWN	300	5K AGL	0 +/-5	HEAD	250	1K AGL	M	
7	LOOK UP	300	1K AGL	0 +/-5	HEAD	250	FTR+15K	D	
8	LOOK UP	300	1K AGL	0 +/-5	HEAD	250	FTR+15K	M	
9	LOOK DOWN	300	15K AGL	0 +/-5	TAIL	250	5K AGL	D	
10	LOOK DOWN	300	15K AGL	0 +/-5	TAIL	250	5K AGL	M	
11	LOOK DOWN-45°	300	15K MSL	45 +/-5	45°	300	5K AGL	D	
12	LOOK DOWN-LO ALT	300	5K AGL	0 +/-5	HEAD	250	500 AGL	D	
13	LOOK DOWN-LO ALT	300	5K AGL	0 +/-5	TAIL	250	500 AGL	D	
14	LOOK UP-45°	300	15K MSL	45 +/-5	45°	300	20K MSL	D	
15	LOOK DOWN	0.9 MACH	30K MSL	0 +/-5	HEAD	250	500 AGL	D	
16	LOOK DOWN	0.9 MACH	30K MSL	0 +/-5	HEAD	250	500 AGL	M	
17	HIGH SPEED	1.5 MACH	30K MSL	0 +/-5	HEAD	1.5 MACH	35K MSL	D	
18	LOOK DOWN	MAX	5K AGL	0 +/-5	HEAD	500	500 AGL	D	
19	LOOK UP	300	5K AGL	0 +/-5	TAIL	300	15K MSL	D	SEPARATION VARIABLE BETWEEN TWO TARGETS TO CHECK AZIMUTH RESOLUTION.
20	LOOK DOWN	300	15K MSL	0 +/-5	TAIL	300	1K MSL	D	SEPARATION VARIABLE BETWEEN TWO TARGETS TO CHECK AZIMUTH RESOLUTION.
21	LOOK UP	0.9 MACH	5K AGL	0 +/-5	TAIL	300	15K AGL	D	SEPARATION VARIABLE BETWEEN TWO TARGETS TO CHECK RANGE RESOLUTION

TABLE 3 (CONTINUED)

RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER ALT (FT)	LOOK ANGLE (DEG)	TGT ASPECT	TARGET SPEED (KNOTS)	TARGET ALT (FT)	TERRAIN	REMARKS
22	LOOK DOWN	300	15K MSL	0 +/-5	TAIL	300	1K AGL	D	SEPERATION VARIABLE BETWEEN TWO TARGETS TO CHECK RANGE RESOLUTION
23	LOOK DOWN	300	5K MSL	0 +/-5	TAIL	250	500 MSL	SEA	
24	LOOK UP	300	1K MSL	0 +/-5	HEAD	250	17K MSL	SEA	
25	LOOK DOWN	300	15K MSL	0 +/-5	TAIL	250	5K MSL	SEA	
26	LOOK DOWN	0.9 MACH	30K MSL	0 +/-5	HEAD	250	500 MSL	SEA	

NOTES: 1. TERRAIN TYPES ARE: M - MOUNTAINOUS
D - DESERT
SEA - SEA

2. GS IS GROUND SPEED



Of primary importance is the maximum radar lock-on range to a target. Normally, acquisition would be attempted as soon as a detection is displayed to see if the system will lock on to any target it can detect. The rate of success of lock-ons attempted (number of successful lock-ons versus the number of opportunities) will be evaluated with respect to the criteria used to have the pilot designate (i.e., whether to start at the first target detection, or to wait until a predefined number of detections are displayed). In some cases the radar may detect a target but will not be able to lock on to it until it is closer in range. Examples of these cases include: attempting a lock-on from a low PRF detection when the radar only tracks in medium PRF; when the radar sensitivity is significantly different in detection versus track; or trying to lock on to a friendly aircraft for a rendezvous after having detected it in beacon mode.

The ability to acquire a target can sometimes be used by the operator as a discriminator between a true target and a false alarm. The minimum acquisition range and the fighter/target range rate envelope (both opening and closing rates) should be thoroughly investigated, especially to see if there are any effects on acquisition capability or initial target data filtering required to obtain a good track.

Specifications may have a requirement for the evaluation of "time to stable track." Unfortunately, the start and stop times often have not been sufficiently defined. One method which can be used to define the measured interval is: the time from pilot designation on a non-maneuvering target to the time that the system achieves target range, range rate and angle tracking accuracies within the two sigma values of the steady-state STT accuracy requirements. This time will vary depending on the search mode, track pattern size and antenna position (unless it is an electronic scan) at the time of designation, as well as the radar processing time required to redetect and confirm target presence. Time to stable track should be measured for lock-ons initiated from detection in medium and low PRF RWS, and from VS. The operational time requirement for stable track is highly dependent on the accuracies needed for weapon deployment "first shot" under the particular circumstances of the engagement. Also, the time required to reach stable track may be used by the operator as a discriminator between a target and a false alarm.

The target information displayed to the pilot (such as closing velocity, target altitude or altitude differential, and aspect angle) should be assessed for usefulness in helping the pilot rapidly identify a target versus a false alarm, and determining if it is a lock-on to the intended target. This can involve an assessment of what data should be displayed to the pilot during the acquisition cycle. The questions to be explored include a determination of what should be displayed to indicate that the system has acknowledged the acquisition command, and that it is attempting to lock on to the designated target. Also, the system internal "confidence level" required before the target information is displayed to the pilot should be investigated to ensure it is appropriate and not prematurely indicating a "good" track, or conversely, demanding an excessive level of confidence for a good track. The pilot will need to know as soon as possible whether the target track data is sufficiently settled for weapon launch (i.e., can he shoot?). The evaluation should be conducted such that a decision can be made between the options of displaying target data immediately, waiting until it is "good enough" to shoot, or displaying the data but inhibiting a missile launch until the data is "good enough."

4.4.2 Conditions and Factors for Evaluation

Manual acquisition should be evaluated under all conditions of target detection: combinations of fighter and target altitude, aspect angle, velocity, opening and closing rate, radar operating frequency, clutter background, target RCS and the presence of multiple targets. Manual acquisition should not be evaluated on the same test run used to measure P_D since the system should normally be able to lock on before P_D reaches even 50 percent, and sufficient detection data would not be acquired. Manual acquisitions should be attempted in the presence of ground moving targets (GMT) in order to determine discrimination capabilities between GMT and the airborne target of interest. Also, very high closure rate and multiple closely spaced target resolution runs will be required in order to verify the operational adequacy of the acquisition window size.

Radar lock-ons should be attempted at extremely short ranges and on very large targets at short ranges to ensure the radar does not lock on to target returns from an antenna sidelobe. If that were to happen, it would likely result in antenna position errors, leading to a breaklock.

Since the adequacy of the manual acquisition capability is partly dependent on the information displayed to the pilot, tests should be accomplished with at least three different pilots in order to fully assess suitability. Multiple pilots will also provide guidance in several areas such as determining the best lock-on criteria. Typical test conditions for a/a manual acquisition testing are contained in Table 5 (in section 4.6.2 on tracking evaluation) since acquisition and track are normally evaluated together.

4.5 Automatic Acquisition

Automatic acquisition capabilities, referred to as Air Combat Maneuvering (ACM) modes, are mechanized to have several different selectable scan patterns. ACM is generally designed for shorter range (typically 10 nm or less) maneuvering automatic lock-on to the target.

Some ACM evaluations include an analysis of probability of detection. However, since the system is mechanized such that target detection and then lock-on occur automatically and nearly simultaneously, there is no counting of detections and no P_D curve. The analysis is really one of determining if lock-on occurs at the first opportunity (when the target is within the field of view and the antenna scans across it) or later. However, it is possible to temporarily disable lock-on in ACM to more fully investigate the detection capability. This is normally done only if significant problems are encountered in ACM mode detection. Lock-on range is an important factor, although if the system mechanization is similar to that of normal detection and manual acquisition, this is not usually a significant problem area since ACM is restricted to well within the normal manual acquisition range. However, the radar may have a different mechanization for target detection or discrimination to minimize false lock-ons to larger discrete targets such as the altitude line. If the system is equipped with an altitude line tracker/blanker, its effectiveness should be evaluated with respect to: proper positioning during fighter maneuvers; width sufficient to prevent altitude line lock-on but not too great so as to cause excessive holes in mode capability; and mode performance variances when the altitude line is positioned based on radar altimeter versus barometric aircraft data.

The false alarm lock-on rate should be evaluated in ACM using all possible GMTR selections, when so equipped. Time to lock-on and time to stable track are evaluated the same as in manual acquisition although the scenario dynamics will be greater in the ACM conditions. The start time for both would normally be when the target enters the ACM field of view.

The functional adequacy and quantitative capability of each of the ACM scan patterns (HUD/supersearch, vertical, slewable and boresight) should be evaluated with respect to different fighter/target scenarios. The size of each pattern, the scan rate, and the scan direction are factors in the evaluation, especially with respect to the fighter body and the estimated direction of target movement when it enters the field-of-view (FOV). For example, during a tight turning maneuver with the fighter in trail of the target, the target will usually enter the HUD FOV from top to bottom. If the scan pattern were mechanized to scan in horizontal bars starting from top to bottom, it could very well end up "chasing" the target and never locking on to it, whereas if it started from bottom to top it would have a much higher probability of crossing the target path and achieving a lock-on.

Airborne target lock-on, breaklock, and reacquisition in the presence of multiple targets must be functionally verified to determine if: 1) the system breaks lock when commanded or when the target fades, 2) it then acquires the next target in range or angle properly and timely, and 3) it allows the operator to adequately differentiate between targets of interest using a combination of scan patterns. This also includes determining which target the radar will acquire if more than one is within the acquisition window (target discrimination and resolution) and the capability for the pilot to manually switch track from one target to another.

4.5.2 Conditions and Factors for Evaluation

The ACM mode is tested using a number of combinations of maneuvering fighter and target. The runs should be described and conducted so as to be repeatable, to obtain adequate sample sizes (at least three runs of each test condition) and to make comparisons when changing a variable such as clutter background or frequency. Test conditions should be conducted in a build-up fashion in terms of starting with benign target line-of-sight (LOS) angles and rates, then increasing to high rates since that is the most critical and most difficult for the mode. Additionally, the most effective scan patterns should be determined for each condition. Fighter maneuvering also will verify the radar system (primarily the antenna) capabilities in worst case (high g loading) conditions. This is especially important when high scan rate antennas are coupled to modern highly maneuverable aircraft.

Testing over several different terrains is required since the radar system is automatically determining target presence, and it is highly undesirable that terrain or clutter returns be mistaken for targets resulting in a lock-on attempt. Over water is often the worst case, since it presents such a strong radar return, although large discretes over land can also cause problems. One of the most demanding and thorough ACM test situations is to have the target do a split-S maneuver towards the ground and than have the fighter follow it. This places the target in competition with a strong clutter return and will also achieve angles to determine the effect of radome reflection lobes on ACM auto acquisition. ACM modes should be tested with the airborne target in the presence of ground moving targets to determine if the radar will properly discriminate and lock on to the proper return. Multiple airborne targets will be required to set up at the same azimuth but trailing in range, or at the same range but separated in azimuth. Table 4 contains typical test conditions for a/a ACM testing.

TABLE 4 TYPICAL A/A AIR COMBAT MANEUVERING FLIGHT TEST CONDITIONS

RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER (FT) (ALT)	TGT ASPECT	TARGET SPEED (KNOTS)	TARGET (FT) (ALT)	BEGIN RUN	END RUN	REMARKS
1	20 X 20 SCAN	300	20K	TAIL	300	23K	AR	AR	TGT SPLIT-S IN FRONT OF FTR AT 3 NM SEPARATION.
2	20 X 20 SCAN	300	20K	TAIL	300	20K	AR	AR	TGT AND FTR DO 45° BANK TURN SAME DIRECTION, TGT SHALLOWS TO 30° BANK, FTR REVERSES TO 3.5G TURN AND SELECTS ACM AT 2-3 NM SEPARATION.
3	20 X 20 SCAN	400	20K	TAIL	400	20K	AR	AR	ONE NM SEPARATION, OFFSET, TGT DOES 4G TURN, FTR DOES HIGH G TURN TO BRING TGT INTO AND THROUGH FOV.
4	20 X 20 SCAN	350	1.5K AGL	TAIL	300	500 AGL	AR	AR	ONE NM SEPARATION, OFFSET, FTR TURNS TO PULL TGT INTO AND THROUGH FOV.
5	10 X 40 SCAN	300	8K AGL	ABREAST	300	5K	AR	AR	FTR COMES OFF PERCH, PULLS TGT INTO AND THROUGH FOV.
6	10 X 40 SCAN	400	20K	TAIL	400	20K	AR	AR	ONE NM SEPARATION, OFFSET, TGT DOES 4G TURN, FTR DOES HIGH G TURN TO BRING TGT INTO AND THROUGH FOV.
7	10 X 40 SCAN	300	15K	TAIL	300	15K	AR	AR	ONE NM SEPARATION, TGT DOES SPLIT-S, FTR DOES SPLIT-S AT 60° ANGLE OFF AND PULLS TGT INTO AND THROUGH FOV.
8	BREAK LOCK	350	20K	TAIL	350	20K	AR	AR	WITH 3000 FT SEPARATION, TGT AND FTR DO SCISSOR MANEUVER.
9	BREAK LOCK	450	25K	TAIL	250	25K	AR	AR	TGT INITIATES 30° TURN FTR BARREL ROLLS AT 1 NM SEPARATION.
10	MED ALTITUDE SLEWABLE LOW LOS RATE	300	10K	TAIL	300	10K	1NM	1NM	ACQUISITION TIME LOW LOS RATE.
11	MED ALTITUDE SLEWABLE HI LOS RATE	300	10K	TAIL	360	10K	1K FT	1KFT	ACQUISITION TIME HIGH LOS RATE. TARGET MAKES 2 G "S" TURNS.
12	MED ALTITUDE SLEWABLE OPENING	250	10K	TAIL	450	10K	500'	10NM	ACQUISITION TIME TARGET OPENING.
13	MED ALTITUDE SLEWABLE CLOSING	450	10K	TAIL	250	10K	10NM	500'	ACQUISITION TIME TARGET CLOSING.
14	MED ALTITUDE TAILCHASE SLEWABLE	350	13K	TAIL	350	15K	5NM	1000'	SIMULATED ACM. TARGET PERFORMS LOOP THEN LEVEL TURN. FIGHTER FOLLOWS MAKING REPEATED ACQUISITIONS.
15	MED ALTITUDE TAILCHASE BORESIGHT	350	15K	TAIL	350	15K	2000'	1000'	SIMULATED ACM. TARGET PERFORMS SPLIT-S, FIGHTER FOLLOWS MAKING REPEATED ACQUISITIONS.

TABLE 4 (CONCLUDED)

RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER (FT) (ALT)	TGT ASPECT	TARGET SPEED (KNOTS)	TARGET (FT) (ALT)	BEGIN RUN	END RUN	REMARKS
16	MED ALTITUDE OPENING BORESIGHT	250	10K	TAIL	450	10K	500'	10NM	ACQUISITION TIME TARGET OPENING.
17	MED ALTITUDE CLOSING BORESIGHT	450	10K	TAIL	250	10K	10NM	500'	ACQUISITION TIME TARGET CLOSING.
18	MED ALTITUDE 30X20 LOW LOS RATE	300	10K	TAIL	300	8K	1NM	1NM	ACQUISITION TIME LOW LOS RATE.
19	MED ALTITUDE 30X30 HIGH LOS RATE	300	10K	TAIL	360	8K	2500'	2500'	ACQUISITION TIME HIGH HIGH LOS RATE.
20	MED ALTITUDE 30X20 OPENING	250	10K	TAIL	450	8K	2500'	10NM	ACQUISITION TIME TARGET OPENING.
21	MED ALTITUDE 30X20 CLOSING	450	10K	TAIL	250	8K	10NM	500'	ACQUISITION TIME TARGET CLOSING.
22	MED ALTITUDE 10X40 LOW LOS RATE	300	8K	TAIL	300	10K	1NM	1NM	ACQUISITION TIME LOW LOS RATE.
23	MED ALTITUDE 10X40 OPENING	250	8K	TAIL	450	10K	2500'	10NM	ACQUISITION TIME TARGET OPENING.
24	MED ALTITUDE 10X40 CLOSING	450	8K	TAIL	250	10K	10NM	2500'	ACQUISITION TIME TARGET CLOSING.
25	MED ALLTITUDE 10X40 HEAD-ON	350	12K	TAIL	350	15K	5NM	1000'	SIMULATED ACM. TARGET MAKES LEVEL TURN, FIGHTER FOLLOWS MAKING REPEATED ACQUSITIONS.
26	MED ALTITUDE 30X20 TAILCHASE	350	18K	TAIL	350	15K	5NM	1000'	SIMULATED ACM. TARGET PERFORMS A SPLIT-S, FIGHTER FOLLOWS MAKING REPEATED ACQUISITIONS.

NOTE: ALL ALTITUDES ARE MSL UNLESS OTHERWISE NOTED.

4.6 Tracking A Single Target

4.6.1 What to Evaluate

Single target track (STT) is usually mechanized and evaluated using the same methods whether entered from manual acquisition or ACM, although the more dynamic nature of the ACM mode test conditions will normally produce tracking under more dynamic situations. The evaluation will determine the radar's capability to track an airborne target within a specified envelope of fighter and target opening and closing velocities, ranges, roll rates and accelerations, pitch rates and accelerations, and yaw rates and accelerations. The percentage of successful tracks and the ability to maintain track with minimum fading, breaklocks or blind zones should be verified. Track mode accuracies to be determined (comparisons between the radar and reference data) include: target slant range, range rate, range vectors (X, Y and Z), velocity vectors (X, Y, and Z), acceleration vectors (X, Y, and Z), and LOS angle. These accuracies may change (and may be allowed to do so by the system requirements) with target range, LOS angle, LOS angle rate and jerk (rate of acceleration). Also, correlation accuracy of radar track data with on-board detected IFF targets should be evaluated when the fighter is so-equipped.

Noise (rapid changes) in the target tracking data will adversely affect weapons delivery algorithms and displays, yet excessive damping of noisy track data can induce undesirable amounts of lag. Therefore, the track algorithms are necessarily a compromise and the test program may be required to evaluate several different tracking algorithms under multiple weapons delivery situations to determine the adequacy of each one. Target track noise will affect intercept steering commands given to the pilot and his capability to interpret and follow them. Also, for weapons delivery situations, such as the radar providing target pointing information to launch an IR missile, the displayed launch cues on the HUD could turn out to be a blur on the target circle due to excessively noisy track data.

In a pulse doppler look-down radar, the target will go into a doppler notch--the target return will compete with the clutter return--during maneuvers which put the target in a beam aspect. Typically, the radar will be mechanized to enter a "coast" mode and extrapolate the target track based on the last returns received. The evaluation should measure the extrapolation errors, whether the target track data becomes less stabilized, and whether the radar will reacquire the target successfully when it comes out of the notch. If the radar is mechanized to track through the notch (by dynamically determining the notch position and width based on the fighter situation), maneuvers must be set up to give a broad sampling of notch crossing rates to determine if any limitations exist. Also, "coast" should be evaluated to determine if sufficient track accuracy is maintained to still allow weapons employment, such as pointing for a radar or infrared guided missile.

During all tracking conditions, the evaluation will also assess the value and usefulness of track quality indicators (if equipped), the capability to track across any ranges where the internal processing changes (such as from long range to short range tracking algorithms), and evaluate system extrapolation effectiveness through mode changes--especially in the case of a radar which is able to interleave modes.

When the radar does break lock on a target, its reacquisition capability will require evaluation. This should assess whether the radar will reacquire the target automatically, how long it takes to do so, and the existence of limitations such as fighter or target velocity, range or LOS angles. The usefulness of the radar reacquisition mechanization is especially critical in a tactical situation wherein the pilot may not want the radar to take the full time to attempt target reacquisition; but rather may want to take control and force it back to a search mode if the radar can't rapidly determine the target location and activity.

The possibility of track transfer from one target to another is an important area to test since, in STT, the radar is blind to all other targets. If the system becomes confused and transfers track to a crossing target, especially if it is not evident to the pilot, an operational engagement could result in dire consequences. Tests should also be run to determine if the radar will transfer track to ground clutter returns.

Evaluation of automatic range scale switching adequacy is normally a qualitative determination of its usefulness based on operator comments throughout the performance envelope. Typically, range scale switching to the next higher or lower range scale will occur when the tracked target reaches 95 percent or 45 percent, respectively, of the current selected range scale.

The raid assessment mode needs to be evaluated in terms of the ability to discriminate between closely spaced multiple targets, especially formations of targets of varying sizes. This includes a determination of ease of entry into RAM, the doppler resolution, RAM processing time (the time required for multi-target indication), time required for an actual target count, and any effects of RAM on other track files.

If the radar interfaces with a radar missile which requires telemetry of target data to the missile, the accuracy of the data sent must be evaluated. The radar track accuracies may be different from normal STT since it will require periodically interrupting radar operation to T/M data to the missile. Conditions starting from benign and progressing to higher maneuvering rates need to be accomplished in order to evaluate the capability of the radar to correctly decide how much time it can afford to spend away from tracking the target and still maintain a lock-on.

4.6.3 Conditions and Factors for Evaluation

The initial tracking evaluation should be conducted under fairly benign, straight and level flight conditions in order to establish a baseline accuracy. Then, combinations of fighter and target speeds, closing and opening rates and maneuvering conditions under increasingly dynamic situations will be required. The track run conditions must be set up and described so that they are controlled and repeatable since a sufficient sample size may require three or four identical runs in order to draw any conclusions. An instrumented target capable of providing time-correlated maneuvering data (attitude, velocities, and accelerations) may be required since it is difficult to get attitude data with the required accuracy from a ground-based reference system. Target RCS is not as great a factor in STT as in detection range testing, yet the extreme cases, such as a large tanker/bomber size target at close range, should be tested in order to verify the capabilities of the radar track automatic gain control mechanizations.

Maneuvering runs should include the fighter maneuvering both vertically and horizontally, and eventually progress to both the fighter and target maneuvering in a dogfight to ensure achievement of a variety of target ranges, LOS angles, and LOS rates. High target LOS rates can be produced in a tail chase by maneuvering the fighter to the opposite side of the target (reverse lateral separation) at a high rate, then reducing the tail chase range separation and repeating the lateral maneuver (to achieve higher LOS rates). Runs should include relative velocities varying between positive and negative values and some runs should continue closing until "break-lock" occurs to assess minimum tracking range. The fighter should be maneuvered in pitch and roll, one axis at a time, to determine if the display destabilizes. As much as possible, the maneuvering runs should be repeatable, although precise fighter/target set up and maneuvering is difficult.

Runs should be set up to place the target with ground clutter and ground moving targets in the background to assess any degradation on track accuracy and if any track transfers or breaklocks occur. Multiple airborne targets will be required to determine under what conditions track transfer will occur. This can be accomplished by varying their flight path crossover rates and angles. Several target sizes are required, especially a large target at close range, to test STT dynamic range (generally compensated for by the automatic gain control (AGC) mechanization). Various sized targets will also evaluate STT in the presence of target scintillation (caused by rapid amplitude fluctuations of target returns) and glint (which is predominant at close ranges), and will help determine if track loss occurs due to differences in target RCS. For this reason, the tester needs to have a capability to automatically correlate target RCS data at all flight conditions (primarily target aspect angles) with test results. Various types of targets, such as helicopters and propeller-driven aircraft in addition to the standard jet aircraft, will also be required in order to determine the effects of target return signal modulations on STT. Table 5 contains typical test conditions for a/a STT testing.

4.7 Detection and Tracking of Multiple Targets

Two types of multiple target detection and tracking schemes are search-while-track (SWT) and track-while-scan (TWS). In SWT the radar system has a basic single target track capability but occasionally interrupts (while maintaining the track in memory) and scans to detect if other targets are present. This mechanization is less common since it has fairly limited capabilities and is applicable primarily where radar system computer processing is limited. The more common multiple target scheme, TWS, uses a continuous scan while detecting, establishing track, and maintaining track files on a number of targets simultaneously. Both SWT and TWS are evaluated in a similar manner, although much less extensive testing is required for SWT.

4.7.1 What to Evaluate

A prime TWS evaluation criteria is the number of targets the system is capable of displaying and tracking simultaneously. Since there is a tradeoff between the number of targets to be tracked versus the time available to obtain and process data on each one, depending on the scan rate and scan volume, the effects on tracking capabilities must be assessed. The amount of available radar system processing time is the primary limiting factor. The TWS evaluation criteria will be very similar to that for single target detection, acquisition and track: detection and tracking envelope, false alarm rate, time to stable track, the ability to maintain track--especially against a maneuvering target (TWS may not be able to accommodate as much maneuvering due to less data time on the target), weapons interfaces (such as missile pointing commands), and correlation with on-board detected IR targets. Track accuracy requirements in TWS will generally be less stringent than in STT, and the probability of a successful radar missile launch may be lower due to the less accurate target data. Track transfer from one target to another will not be as critical since the radar is not "blind" to other targets as in single target track, however track through the notch may not operate due to less target data time.

The TWS evaluation includes determining the maximum target detection range, the maximum range at which a valid track file can be established, the time from initial detection to

TABLE 5 TYPICAL A/A SINGLE TARGET TRACK FLIGHT TEST CONDITIONS

RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER ALT (FT)	TGT ASPECT	TARGET SPEED (KNOTS)	TARGET ALT (FT)	REMARKS
1	LOOK DOWN	300	5K AGL	HEAD	250	500 AGL	
2	LOOK DOWN	300	5K AGL	TAIL	250	500 AGL	
3	LOOK DOWN	300	5K AGL	TAIL	300	500 AGL	ZERO KNOTS RANGE RATE.
4	LOOK DOWN	250	5K AGL	TAIL	350	500 AGL	FTR CLOSE ON TARGET, LOCK ON, THEN BACK OUT TO TEST TRACKING AT NEGATIVE RANGE RATE AND BREAKLOCK.
5	LOOK DOWN	300	15K AGL	45°	300	10K MSL	
6	LOOK UP	300	15K MSL	HEAD	250	30K MSL	
7	HI LOS RATE	1.5 MACH	35K MSL	HEAD	1.5 MACH	20K MSL	
8	CHECK COAST	250	20K MSL	TAIL	300	20K MSL	TARGET MAKE SHARP TURN FOLLOWED BY SPLIT-S.
9	CHECK BREAK LOCK	300	15K MSL	TAIL	300	10K MSL	TWO TARGETS WEAVE BACK AND FORTH TO SEE IF RADAR CONTINUES TRACK ON SAME TARGET, TRANSFERS LOCK OR BREAKS LOCK
10	CHECK BREAK LOCK	300	15K MSL	TAIL	300	10K MSL	TWO TARGETS--1 TARGET STRAIGHT AND LEVEL, OTHER TARGET WEAVES BACK AND FORTH TO CHECK RADAR LOCK.
11	CHECK COAST	300	10K MSL	TAIL	300	6K MSL	TARGET DOES 180° REVERSAL TO HEAD-ON ASPECT.
12	CHECK COAST	250	10K MSL	HEAD	350	6K MSL	TARGET DOES A 360° TURN
13	CHECK COAST	250	10K MSL	HEAD	350	6K MSL	TARGET DOES HORIZONTAL S-TURN WITH ROLLOUT TO ORIGINAL HEADING, PUTTING TARGET IN NOTCH MAXIMUM POSSIBLE TIME.
14	HI LOS RATE	1.6 MACH	35K MSL	HEAD	HI	HI	

establishment of a track file, and the frequency of success in achieving and maintaining a track on a target. Test conditions will be required to explore the tradeoff between antenna scan/target data refresh rate verses probability of target detection, since the optimum answer is highly dependent on the scenario and target size (such as a cruise missile verses a fighter or a bomber). This may mean the addition of the capability to make scan rate or pattern size operator selectable depending on the situation and desired target(s). If so, testing will require multiple targets of differing sizes in operational situations for evaluation. The update rate at which target data is received will also affect how long the system can go before breaking lock on a target, typically on the order of not more than 10 seconds.

If the TWS mode includes the capability to automatically initiate lock-on, the lock-on criteria must be fully evaluated in order to assure a minimum number of lock-ons to undesired or false targets. TWS track accuracy is highly dependent on correctly correlating detections with tracks. The criteria for automatically establishing a target track is critical, otherwise the correlation and the resulting displayed track may be false. A false correlation could result in the radar incorrectly associating a target detection with the wrong track, or not associating a target detection with the correct track, and either way develop a false and misleading track without the pilot knowing what has occurred. The adequacy of the correlation window size (especially if it is dynamic, i.e., it changes based on detected target parameters) needs to be determined to see if the radar will correctly follow a maneuvering target versus incorrectly correlating data from another target. The correlation criteria needs to have reasonableness limits defined for target maneuvers, such as target velocity and turn rate, to help the system judge if it is a possible true track. The utility of the TWS mode is dependent upon operator confidence that it is tracking or extrapolating the target track accurately.

Also to be evaluated are multiple target range, azimuth, elevation and range rate resolution, transitions from STT to TWS and back, the capability to properly sort and prioritize targets, and the ability of the pilot to override the system priorities. The TWS displays should be evaluated with respect to the logic for centering, presentation of target priorities, the usefulness of expanded scales and display adequacy for presenting target identification and data.

If the radar is equipped with a RAM capability in TWS to determine the presence of closely spaced targets, the evaluation should determine the time required for multi-target indication and identification in RAM, the time required for actual target count in RAM, and the effect of RAM on other track files.

4.7.2 Conditions and Factors for Evaluation

Test conditions in TWS will generally be similar to those for single target track with possibly less maneuvering involved. This includes starting with benign (straight and level) runs to establish a baseline, and then progressing to more dynamic fighter/target conditions, all of which must be controlled and repeatable. There will be a need for instrumented targets and various target sizes (RCS). Dissimilar target sizes will be a more strenuous test of the radar prioritization capability so that runs need to be set up which require the system to correctly determine priorities based on the potential threat to the fighter. Also, it is important to have look-down conditions where the targets compete with the clutter. The multiple target formations should include a number of combinations of target speeds, opening and closing rates, separations and maneuvering levels sufficient to evaluate the detection, lock-on, prioritization and tracking capabilities.

The automatic track initiation feature needs to be evaluated to determine the capability of the TWS mode to assign target detections to the proper track files under conditions of maneuvering targets, maneuvering fighter, and combinations of maneuvering target and fighter. A thorough evaluation of TWS will include test conditions to fully explore the multiple target capabilities with respect to operationally significant scenarios. The use of multiple maneuvering targets (with the added possibility of manned and unmanned targets), along with a maneuvering fighter, presents a significant impact on the range control system as well as on the area required to conduct the tests. TWS testing can make much use of targets of opportunity and then add some dedicated targets to make up the difference, especially for runs which require the largest number of targets.

The TWS evaluation lends itself very well to ground and lab testing since mode performance is less dependent on the RF chain than on the radar processing capabilities. (Not to be forgotten is that less target return signal may be available due to the shorter dwell time and less target detections, which may result in a lower probability of detection and less target information in TWS than in STT). The lab simulation can give an early mode assessment, which is especially important since it will minimize the large amount of support (e.g., multiple targets and tracking systems) required to do the flight test. The radar system algorithms which determine numbers of targets and threat priorities can be thoroughly checked out, especially since the lab simulation can better control target parameters than in flight. Table 6 contains typical test conditions for a/a multiple target detection and tracking testing.

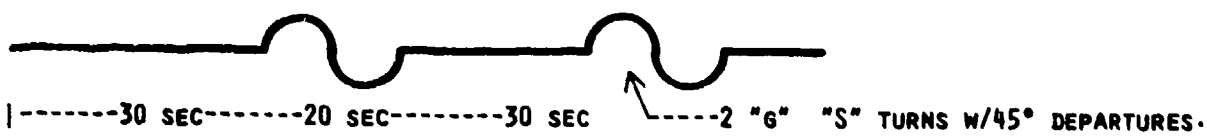
TABLE 6 TYPICAL MULTIPLE TARGET DETECTION AND TRACKING FLIGHT TEST CONDITIONS

RUN #	CONDITION	FIGHTER SPEED (KNOTS)	FIGHTER ALT (FT)	FIGHTER BARS/SCAN	TARGET ASPECT (DEG)	TARGET SPEED (KNOTS)	TARGET ALT (FT)	BEGIN RUN	END RUN	REMARKS
1	HIGH ALT. NON MANEUV. HEAD-ON	520	20K	3 +/-25°	180 +/-5	480	22K	50NM	AR	TWS DETECTION AND TRACK. END RUN 10 SEC. AFTER TRACK IS ESTABLISHED. NOTES: 2, 3, 4, 9
2	HIGH ALT. LOOK DOWN HEAD-ON	520	20K	3 +/-25°	180 +/-5	590	1K	50NM	AR	REPEAT RUN 1 AT HIGH CLOSURE. NOTES: 3, 9, 10
3	HIGH ALT. UP LOOK HEAD-ON	250	20K	3 +/-25°	180 +/-5	300	25K	AR	GL	TWS ACCURACY WITH OUT CLUTTER. BEGIN RUN BEYOND MAXIMUM DETECT RANGE. NOTES: 1, 2, 3, 4, 5
4	HIGH ALT. DOWN LOOK HEAD-ON	250	20K	3 +/-25°	180 +/-5	300	15K	AR	GL	TWS ACCURACY WITH CLUTTER. BEGIN RUN BEYOND MAXIMUM DETECT RANGE NOTES: 1, 2, 3, 4, 5
5	HIGH ALT. TAIL-ON	250	20K	3 +/-25°	0 +/-5	250	20K	10NM	10NM	RANGE RESOLUTION SET UP TWO TARGETS AT 10 NM (NOTE 7). TARGET A SLOWS TO 20 FPS OF B. ONCE THE TWO TARGETS CAN BE DISTINGUISHED THEN TARGET A SPEEDS UP TO 20 FPS FASTER THAN B. NOTES: 1, 2, 3, 6, 7
6	HIGH ALT. TAIL-ON	250	20K	3 +/-25°	0 +/-5	250	20K	10NM	AR	AZIMUTH RESOLUTION. SET UP TWO TARGETS AT 10NM (NOTE 8) FIGHTER ACCELERATE TO 300 KNOTS. ONCE TWO TARGETS CAN BE DISTINGUISHED, THEN FIGHTER SLOW TO 200 KNOTS. NOTES: 1, 2, 3, 6 8. END RUN WHEN ONLY ONE TARGET CAN BE DISTINGUISHED
7	HIGH ALT. HEAD ON	250	20K	3 +/-25°	180 +/-5	250	22K	50NM	AR	TRANSITION TWS TO STT TO TWS. INITIATE STT AND RETURN TO TWS AFTER 5 SEC. REPEAT SEVERAL TIMES. NOTES: 1, 2, 6
8	HIGH ALT. HEAD ON	250	20K	3 +/-25°	180 +/-5	250	22K	50NM	AR	TRANSITION TWS TO STT TO TWS. INITIATE STT AND RETURN TO TWS AFTER 15 SEC. REPEAT SEVERAL TIMES. NOTES: 1, 2, 6
9	HIGH ALT. ALL ASPECTS	250	20K	3 +/-25°	MULTIPLE TARGETS			AR	AR	TWS MODE LOOKING AT MULTIPLE TARGET IN ACMI RANGE ENGAGEMENT. NOTES: 1, 2

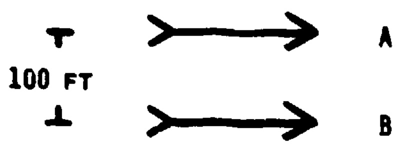
TABLE 6 (CONCLUDED)

RUN #	CONDITION*	FIGHTER SPEED (KNOTS)	FIGHTER ALT (FT)	FIGHTER BARS/ SCAN	TARGET ASPECT (DEG)	TARGET SPEED (KNOTS)	TARGET ALT (FT)	BEGIN RUN	END RUN	REMARKS
10	HIGH ALT. ALL ASPECTS	350	25K	3 +/-25°	12 TARGETS			50NM	AR	TWS MODE LOOKING AT 12 TARGETS. UTILIZE WAVE AND BOX FORMATIONS. NOTES: 1, 2, 11
11	HIGH ALT. TAIL ON	250	20K	3 +/-25°	0 +/-5	250	20K	10NM	AR	ELEVATION RESOLUTION. REPEAT RUN 6 EXCEPT SET UP WITH TWO TARGETS SEPARATED BY 2000 FT IN ELEVATION. NOTES: 1, 2, 3, 6, 8

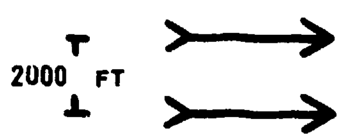
NOTES:
1. SPEEDS ARE KNOTS CALIBRATED AIR SPEED.
2. ALTITUDES ARE MSL.
3. REFERENCE DATA REQUIRED
4. TARGET WITH KNOWN RCS REQUIRED.
5. THE FOLLOWING PROFILE SHOULD BE FLOWN WITHIN REFERENCE DATA COVERAGE.



6. TWO TARGETS REQUIRED.
7. RANGE RESOLUTION SET UP:



8. AZIMUTH RESOLUTION SET UP:



REFERENCE SYSTEM TRACKS AND MAINTAINS SEPARATION.

9. SPEEDS ARE KNOTS GROUND SPEED.
10. ALTITUDES ARE AGL.
11. EXERCISE TWS EXPAND.
12. AR IS AS REQUIRED
13. GL IS GIMBAL LIMITS.
14. FTR IS FIGHTER
15. TGT IS TARGET

5 FLIGHT TEST TECHNIQUES - ADDITIONAL CONSIDERATIONS

This section covers radar flight test evaluations which should be considered in addition to those enumerated in section 4. Coverage here is not intended to imply that these considerations are of any lesser importance than those primary modes previously covered. Some of these evaluations may require additional dedicated flight test runs, however most do not.

5.1 Self-Test/Built-in-Test

Self-test is usually defined as continuous, non-interruptive, automatically accomplished testing, whereas built-in-test is run only upon operator initiation and interrupts normal system operation to accomplish fault isolation. Self-test/built-in-test (ST/BIT) functions are frequently the last capabilities to be implemented during radar system development. This then raises a question of when the ST/BIT indications are correct and should be used by the testers to make flight decisions. Historically, radar system development has started with the air-to-air modes, progressed to the air-to-ground modes, then ST/BIT, and finally development of special capabilities such as ECCM. Future testing, however, will likely place increased emphasis on early completion of ST/BIT development in order to better assess system reliability. Also, future automatically reconfigurable systems may require a different concept in ST/BIT, and could even require a DT&E unique ST/BIT configuration in order to assess when the radar gracefully degrades or reconfigures. This is especially important when that information would not normally be displayed to the pilot or recognised by him since the system is still fully capable.

The three ST/BIT capabilities usually specified and evaluated are: 1) failure detection probability--normally a high value of at least 90 percent probability of detecting and notifying the operator of a failure, 2) false alarm rate--a low value such as 5 percent, to minimise the occurrences of failure indications when a failure does not actually exist (if the ST/BIT false alarm rate is high, the operator will soon disbelieve and ignore the system), and 3) fault isolation capability--if a failure occurs, the system's ability to isolate it to a component level such as a Line Replaceable Unit (LRU). This may be further specified such that BIT must isolate the failure to, for example, 1 LRU 90 percent of the time, to within 2 LRUs 95 percent of the time, and to within 3 LRUs 100 percent of the time to allow faster repair times.

Some typical radar characteristics monitored or tested by ST/BIT include: the transfer of data, voltage standing wave ratio (VSWR), peak power, waveguide arcing, antenna azimuth and elevation pointing errors (commanded versus actual position), and motor status. Exceeding temperature limits and the presence of waveguide arcs may result in automatic shutdown of the system. Built-in-Test is necessarily interruptive to the normal operation of the radar since it may include: checks of the transfer of data by wrap-around tests, analyzing antenna position accuracy through the use of static commands, conducting other specialized checks for antenna positioning, and exercising other system functions which could not be done while maintaining normal radar operation. The pilot is also usually involved in BIT (such as observing specific patterns generated on the display) in order to make an assessment of system pass or fail. Some BIT mechanisations may include self-calibrating features such as sending a known signal to the analog-to-digital converters and calibrating the output. Another possibility is conducting an automatic alignment after the radar antenna has been replaced.

During a flight test program, the ST/BIT evaluation is usually based only on the failures that happen to occur (rather than intentionally inducing failures in flight), and is therefore treated as only an indication of what may happen in the field. The question of how representative the flight test ST/BIT results are also occurs due to the comparatively low number of system operating hours, and the fact that different skill level personnel (usually the contractor field engineers) accomplish the repairs versus the military maintenance personnel who will be used in the field. However, the results from flight tests may give early information on any system weak points if a failure occurs frequently, and flight testing is a more controlled environment to check failures induced by vibration or temperature. Larger sample sizes can be obtained during operational testing in the field using many systems and maintenance actions over a period of many months or years, and would be the final determining factor in the adequacy of the ST/BIT capabilities. If a ST failure is indicated in flight, BIT should be initiated (when convenient with respect to the test conditions) to attempt to further isolate the failure and determine the validity of the ST indication. BIT should also be run periodically, even when ST is not indicating a failure, in order to measure the BIT false alarm rate (i.e., does it indicate a failure when one does not actually exist?).

The capabilities of ST/BIT can be further determined during a flight by comparing any reported failures with the available telemetry data to see if the instrumentation system is detecting the problem, and conversely, if the telemetry data reports a problem without a corresponding ST/BIT failure indication. Throughout the test program, each LRU that is removed must be tracked to see if it really did contain a failure in order to determine if the indicated failure was true or false, or to determine if a failure did occur but was not indicated. This tracking system must be set up in advance of testing and able to accommodate a quick turnaround in the data. There may also be a test-unique requirement for a ST/BIT capability for the radar instrumentation in order to make best and most efficient use of the limited test time available by minimizing instrumentation system down time.

Normally, testers are very reluctant to induce in-flight failures since there are many other higher priority radar modes and features which must be evaluated. This is additional justification to do extensive laboratory tests for ST/BIT evaluation since many failures may never be seen during the relatively short flight test period. The determination of ST/BIT specification compliance is normally accomplished in a laboratory where a large number of faults are induced and the tests can be much more controlled. Since running every combination of induced failure and ST/BIT would be very time consuming and expensive even in a lab environment, the conditions to be evaluated may be randomly chosen out of the total number of tests available (such as 80 percent of the total), and these faults intentionally induced to determine the radar system's reaction. There are some limitations which should be considered when doing ST/BIT evaluations in a lab: some inserted failures may not necessarily be representative since in-flight conditions can be intermittent and not a constant ("hard") failure (for example, those that are induced by aircraft vibration or altitude changes), and certain catastrophic failures would not be intentionally induced since they could result in damage to the system.

The implementation of ST/BIT, and its utility in a test and an operational environment, will evolve during the test program. The thresholds used for an individual test (such as the VSWR limit or transmitter power or temperature) used to declare test pass/fail, plus the determination of the ST and BIT failure indication criteria (how many (N) times that test must fail out of how many (M) times the test is run) will likely have to be varied during the course of the test program. This will be necessary to achieve the optimum balance between false alarm rate (when the thresholds are set too low and incorrectly indicate a failure) and too low a probability of detection (when the radar system is not operating normally but the thresholds have been set too high to detect it). The designers must also determine if there should be a delay in declaring that a particular failure exists, i.e., that it must be present for a given amount of time to not mistakenly declare a minor transient as a fault. Some ST/BIT mechanizations include an estimate of the severity of the failure as a part of the failure report, although this is very difficult to determine in such a complex interrelated system. A more achievable goal may be to have two severity levels: critical and non-critical.

The flight test program will need to evaluate the amount and types of radar failure information which is displayed to the pilot. This involves determining how useful are the indications, especially in a combat environment; and whether it gives the pilot sufficient time, information or options to reconfigure the radar or weapons system in order to maintain adequate combat capability. As anxious as the designers may be for the system to "tell the pilot everything," the radar should display only meaningful ST/BIT data when needed and usable. For example, is the radar system now so degraded that the pilot should pass the lead to someone else in the formation, or depart the area and head for home since he no longer has an effective weapon system? In addition to what information is displayed, how it is displayed should also be evaluated. The method of attracting the pilot's attention (such as changing colors on the display versus aural warnings) and the means of imparting the information (such as coded numbers versus English language statements) should be evaluated for effectiveness in operational situations. If the system is mechanized to automatically switch to a redundant or backup configuration, should the pilot be "bothered" with the information that the radar now has less redundancy? For example, when a non-a/a detection failure occurs while in an a/a detection mode, the pilot may want the radar to indicate system status such as no air-to-ground mapping capability or no communications capability with an a/a missile, and have the radar automatically reorient the a/a display so that the best use can be made of the remaining capabilities.

The ST/BIT capability may also be set up to retain additional information to be read out on the ground (or removed from the aircraft via a data cartridge) by maintenance personnel for troubleshooting and repair after the flight. Analysis of this information is a good way to track radar performance or failure trends in order to better allocate spares or upgrade planning. It is often useful to include additional information on failures, such as the environmental and flight conditions under which the failure occurred. The adequacy and usefulness of this data must also be evaluated since the time required by maintenance personnel for testing and fault isolation can comprise a majority of the total maintenance time.

In many installations, the aircraft weight-on-wheels ("WOW" or "squat" switch) prevents ground operation of the radar (such as after engine start, taxiing out or during pre-takeoff clearance checks) so the pilot must further depend and rely on the accuracy of ST/BIT to ensure that a fully capable system will be available in the air. This involves a tradeoff between allowing more radar ground operation (if there is less confidence in the ST/BIT capabilities) versus concerns for personnel safety (personnel penetrating the danger zone of the operating radar) and security (unfriendly forces detecting the radar transmissions). During the test program, BIT should always be initiated as a part of the pre-flight checks in order to gain more confidence in its capabilities, and to use it as a flight go/no-go determination once sufficient confidence is achieved.

Another means of explaining radar ST/BIT evaluation is shown in Table 7. This is a brief breakdown to several levels of complexity (with the least complex level shown as number 1) and the corresponding limitations and advantages which can be considered depending on the amount of available test time, equipment and funding.

Table 7 Self-Test/Built-In-Test Levels

LEVEL	What Can Be Done	What Is Required To Do It
1	Detailed investigation of only a few problems, with detection or false alarm data.	Manpower and expertise to determine all circumstances and possible causes, and detailed data investigations.

Limitations
a) Very limited evaluation of only highest priority areas.
b) Assumes radar designer has little interest and program office response is weak.
c) Testers would not only be identifying problems but would also have to help in determining cause.

LEVEL	What Can Be Done	What Is Required To Do It
2	Determine probability of failure detection, false alarm rate, and fault isolation capabilities.	Verification of existence or non-existence of failure through maintenance actions. Requires tracking of failure indications and correlation with actual failed items.

Limitations
a) Non-production configured components.
b) Lack of adequate spares.
c) Lack of production intermediate shop equipment.
d) Small sample sizes - may be statistically unsound.
e) No intentional failures allowed - only in lab.
f) Unavailability of most production technical data during test program.
g) Requires off-site tracking of repairs (at contractor facilities).
h) Numerous configuration changes are made during development.
i) Usually results are only indicators of field performance - not necessarily true performance.
j) May require active operator involvement (for example: display interpretation) in addition to the automatic tests.
k) May require unscheduled maintenance actions (such as opening panels) to check ST/BIT indicators for false alarms.
l) Requires running BIT for most or all ST indications - interrupts normal system operation.

LEVEL	What Can Be Done	What Is Required To Do It
3	Same three statistical evaluations as 2, but include usage of an avionics integration lab to obtain a greatly increased number of operating hours.	Use of data collection and tracking systems on lab avionics equipment in addition to aircraft avionics equipment.

Limitations
a) All of limitations in 2 above except d) and l) still apply.
b) Requires more manpower to collect data.

Advantages
a) Greatly increased sample size.
b) BIT interruptions are acceptable in the lab.

LEVEL	What Can Be Done	What Is Required To Do It
4	Same as 3, but include intentionally induced failures.	Scheme to statistically determine which failures to induce, system designer support for test planning and conduct.

Advantages
a) Truer evaluation of probability of detection capability.
b) May be able to accomplish specification evaluation in lab for failure detection probability and fault isolation capability.
c) May also be able to accomplish determination of reconfiguration capabilities, remaining effectiveness.
d) No safety-of-flight concerns for failures intentionally induced in lab.

LEVEL	What Can Be Done	What Is Required To Do It
5	Same as 4, but add intentionally induced failures on the test aircraft.	Additional flight test time and system modifications.

Limitations
a) Limited test time available.
b) Safety-of-flight concerns will have to be addressed.

a) Greater sample size.
b) More realistic situations.

6	True effectiveness: severity of failure(s), assessment of remaining capabilities.	Requires detailed knowledge of system M's/N's, individual component failure tolerances and thresholds.

Limitations
a) Nearly impossible task for even system designers to determine severity and remaining capabilities.
b) Difficult to verify, especially if there are only chance occurrences.
c) Would really require intentional failure(s) and dedicated tests of remaining capabilities.
d) Combinations and permutations of failures verses capabilities would be enormous.

5.2 Electromagnetic Compatibility

Radar electromagnetic compatibility (EMC) flight tests are usually functional in nature, i.e., limited quantitative on-board level measurements are obtained. A primarily qualitative evaluation is accomplished using a matrix of possible interference sources and victims. The primary emphasis is on the radar system--both as a source of interference and as a victim--and is intended to be a functional evaluation. An in-depth and time consuming EMC quantitative and safety-of-flight evaluation on the entire aircraft is usually accomplished on the ground using a production configured, non-instrumented aircraft. The flight test may highlight potential problem areas which the in-depth tests will concentrate on later. Additionally, while OT&E test aircraft may not be as heavily instrumented as those used for DT&E, OT&E tends to point out potential EMC problem areas in an operational situation. EMC flight testing is also necessary since it is difficult to model all the electromagnetic interference (EMI) coupling paths which exist, and the installation in a radar lab or testbed will likely not be representative from an EMC standpoint.

Radar EMC tests can be categorized as: internal, external, and with other aircraft.

Internal EMC is radar compatibility with all other aircraft radiating and receiving equipment, such as radios, radar altimeters, threat warning systems, internal jamming systems, and other antenna installations. This includes power switching transients caused by interaction of any on-board systems with the aircraft electrical power system.

External EMC is radar compatibility with aircraft external stores that can be carried, especially ECM pods, weapons with electro-explosive devices (EEDs) and other transmitters. Blanking signals may be sent between the radar and other systems to minimize interference. Radar performance while blanking, and ECM pod performance during blanking, should be evaluated to determine if any degradation or loss of effectiveness exists. This may include the use of a threat range to stimulate the automatic response modes of the ECM equipment.

Evaluation of radar EMC with other aircraft is especially important if the fighter is to be operated in formations or as part of a mixed force. This would include EMC with similar radar-equipped aircraft, dissimilar friendly radar-equipped aircraft (especially when that radar operates partially in the same frequency band), and ECM-equipped friendly forces. Flight tests with other aircraft should include runs with both the fighter and EMI source aircraft each in a radar detection mode; the fighter in a detection mode and the source in track (locked on to the fighter); and the fighter in track on another target with the source in track on the fighter. The use of the other target in this case will check for any degradation of radar operation or sensitivity in the presence of interference, especially since interference can desensitize the radar without indicating this to the pilot. Test conditions should be run at several radar frequency combinations, and include scenarios with the fighter and EMI source line abreast, one aircraft leading the other, and head-on. While not necessarily a duplication of combat scenarios, these test conditions should present worst-case situations to make most effective use of limited available test time. Further operational testing should be accomplished to evaluate radar compatibility with other friendly fighter aircraft during a/a operations such as formation takeoff, flight, approach, and landing.

The range space used for EMC flight tests should be set up to minimize the possibility of other unknown EMI sources affecting the test. However, known high power airborne (such as an early warning aircraft) and ground-based (search radars) transmitters should be used under controlled conditions to see if their operation affects the fighter radar. During all flight test conditions, it would be of great benefit to have an on-board electronic support measures (ESM) receiver which would sense the surrounding electromagnetic environment in order to best determine any source of interference and its location so as not to obtain misleading results. Typical EMC test conditions are shown in Table 8.

Several types of ground tests can be of benefit in evaluating radar EMC. Tests can be run in an anechoic chamber, although a large chamber would be required to adequately obtain the far-field effects and have the entire aircraft inside it. Ground tests with the radar in a lab can be accomplished, although an elaborate mockup should be used to attempt simulation of the coupling effects. A lab environment is beneficial since it can be used to check out the presence of any voltages or power spikes on a mockup, since the avionics systems are more accessible than on the aircraft.

5.3 Electronic Counter-Countermeasures

Most modern radars incorporate extensive electronic counter-countermeasures (ECCM) features designed to negate the effects of enemy electronic countermeasures (ECM). The main ECM types used are noise and deception, with less emphasis on chaff due to its limited effect on pulse doppler radars. The radar flight test program should include a determination of the capabilities of each radar mode in the presence of ECM. This should be done for each mode whether or not there are specifically designed passive or active ECCM features in that mode. Both qualitative and quantitative performance comparisons should be made between ECM on and off--especially to see if there is: 1) a degradation in mode accuracy, 2) an effect on the radar usability, 3) loss of a mode capability (such as loss of track while in STT), or 4) loss of the mode capability altogether.

The description and testing of specific radar ECCM techniques is not presented in this volume to avoid security and proprietary issues, and to allow wider dissemination of a/a radar test information to more flight test personnel. In-depth testing of any one particular ECCM technique is unique and may not apply to other radar systems. Also, there is not universal agreement on threat specifics, and the judgement of what types of threats will be encountered and tested varies among users. This volume presents general radar ECCM flight test principles.

Because of security considerations and constraints, and the practical problems of creating a realistic electromagnetic environment, testing to determine the vulnerability to countermeasures is very difficult and costly. Since the radar system development and acquisition cycle is relatively long with respect to changes in the ECM threat, the characteristics of the threat can change significantly during this cycle. There is a lot of room for judgement in identifying and defining a radar design to negate a threat which may be encountered several years in the future. Also of concern are the difficulties of creating a realistic test environment, identifying and measuring system characteristics most critical to satisfactory radar performance, and deciding how to conduct such tests.

Radar ECCM testing has typically experienced a very low priority in the hierarchy of test planning. While a performance baseline in a non-ECM environment must be established and then comparisons made to radar performance in an ECM environment, ECCM testing is often deferred since it has all the potential to make the system "look bad" by pointing out its weaknesses, and can cost a considerable amount of time and money to accomplish. Several points need to be addressed prior to accomplishing radar ECCM tests. A determination should be made as to what specific threat signals will be used, i.e., should the signals be limited to only those the postulated threat is assumed capable of generating (and how much knowledge of the radar system design should be assumed known by the enemy in order to have designed the threat signals), or should the ECM techniques used for testing take into account detailed knowledge of the radar system design? If the latter approach is selected, any system weaknesses can be found in advance of the enemy developing the technique. A countermeasure can then be designed and ready for implementation in the radar when it appears the enemy now employs that ECM technique. This tradeoff in what techniques and environments to use for testing needs to be carefully made since it could have a significant impact on the amount of testing required and the interpretation of the results. Some organizations have a "Red Team" concept during the radar system design and test planning; this team's objective is to simulate the enemy and try to determine the vulnerability of the radar system in order to strengthen the ECCM capabilities by pointing out deficiencies at an early stage.

Much radar ECCM testing can be done in a ground lab, preferably prior to flight testing. Since many ECCM techniques are based on radar processing rather than use of the RF chain, many of the algorithms can be developed and preliminarily tested using simulated threat signals. Flight test conditions can then be set up to verify the results of ground testing. The primary flight test configuration is to have the source of ECM on the target aircraft. Secondary, although still important, test configurations are stand-off and escort jamming (the jammer mounted on an aircraft other than the radar target), and a/a target detection, acquisition and tracking in a down-look situation in the presence of ground-based jamming. Testing in a multiple jammer environment (the most likely situation to be encountered operationally) is highly desired but the most difficult to set up and accomplish. This should be done with multiple airborne jammers, in the vicinity of ground-based jammers, and in the presence of friendly aircraft which are also jamming other threats.

In order to adequately evaluate the radar ECCM features, flexible ECM systems are required, and often involve highly advanced technology of their own to provide the many variations of threat signals to be used for testing. They also need to be as realistic as possible to understand whether an ineffective ECM technique is due to the lack of simulator realism or to a true radar deficiency. Pods have been specifically developed to simulate radar jammers and sized to be able to be carried on fighter-type aircraft.

... ELECTROMAGNETIC COMPATIBILITY FLIGHT TEST CONDITIONS

RUN #	FIGHTER SPEED (KCAS)	FIGHTER ALT (FT)	EMI SOURCE TYPE	EMI SOURCE ASPECT	TARGET SPEED (KCAS)	TARGET ALT (FT)	REMARKS
1	AR	AR	N/A	N/A	N/A	N/A	VERIFY RADAR EMC WITH OTHER ON-BOARD SYSTEMS.
2	AR	AR	FTR A	HEAD-ON	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED. FTR IN SEARCH, EMI SOURCE IN SEARCH.
3							REPEAT # 2 WITH FTR IN SEARCH, EMI SOURCE IN TRACK ON FTR.
4							REPEAT # 2 WITH FTR IN TRACK ON TGT, EMI SOURCE IN SEARCH.
5							REPEAT # 2 WITH FTR IN TRACK ON TGT, EMI SOURCE IN TRACK ON FTR.
6	AR	AR	FTR A	ABREAST	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED, FTR IN SEARCH EMI SOURCE IN SEARCH.
7	AR	AR	FTR A	TAIL-ON	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED, FTR IN SEARCH, EMI SOURCE IN SEARCH.
8							REPEAT # 7 WITH FTR IN SEARCH, EMI SOURCE IN TRACK ON FTR.
9							REPEAT # 7 WITH FTR IN TRACK ON TARGET, EMI SOURCE IN SEARCH.
10	AR	AR	FTR B	HEAD-ON	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED, FTR IN SEARCH, EMI SOURCE IN SEARCH.
11							REPEAT # 10 WITH FTR IN SEARCH EMI SOURCE IN TRACK ON FTR
12							REPEAT # 10 WITH FTR IN TRACK ON TGT, EMI SOURCE IN SEARCH.
13							REPEAT # 10 WITH FTR IN TRACK ON TGT, EMI SOURCE IN TRACK ON FTR.
14	AR	AR	FTR B	ABREAST	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED. FTR IN SEARCH, EMI SOURCE IN SEARCH.
15	AR	AR	FTR B	TAIL-ON	AR	AR	EMI SOURCE CHANNELS WILL BE VARIED, FTR IN SEARCH, EMI SOURCE IN SEARCH.
							REPEAT # 15 WITH FTR IN SEARCH EMI SOURCE IN TRACK ON FTR.
							REPEAT # 15 WITH FTR IN TRACK ON TGT, EMI SOURCE IN SEARCH.

NOTES:
1. FTR A IS EQUIPPED WITH SAME TYPE RADAR AS THAT UNDER TEST.
2. FTR B IS EQUIPPED WITH DIFFERENT TYPE RADAR THAN THAT UNDER TEST.
3. AR IS AS REQUIRED.
4. N/A IS NOT APPLICABLE.
5. FTR IS FIGHTER
6. TGT IS TARGET.

These pods tie into existing aircraft wiring and may have the capability to record some data on-board or telemeter it to the ground during flight. However, these pods are somewhat restricted in that they usually have a limited number of signals which can be selected in flight, and have little or no instrumentation. Also, the location of the jamming pod on the jamming aircraft is normally constrained to one of the existing attachment points, which may not be an optimum location for multipath and phasing of the jamming signals. The "ideal" situation is to have a larger aircraft, with the jammer electronics mounted internally, with controls to change all signal characteristics and considerable instrumentation.

The requirement for a substantial amount of instrumentation on all the jammers and the test radar is extremely important to the success of radar ECCM testing. The exact jammer characteristics must be known at all times and be correlatable with the radar operation. Typically, more involved radar system instrumentation is needed for ECCM testing than for most other modes. This allows not only a determination of what effect the jammer has, but an extrapolation can be made of what effects other ECM techniques might have without having to test them all in the face of time, money or security constraints. For example, if a particular ECM technique did not cause the radar to break lock, with the proper instrumentation, it may be possible to state that it would break lock given a slight ECM signal modification without having to then go test that variation. The additional instrumentation may also allow extrapolation of the test results to a more operationally realistic multiple jammer environment. This need for increased amounts of instrumentation may result in programmable instrumentation systems that can be adapted to record different radar parameters depending on the ECM technique to be tested. Telemetered radar data can be quite helpful during ECCM tests (although security considerations may severely limit its use) to allow the ground personnel to see effects of which the pilot may not be aware. This is especially useful with a deception technique that is impacting radar operation without the pilot's knowledge.

Innovative approaches should be used to most effectively test the radar ECCM capabilities, and the operation of specific jamming techniques in the test environment should not be limited to only its primary use. For example, a track breaking jamming technique (normally initiated only when the victim radar is in track), could also be tested with the victim radar in a search mode to evaluate whether it can even lock on to the target. Simulated ECM signals could be carried on the fighter aircraft (either in a special program in the radar or in a separate signal generator) to inject in flight for both test and training purposes. Not to be forgotten in the evaluation is the effect of jamming on the radar "housekeeping" functions (such as periodic end-of-bar calibrations) which can impact operation in all modes. A helpful device to have for radar ECCM testing is an electronic support measures (ESM) receiver, either mounted on the radar test aircraft or in the vicinity of the test arena, to measure the signal environment. This ESM receiver data would allow an analysis of the actual jammer transmissions (versus what it was programmed to transmit), and the response of the radar to jamming. It could also be used for isolation of any effects on the radar from other unintended signals in the area.

The results of radar ECCM tests need to be carefully weighed to determine their significance and how any deficiencies are to be addressed. When a jamming technique is found to have an effect on the radar, it must be determined if that technique is a realistic one to expect to see in operation. Implementing a fix will also depend on its cost versus the effect the jamming had on the radar system. Care must be taken in evaluating ECCM test results and reaching conclusions if constraints were put on the test conditions to achieve a certain point that may not be operationally realistic (but that can help in the design of the radar ECCM capabilities).

5.4 Displays and Controls

The adequacy and suitability of the displays, the data displayed on the HUD, and the controls should be evaluated during all radar tests. In addition, dedicated test time may be needed to assess areas such as mode priorities, lighting conditions and operator workload. Both the static (e.g., range scales, azimuth and elevation marks) and dynamic (e.g., target symbols and target data) symbology should be evaluated for readability. This encompasses assessment of scale size and placement, occlusion zones, displayed data stability, and the suitability to the operator of the gain, brightness and contrast adjustments. Typically, human factors engineers will also be involved in evaluating the radar displays and controls.

The switchology evaluation includes the following factors: 1) accessibility of switches and controls to the operator, 2) the availability of "hands-on" (stick and throttle) controls, 3) the potential for inadvertent actuation of controls, and 4) control suitability under high workload, stressful situations. Also to be tested is the adequacy of the system mechanizations such as: 1) the operator actions required to change modes, 2) automatic versus manual selection of modes, range scale, scan pattern size or direction, 3) the smoothness of transitions from mode to mode, and 4) the direction of a control movement relative to a display function. An example of item 4) is the radar cursor control which can be mounted such that forward/reverse or sideways movement translates into up/down or an increase/decrease in displayed cursor range.

Evaluation of the adequacy of the radar display under various lighting conditions should include: 1) the location of the display in the cockpit, 2) the requirement for an automatic brightness or contrast control, and if so equipped, how well it accommodates dynamic changes in lighting, 3) flight in and out of clouds or weather, and maneuvering night lighting evaluation should include: 1) the usability of the display brightness control, 2) the consistency of display visibility while changing modes and display formats, and 3) visibility in a variety of outside lighting conditions (over city lights, a runway or only darkness).

The displays and controls assessment is partially dependent on the user of the radar system, i.e., will it be in a single seat aircraft where the pilot has many things to do in addition to operating and observing the radar, or in a multiple seat aircraft with a dedicated radar operator. It is especially important in a single seat installation to determine what the operator really needs to see. Sometimes the fact is overlooked in the design process that the radar is an aid to the operator but is only one of a number of avionics systems that requires operator attention during flight.

The increased use of multifunction displays (MFDs) provides significantly more flexibility to display data from several sensors and usually eliminates the need for a dedicated radar control panel. Since most radar controls are now programmed function buttons which surround the MFD, additional user interpretation is required. An example of this is the use of two buttons to increment display symbology up and down, versus previously turning a knob on a control panel. The dedicated radar controls, such as antenna elevation and cursor positioning knobs located on the stick or throttle, can be programmed to be either rate or position sensitive and the evaluation should determine which is preferred. For example, the cursor movement can be set to a constant rate and move a distance based on the control displacement, or the rate can vary depending on the control displacement. Regardless of the mechanization, the cursor controller sensitivity must also be evaluated. If overly sensitive, the cursor could be inadvertently slewed off the target during the designation process. If lacking in sensitivity, large cursor displacements could be slow and inaccurate to the point of degrading operations. For the antenna tilt controller, the evaluation should include an assessment of any dead bands (an area where movement of the control causes no antenna tilt). If the radar uses an electronic scan with no physical antenna movement, the same control would move the radar beam and should be evaluated similarly.

Additional considerations for the evaluation include any display enhancements which may be included in the system. The use of color displays will greatly expand the data and messages which can be presented to the pilot. Current displays may have warnings built in, such as flashing the target symbol at a rapid rate in a track mode when break lock is imminent. Some aspects of the display design or symbology may not be finalized until flight testing has been accomplished in order to best determine the final design based on actual in-flight operation. While not a part of the radar system evaluation criteria, the instrumentation systems need to have adequate controls and displays to be used effectively and minimize pilot distraction from the radar test tasks.

An evaluation is also required of the radar set up and turn on procedures, and terminology. For example, the term "radar ready" has caused considerable confusion in the past since it may be interpreted that the radar is warmed up, self-tested and ready to operate immediately, or that it is still in the start-up process and will not be usable for a period of time.

The primary method of the radar displays and controls evaluation is a qualitative assessment made by the pilot or operator during the course of the flight test program. Some tests can be done in a ground-based simulator, but to do so the simulator should have an ergonomically correct layout. For all operator dependent manual operations, more than one operator's opinion is required, and more than one operator experience level should be used. The test planning should be constructed such that multiple opinions will be collected for all mode and scenario combinations. There are usually no dedicated test conditions for assessing the displays and controls, rather it is done on a continuous basis throughout the course of the test program. The run cards should include reminders to look for specific controls or displays usage during applicable test conditions.

The main sources of evaluation data are pilot comments, video recordings of the displays, and some aircraft avionics MUXBUS data. There are two "schools of thought" on the method of video recording: 1) use a cockpit mounted camera, or 2) feed the displayed radar video signal directly to a recorder. While the direct method eliminates any interference from cockpit light and is generally much easier to observe during playback, the camera method does record what the operator really sees in flight, taking into account all the factors which affect the display readability. MUXBUS data can be used to help in the assessment of pilot workload by analyzing the operator-commanded system changes and system-commanded changes under different operational scenarios.

5.5 Degraded and Backup Modes

Since it is undesirable to have a modern radar system susceptible to single point failures, degraded or back-up modes may be a part of the design and should therefore be tested. For example, if the Inertial Navigation System (INS) which provides data for radar antenna stabilization fails, the radar could use the Head-up Display (HUD) rate gyros as a backup. Tests should be accomplished to determine what aircraft/radar maneuvering limitations may then be introduced, such as whether the ability to eliminate clutter in look-down search modes has been retained or degraded. Other degraded or backup radar modes might be due to the effects of a central computer failure on the radar altitude line tracker and display when aircraft altitude data is lost, or the effects of slower system updates when the backup aircraft avionics MUXBUS controller causes a loss of displayed data. For whatever degraded or back-up modes exist, the evaluation should determine the remaining radar capabilities, limitations and accuracies as compared to the full-up system in all affected modes. This evaluation may involve quantitative as well as qualitative comparisons since the radar system requirements may allow a specific reduction in accuracy under some degraded conditions. Generally, degraded and backup a/a radar modes are not a safety concern, unless the radar is tied into the aircraft flight control system to help in a/a combat situations, or when there is an emergency override option which the pilot can use to override the radar automatic shutdown features and avoid a catastrophic system failure. The flight control interface could be tested with careful planning to determine the operational impact, while it is highly unlikely the override feature would be intentionally initiated.

Prior to testing, an analysis should be accomplished to estimate the probability of failure occurrence which will cause the radar to revert to a degraded or backup mode in order to determine the requirements for test. If the probability for a particular degraded mode is extremely low, and the effects are minimal, testing of that mode would be much lower in the test planning priority. Testing of degraded and backup modes requires ground lab tests prior to flight, especially in the area of verifying interfaces with other systems on which the radar depends. An example of this system interaction is when the radar recognizes the INS has failed and requires a different data word from the HUD. Whereas some degraded modes may be easy to intentionally initiate (such as by turning off the INS), others may require system modifications and/or additional interfaces to intentionally cause them to occur. This phase of testing may be made much more effective by an analysis which determines the probability of various failure modes.

Specific test conditions should be set up for types of degraded capabilities such as the INS failed situation where radar antenna/beam stability can be affected. These tests include repeating tests run in normal modes (as described in section 4 of this volume) such as look-down search modes in the vicinity of various types of clutter while maneuvering, acquiring and tracking a target to gimbal limits, and maneuvering to check track stabilization and auto range scale switching. Test conditions for all applicable modes should be set up to determine the limited radar capability, and to define what will still be operable and useful given the operational situation. In addition, failure response actions require definitions such as continuing combat, landing as soon as possible or returning home. The utility to the operator of each degraded or backup mode needs to be evaluated, and a determination made if he should even be notified of system reversion to a backup mode that still retains full radar operation. This may become more important with the use of systems which have graceful degradation, such as multiple phased array antennas where numerous elements may fail with no perceptible effect on radar operation. When the situation does warrant informing the pilot, the evaluation should determine the best way to display the information for rapid assessment of the situation. Remaining radar capabilities should also be examined with respect to any degradation of ECCM performance, i.e., if the system is now more vulnerable to ECM.

5.6 Alternatives for Mode Mechanizations

The radar system specification may require that the design of some system mechanizations be finalized only after evaluating a range of alternatives during flight test. This occurs in situations where mode analysis and ground tests alone could not adequately define the design. These flight tests would use identical test conditions for all the alternatives and compare performance to determine the best solution. Areas appropriate for examining alternatives in flight can include: 1) ACM modes scan pattern size and location (the FOV coverage relative to the fighter aircraft), which is dependent on fighter versus target maneuvering capabilities and requires an in-flight assessment, 2) the track coast time through the doppler notch (the length of time before the radar returns to search) with respect to the extrapolation accuracy required to reacquire the target, 3) the ACM maximum acquisition range (a tradeoff between discriminating among a number of targets in an operational scenario versus the requirement for a close-in mode, 4) the use of coast and its time limits in TWS mode, 5) clutter cancellation filtering techniques which affect false alarm thresholds, 6) ground moving target rejection (GMTR) velocity thresholds, 7) ECCM mechanizations, and 8) mode priorities, especially during high workload situations. Operational considerations must be taken into account to make mechanization decisions based on how the system will be used. The flight test conditions should be as close as possible to the predicted operational environment, yet repeatable in order to properly compare the alternatives. This testing may be more appropriately termed "mode optimization" since it is optimizing the mode parameters for the intended environment.

In order to conveniently test mechanization alternatives, the radar system (in particular the software) needs to be sufficiently flexible to easily implement changes during the flight test program. The ideal situation is to be able to select from the alternatives in flight (such as using on-board special controls as explained in section 7.5 of this volume) so that immediate comparisons can be made under the same test conditions. It must be emphasized that effective configuration management must be exercised at all times since this area of trying alternatives could easily lead to loss of the radar system configuration knowledge or control. The instrumentation setup should acquire data such that other techniques can be examined without having to fly them all. For example, to evaluate the coast time, sufficient acquired data would minimize the number of points required to be flown with different coast times while

... when the system would have broken lock. Timely feedback of the test results is required in order to make the design changes and still fully evaluate them within the test program schedule.

5.7 Radome Effects

Radomes for airborne radars are most often designed for their aerodynamic characteristics with attendant electromagnetic considerations a secondary factor. Radomes should be mechanically strong but lightweight, and have minimal attenuation, distortion, or boresight shift effects on the radar beam. Thus, radome design for airborne application is largely a process of compromise to achieve the desired RF performance. Radomes typically have specifications which require characteristics of: high transmission efficiency; low power reflection; small beam deflection magnitude with good repeatability and low rate of change with angle through the radome; and low pattern distortion. Radome losses are a function of the type and thickness of the material used in construction and the radar operating frequency range. The flight test conditions should ensure the radar beam is transmitted through many radome azimuth and elevation angles to determine any possible performance effects or limitations. The manifestation of these effects may include inducement of false alarms or tracking errors due to radome reflections caused by: radome shape, polarization effects, ice buildup, or radome hardware such as anti-static materials, de-icing equipment, a pitot boom or other antennas. Reflections from the main beam and sidelobes can vary and are usually worst at the antenna azimuth and elevation scan limits.

A substantial amount of ground testing for radar antenna and radome compatibility is required on an antenna test range prior to flight. This is also the only way to verify specifications that are written for radar performance without the radome installed. A number of antenna/radome combinations should be run in order to obtain a representative sample of performance limits, with subsequent flight tests designed to verify the ground test results. In-flight antenna patterns may be run using sensitive receivers on the ground, but are usually not required. If the radar is mounted on the aircraft in a location where there is potential interference with the beam (such as in a wing-mounted pod blocked by the fuselage at some angles) it will require implementation of masking algorithms for operation. A mockup of the appropriate areas should be used for ground testing, and an operational verification should be made in flight.

Some radar systems are used with different radomes in more than one type of aircraft. If this is the case for the system under test, an in-flight side-by-side performance comparison can be made using these different aircraft (assuming the test conditions are set up to exclude mutual interference) to isolate suspected radome-caused anomalies. It is particularly important that both aircraft be equipped with adequate instrumentation systems.

Radome compensation algorithms can be designed into the radar for systems requiring the highest degree of angular accuracy (such as gun directors). This then creates new configuration and maintenance problems which must be addressed, and could add the requirement that the radar LRU containing the compensations and the radome must be changed and handled as a set! When radome compensation algorithms are implemented in the radar, the ability to adequately compensate for radome effects should be determined under all conditions.

The following paragraphs on radome reflection lobes are based on Reference 4. A major source of target false alarms can be the presence of very large RCS discrete targets in the antenna sidelobes and radome reflection lobes. Radome reflection lobes can be produced as a result of imperfect transmission of the energy in the antenna main beam through the radome wall. The small portion of the main beam energy not transmitted through the radome wall is reflected and transmitted through the opposite side of the radome. The secondary transmission (and reception) path thus formed is typically many decibels down from the main beam, but it is still possible to detect very large discrete targets (RCS on the order of 100,000 square meters) via this secondary path. Main beam clutter cancellation is not effective against these targets since they do not originate from the area covered by the antenna main beam, rather, the reflection lobe azimuth is generally on the opposite side of the nose from the main lobe position.

Existence of radome reflection lobes can be verified and quantified by measurements on a radome/antenna pattern range. (Note: further information on antenna pattern measurements can be found in AGARDograph series 300, "Determination of Antennae Patterns and Radar Reflection Characteristics of Aircraft.") By taking data from a series of patterns at different antenna azimuth angles, it is possible to construct a plot of reflection lobe azimuth angle versus main beam azimuth scan angle. As long as the aircraft is in straight and level flight, right versus left symmetry exists allowing a prediction of reflection lobe positions for main beam azimuth scan angles both right and left of the aircraft nose. These predictions can then be used to correlate with the false alarm data from flight tests to verify whether the false alarms were caused by large discrete targets entering the system via radome reflection lobes.

Look-down flight tests should be conducted in an area with low backscatter coefficient terrain on one side of the ground track and large discrete targets (such as large ships in calm water, or large buildings or hangars in desert areas) on the other side of the ground track. When large discrete targets are present on both sides of the flight path, more false alarms may be created, but it will be harder to isolate and determine if they were caused by radome reflection lobes. If testing does reveal significant problems due to reflection lobes from large discrete targets, the radar system may be modified such that the effective RCS of these targets can be measured in flight using a radar ground map mode and calibrated attenuators installed in the system.

Testing should also include rolling maneuvers which cause the antenna to illuminate many radome locations to observe if false alarms are caused by antenna sidelobes and radome reflection lobes. The shape of the radome (such as a circular versus non-circular cross-section, or flat apertures) will dictate how much testing and how many angles should be used. If the radome is symmetrical, it is unlikely any changes in false alarm rate would result. However, if it is not symmetrical, the interaction between antenna sidelobes and differences in reflection lobe characteristics may substantially change the false alarm rate.

The following four steps can be used for post-flight data reduction to determine if false alarms are being generated by reflection lobes:

1) Analyse the recorded radar data (from video tape or internal radar data recordings) to separate "true" detections (detections on the target, other aircraft, or ground moving targets at speeds above the GMTR threshold) from "false" targets.

2) Using the indicated range and azimuth of each "false" target and the aircraft position data, plot the locations of each indicated "false" target on a detailed map of the area.

3) Using the plot of reflection lobe azimuth angle versus main beam azimuth angle, convert the indicated azimuth of each "false" target to a reflection lobe azimuth. The reflection lobe azimuth and the indicated range are then used along with aircraft position data to plot a second set of "false" target positions referred to as the reflection lobe positions.

4) After plotting the indicated and reflection lobe positions of each "false" target, visually inspect the map to determine the source of the target. If a number of "false" targets are now shown to be in the area of known large discrete reflectors, they are likely the result of reflection lobes. Likewise, those targets that are now shown to be in a clear area are likely returns from true targets.

5.8 Radar Processing Capability

Radar processing memory and/or speed limitations may become apparent during the design phase or during the test program, particularly as tradeoffs are made in the system implementation. This is especially important in this era of software-controlled radar systems and differences in processing techniques among various radars. Typically, the anomalies seen are more often the result of limitations in processing through-put rather than memory. "Smarter" more sophisticated systems may reconfigure or reallocate processing resources to allow a reduction in data accuracy so as not to lose tracked targets. These systems may also have some type of "tip-off" message to notify the pilot of excessive computer loading. Future avionics suites may have a partitioning of functions for all associated avionics wherein the radar computations may be done in one of several computers depending on the situation. This sharing can save weight by eliminating underutilized computers and will improve processing and data transfer efficiency.

Specific flight test conditions can be set up (based on the system design and operational considerations) to evaluate the radar under conditions of maximum computational loading. For instance, an appropriate flight test condition may be to have the fighter maneuvering in TWS mode, using the maximum number of targets with some of them maneuvering, in a high clutter and ECM environment, while exercising other system options such as telemetering data to a radar missile. A combination like this might result in system overload manifested as a slowdown or loss of data sent to the display and/or the rest of the weapons system. The test conditions used should be based on knowledge of what tradeoffs may have been made in the radar design, coupled with an operationally realistic high system workload situation. This will require the test planners to have a good understanding of the radar design to intelligently devise the most appropriate test conditions.

Some ground lab testing of radar processing limitations is appropriate, although it may be much more difficult to simulate the full situational environment described above to obtain the greatest system loading. However, the test conditions in a lab are more repeatable, and would cost far less than the amount of time and money required to set up the complex flight environment. To add to the realism of the lab tests, ground clutter signals could be recorded in flight, and then played back in the lab.

In recognition of possible radar system limitations, early production runs of new radar systems are often designed to be more easily reprogrammable (such as using electronic or ultraviolet erasable memory chips), or to easily allow the addition of more memory to rapidly correct problems and implement changes found necessary during the flight test program.

5.9 Environmental Considerations

All environmental extremes which the radar system will encounter during operation should be incorporated as a part of the flight test program. For a highly maneuverable fighter aircraft, high g's during maneuvers are usually the most stressful on radar antenna movement, i.e., its ability to scan in search modes or stay pointed towards the target in track modes. This may require instrumenting the antenna drive system to determine if it is approaching its performance limits in terms of slew rate, dead bands and other parameters. High altitudes affect primarily the pressurised components such as the antenna, transmitter and waveguide where arcing might occur under low pressure conditions. A climatic evaluation will normally include the use of a climatic laboratory and deployments to representative operating locations to verify radar operation for all potential extremes of humidity, moisture, heat and cold. This is to observe the radar's capability to operate (both electrically and mechanically) and the pilot's ability to operate and control the system, such as operating the controls while wearing gloves. Further information on climatic testing can be found in AGARDograph series 300, "Flight Testing Under Extreme Environmental Conditions."

The electrical power and environmental control system (ECS) which interface with the radar, can be instrumented to determine if they have sufficient capacity, are within acceptable fluctuation limits, and provide sufficient cooling capacity. If the aircraft is equipped with a gun (which will likely be mounted near the front of the aircraft close to the radar), test conditions should include gunfire in flight to verify that the radar can tolerate the vibration and acoustic environment. This is especially important since a representative laboratory simulation of gunfire effects is extremely difficult. Although less likely a problem, testing should also evaluate any radar effects due to gun gas ingestion.

Rain or snow in any significant amount can degrade the performance of most a/a radars with the level of degradation dependent on factors such as operating frequency. Most flight testing of weather effects will be qualitative in nature since it is very hard to "schedule" the type of weather required, and even more difficult to exactly determine it's composition (rainfall rates, for example) when encountered. When weather is present, the test conditions should include operation at several radar frequencies and polarizations (when so equipped) using detection mode conditions similar to those accomplished in a non-weather environment for comparison. In the future, greater radar detection ranges will make weather effects an even bigger factor since the weather related losses (whether in terms of a percentage or decibels) will translate into more nautical miles of detection range lost.

5.10 Interfaces With Other Avionics

Since a modern radar is highly integrated with the rest of the aircraft avionics suite, its ability to properly interface and operate with these other systems should be a part of the a/a radar evaluation. Testing can occur during dedicated radar tests, but will also occur during overall aircraft navigation and weapon delivery tests after the various subsystem tests are completed. Areas of consideration include the following items: 1) information data rates, 2) noisy data (large jumps which may wreak havoc on weapon delivery algorithms or displays), 3) data accuracy and timing tolerances, 4) aircraft avionics MUXBUS capacities, 5) boresighting the radar with the INS and HUD, 6) mode commands, 7) multifunction displays, 8) automatic mode controls, 9) gun firing and missile pointing/guidance information, and 10) launch cues. The two prime types of radar missile guidance operate differently and impose additional requirements on radar operation. One type of guidance uses the target return to home in on the target. This method requires the radar to maintain a continuous target track throughout the missile intercept. The other missile guidance method relies on telemetered data from the radar aircraft to the missile to control the missile trajectory during the initial phases until the missile radar system takes control. For the case of a missile requiring telemetered target data, a receiver can be mounted on the target aircraft to see if the radar-transmitted data is accurate and correctly transmitted. If the fighter is equipped with a jammer, the blanking signal interface with the radar needs to be evaluated for affects on ECM and radar system effectiveness. The use of "smarter" jammers and radars with multiple operating frequencies puts greater emphasis on this area of evaluation.

Even something as seemingly simple as the type of switches used (such as make-before-break) can cause an interface incompatibility. Sometimes, different interpretations of specifications by the contractors supplying the weapons components can also lead to interface problems. One example includes the requirement for target resolution--the multifunction display must be capable of displaying the radar information sufficiently, otherwise it does little good for the radar to be able to resolve multiple targets without the pilot being able to observe it on the display.

Interfaces should be thoroughly checked in a ground integration lab before installation in the aircraft, although there will likely be some dynamic conditions which will be encountered for the first time in flight. Often, not all of the necessary interfacing subsystems will be available at the same time to be used in the ground lab tests, so some will have to be simulated (at least those functions which affect the radar). An extensive lab simulation setup will be required if the aircraft contains an expert-type system that can automatically and rapidly command radar or weapons system modes and interfaces based on the combat situation and environment. Likewise, if an airborne testbed is available, the interfacing avionics need to be present, or at a minimum need to be functionally simulated.

5.11 Configuration Management

Radar system configuration management (CM) has become an even more important factor during a test program due to the increasing use of digital architectures with multiple integrated data processors. This capability allows making relatively easy and rapid system changes which can have a major affect on radar system operation and on the interfacing aircraft systems as well. If the radar system configuration is not carefully tracked, flight test time may be wasted, invalid data collected, and flight testing may jeopardize the safety of the crew or aircraft. Throughout the test program, it is imperative that strict configuration knowledge and control be maintained in order to assess which radar functions are operable, which are valid (i.e., representative of the "true" production system operation) and the impact of any hardware or software changes on radar capabilities. A standard set of functional check flight (sometimes termed "regression") test conditions should be devised and conducted in a ground lab and in flight each time a significant radar system change is made. These will verify the changes are correctly implemented and also that areas not intended to be changed have, in fact, not been affected. The functional test conditions serve as a good audit trail to track when a problem first occurred and in what radar/aircraft system configuration. It is very important that the test program commit to running these functional conditions, and that they not be passed up in the rush to achieve a program milestone.

The configuration management system should be designed and activated before first loading software into the radar, especially since it is so difficult to catch up if started later after changes are made. The CM system needs to be responsive enough to rapidly accommodate changes during the flight test program (particularly if the radar is a "brassboard" pre-production unit or if it has an on-board reprogramming capability), and may be different from the configuration management system which will be used throughout the life of the production radar. This flight test configuration management system is not intended to circumvent good practice, but to maintain positive control while recognizing that frequent changes must be approved expeditiously during system development. The CM system may include: 1) a Configuration Control Board (CCB) which will review and approve changes prior to flight test to determine they are correct and ready for flight, 2) a configuration and function report provided prior to flight test which describes the new configuration, its operating changes, effects on the radar display and controls, any operational and/or safety restrictions, a definition of which previously reported problems the change is designed to correct, and suggestions on what test conditions to use, and 3) a Management Information System (MIS) data base on a computer to track the configurations and changes of the radar and all interfacing systems. The configuration and function report defined in 2) above should include in detail: 1) the version identification and release date, 2) the CCB date, 3) the discrepancies fixed or software patched, 4) a description of the radar lab tests accomplished, 5) a description of the avionics integration tests accomplished, 6) a list of previous software patches, 7) a list of remaining unfixed discrepancies, and 8) the signed approval of the preparer, reviewers and appropriate test personnel. A single focal point should be established within the test organization to coordinate all configuration changes and tracking with operations, engineering and maintenance groups.

Knowledge of the extent and impact of configuration changes is especially important to determine if previously gathered data is no longer representative of system performance, and have therefore created the need to re-fly some or all of the conditions. This is where a good understanding of the impact of each change is important to the flight test community in order to make informed test decisions. The flight test run cards should include any flight restrictions resulting from the current configuration, as well as a brief list of the configuration used for the flight. The pre-flight mission briefing should also include a description of the configuration and its functions.

Only "released" hardware and software configurations should be used at any time in the flight test program. Released is defined as a configuration that has been: 1) thoroughly documented, 2) checked out and tested in a radar lab, an avionics integration lab and a flying testbed (if available), 3) provided with an explanation of the impacts of changes on system operation and flight test conditions, and 4) functionally flight tested. This does not preclude the use of specially modified software or hardware (such as with alternate mechanizations, instrumentation, and data pumps), only that its configuration is known, it is ensured to be compatible with the hardware, and it has been thoroughly checked out prior to flight. However, it is usually necessary to "freeze" the configuration once it has been developed in order to obtain adequate data sample sizes from the same configuration. It is often difficult to determine when this freeze should occur, as the development community invariably feels that the system can always be improved, even when production decisions are looming in the immediate future.

5.12 Operator Knowledge

The test pilots/operators performing radar testing must be highly knowledgeable in order to most effectively accomplish the test program. It is extremely important that they know at least the basics of the system operation, the test goals and the expected outcome for each of the test conditions. The flight test arena is not the place for on-the-job training. Radar operators must also be able to detect the presence of anomalies, however subtle, during the flight and make decisions as to whether the required data and conditions are being obtained. This is especially important if little or no telemetry data is available to the test engineers on the ground during the flight. Many flight hours and wasted sorties can be prevented by an astute operator recognizing an improper test setup, condition, radar operating anomaly or result, and recommending appropriate action. Having a knowledgeable operator will give a better indication of the radar's true capabilities, and minimize wasted time resolving problems which are due to lack of operator system knowledge. There is a possible "danger" in having only the most experienced test pilots for all the tests--they may be too familiar with the system and have skills not fully representative of the users. This is more likely to be dealt with during OT&E wherein it may be helpful to have some less experienced pilots use the system before the design is finalized.

In order to obtain the required knowledge, as well as have an influence on the system mechanization tradeoffs, experienced test pilots need to be involved early in the design review and test planning phases. Training can be facilitated through the use of lab systems and a flying testbed with which system familiarity can be obtained, since it is always beneficial to have "hands-on" experience. However, the differences between the test aircraft and lab/testbed environments need to be accounted for in the realism of the training. A ground simulator can be used as a valuable aid during the test program to: train the pilot, show him what to look for in flight (especially after a configuration change is made), to help define and refine test plans, and to practice test points prior to flight.

As a part of the preparation for flight, the pilot needs a thorough briefing by test personnel which includes an explanation of all test points, the aircraft and avionics systems configurations, and descriptions of any applicable radar system modifications. During the flight, it is imperative that the run cards be rigorously followed in order to obtain the proper data. The radar flight test results are also highly dependent on the pilot's comments and subjective evaluation of the system (especially with respect to the displays and controls). After all, the radar must be usable and interpretable by the pilot, otherwise it serves no function.

5.13 Radar Testbeds

A flying testbed aircraft can be a valuable tool in a/a radar flight test development and evaluation. Such an arrangement allows in-flight tests to be performed with instrumentation far more extensive than would be possible with the system installed in the "production" aircraft. A testbed aircraft can be employed as a flying laboratory and engineering development tool which gives the latitude for flight operations that are more convenient, less hazardous, and less costly. Use of a testbed aircraft, however, cannot satisfy all radar flight testing requirements. The performance characteristics of all airborne systems are, to some extent, susceptible to the environment of the installation. For example, the radiating characteristics of an airborne radar antenna can be especially installation sensitive. Radar performance considerations can be influenced by differences between the testbed and production aircraft which may include: electrical power, cooling, electromagnetic interference, vibration, acoustics, radome shape and configuration, acceleration, and other environmental effects.

There are tradeoffs to be made when deciding on the size and performance capabilities of the testbed aircraft to be used. The types of radar testbeds in use range from older fighter aircraft to large, multi-engine passenger aircraft, with each having specific advantages and limitations. Since the production a/a radar is typically intended to be installed in a fighter aircraft, the tradeoff in testbeds involves the use of a fighter-sized testbed which more closely represents the performance of the production aircraft versus a large aircraft which can hold more instrumentation and personnel. Whatever the size chosen, the testbed should be dedicated to radar testing (at least during development) in order to most effectively accomplish all the testing required.

While not a lot of statistical evidence is available, all users of radar testbeds have indicated that the use of a testbed reduced overall development time and costs. The development and evaluation time of a new major fighter a/a type radar may be reduced by 6 to 12 months when a radar testbed is used. The testbed allows accomplishment of more flights more often since it is not a new airframe. A new airframe could suffer many developmental problems unrelated to the radar which would minimize the amount of flight time available for radar testing. Detailed below are some specific uses of a radar testbed, suggestions for implementation, and some limitations to consider.

5.13.1 Radar Testbed Uses

Installation of the radar system in a testbed is the first time the radar is exposed to the flight environment. The testbed can be used to test the radar prior to integration with many of the other aircraft avionics systems, and then later on with other avionics systems that may become available for installation on the testbed aircraft. This can be a helpful adjunct to a ground-based integration lab once the radar-only testing is accomplished.

Use of a testbed is advantageous for a number of reasons. Since it will likely be an "off-the-shelf" airframe, it can fly under existing or modified flight regulations, it has an already cleared flight envelope (as opposed to a new production fighter), it is more easily deployable and supportable, and it is much easier to obtain approval to install commercial equipment. This can include commercial test equipment, instrumentation systems, simulators, and early non-qualified versions of the production automatic test equipment. The testbed may also have sufficient room to install radar test stimulators (such as ECM generators) which may not be available in a production fighter aircraft. The testbed airframe is usually less costly to fly, more maintainable, and may carry more people than the production aircraft. The testbed can have a dedicated radar crew while others fly the testbed airplane and cope with all the non-radar related aspects. This is less of a factor if the testbed is an older fighter, but then it should have at least two seats.

The testbed is usually large enough that radar designers and flight test personnel can fly on it and observe the operation of new radar hardware and software configurations prior to being installed in the production aircraft. Also, it is most helpful for them to see in flight what the fighter pilot sees, as opposed to a less representative playback on the ground post-flight. The testbed offers greater flexibility in accomplishing test conditions, and may accommodate in-flight software and hardware changes during the mission, giving a direct comparison of system implementations in the same flight environment. The testbed can have a large amount of radar instrumentation to the point of serving as a test bench where more signals can be brought out and examined. This is more significant for the analog signals which are generally unavailable in the production installation. The testbed is the best system to use if the entire radar (or a proposed modification) is in an early "brassboard" configuration, i.e., is functionally the same as a production system but is packaged such that it takes up considerably more space.

The costs of using a radar testbed are generally substantially lower than those of the production aircraft since more flight hours can be obtained for less money. For example, evaluating numerous alternative mode mechanizations or configurations can take a substantial amount of time, and a testbed can be useful to narrow them down to fewer choices which can then be implemented in the production aircraft. The testbed can be further used for test pilot training prior to testing in the production aircraft, as well as training the first cadre of operational crews for the fleet. Use of the radar testbed should be continued even through the time period of the production aircraft test program, to use for development and problem solving of existing modes, and for implementation of new modes as the program progresses.

5.13.2 Radar Testbed Implementation

One of the most popular sizes of testbed aircraft for an a/a radar has been the "executive jet" - typically twin engine, capable of carrying three or four personnel in the cabin (instrumentation operator(s), flight test engineer(s) and radar system operator) in addition to the cockpit flight crew, maneuverable (capable of doing a roll and a split-S, for example), yet with enough room in the cabin and gross weight capability for instrumentation systems. The differences between this type of testbed and a fighter aircraft usually have minimal effect on a/a radar mode development. The chosen testbed aircraft should be self-contained since flying in the vicinity of various clutter and weather backgrounds may require deployments to other test facilities. The aircraft needs to have sufficient electrical power, cooling and hydraulics (if applicable) to service the radar and associated avionics systems in flight and on the ground. The testbed aircraft power and ECS requirements will be substantially larger than that of a standard passenger configuration and will likely require considerable planning and modification, particularly to accommodate extended ground operations. The testbed aircraft may need additional on-board fire warning and extinguishing gear, an emergency power shutoff, isolation from the testbed aircraft primary (flight safety) power, and oxygen supplies for the cabin personnel. The aircraft may have installed special character and/or audio generators which can ensure that all personnel are adequately warned of out-of-limit conditions and emergency situations while concentrating on accomplishing radar testing.

The testbed interior should be constructed so that it is easily reconfigured with moveable racks and mounting gear to accept a variety of equipment installations. The best approach is to construct a ground mockup of the aircraft interior to determine the best placement of equipment and personnel. The cabin needs to have sufficient room to install all systems (radar LRUs, the radar controls and displays, interfacing avionics to include weapons and electronic warfare systems, and instrumentation). This may require a larger testbed airframe for highly complex and integrated avionics suites at the expense of some maneuverability. It is helpful to also have a navigation station in the cabin which can inform the testers of the aircraft location, scheduled activities along the route, identify specific conditions, estimate time-to-go to geographic locations, and help identify what type of ground clutter is currently in the radar FOV.

The use of commercial test and instrumentation equipment may have environmental limitations, such as allowable pressure altitude, temperature, vibration, and aircraft g's. For example, the heads on a computer disk drive can be very susceptible to loss of data and may sustain damage from relatively low aircraft maneuvering levels. The equipment installation design must eliminate electrical hazards from rack-mounted equipment. Hazards must be avoided if personnel could inadvertently come in contact with them while the testbed is maneuvering, or if there are plans to remove and replace equipment in flight. If sensitive or classified information will be gathered, an analysis and/or test may be required to ensure no compromising emanations occur from the result of the unique testbed installation, use of commercial equipment, the internal communication system, or the on-board data recording and processing equipment.

The design and layout of the testbed interior should emphasize the use of good human factors principles, especially since the testbed flight duration can be considerably longer than that of a typical fighter sortie. The goal should be to achieve safe, reliable and effective personnel performance. Attention should be given to acoustical noise, workspace, interior colors, the direction the seats are facing, illumination, and legibility and operability of the controls and displays. The controls and displays environment may be even more severe in the testbed installation due to glare, lighting, and the greater amount of data to be presented. The displays should be designed to suit the particular conditions under which they are going to be used, and the operator should be able to readily understand the presented information with minimum effort and delay. This may require the use of anti-reflective display coatings to minimize glare for day and night operations. Consideration should be given to display information densities, format, and operator cues. The control and display integration (to include the radar and instrumentation systems) should take into account direction of movement relationships, groupings, coding, and complexity of the task. Maintenance of the installed systems needs to address the ease of removal and replacement of equipment from the mountings and the requirement for, and location of, appropriate handles and handling fixtures.

While the testbed radar and avionics equipment installation need not be identical to that in the production aircraft, the goal is to have it as close as possible. Some radar testbeds have included installation of the production aircraft radome, antenna and avionics compartments to provide the most representative radar configuration. It should be emphasized that any differences between the testbed and the production aircraft, whether installation and/or functional, must be well known and accountable in the analysis of results. Any testbed aircraft limitations (such as speed or maneuverability) which can limit the applicability of the testing to the production aircraft, should also be identified by radar mode. The testbed should have the radar and associated avionics systems controls and displays implemented as close as possible to the production aircraft. The testbed should have a time code correlation capability (either a time code generator or a time code receiver), and should have an on-board analysis capability (such as limited analog and digital data playback) for checking of certain parameters. This can allow limited data analysis in flight and can better identify what data will have to be requested and processed after the flight. It will also be helpful for the testbed to have some form of target relative position determination capability which can be provided by systems such as a/a TACAN or Loran.

The radar testbed can be used to inject additional simulated clutter during look-down testing to simulate other terrain types. It could also be used with the radar in a look-down mode to inject a synthetic target with real clutter in the background. This could be used to help determine the radar capability against smaller targets. Also, for ST/BIT testing, faults could be induced in flight to help evaluate the capability of ST/BIT to detect and isolate them. The installed instrumentation could be used to further develop ST/BIT by providing an independent monitoring of radar system status for comparison to ST/BIT reports.

Data from the testbed can be telemetered to the ground, or when the testbed is deployed to remote locations could be telemetered to a portable receiving station. One aircraft corporation has developed a capability to carry the portable telemetry receiving and data processing station (a van) in the testbed aircraft, carrying it to whatever site is used, and deploying it on the ground for testing in that area. This is an excellent idea (although it requires a larger testbed for a/a radar testing with some tradeoffs as discussed previously) as it precludes the danger of different test ranges having incompatible telemetry formats, provides autonomous operation while minimizing scheduling conflicts, and provides an immediate source of data processing and analysis.

At its home base, the testbed could be set up with links on the ground to tie it directly into ground-based radar test facilities. This can provide a more capable integration "laboratory," with the ground-based facility stimulating the testbed system and recording data from it. During the use of a radar testbed, positive configuration management is still a definite requirement. Steps should be defined for determining when the system with its changes is ready to fly (such as after completing lab tests). Configuration management is especially important in a testbed environment if changes to the hardware or software are made in flight in order to make sense of the results.

The advent of more complex and integrated avionics suites can cause the radar testbed to have to carry a greater portion of the suite in order to adequately evaluate radar only operation. In addition, it is desirable to go beyond the minimum required for radar operation, and include all possible interfacing avionics systems--whether simulated or real. This may even include weapons such as an a/a missile seeker to evaluate the pointing and data interfaces. It may be advisable to put repeater displays and some controls in the front cockpit, to allow some operationally flavored comments from the crewmembers, even though the installation is considerably different from the fighter configuration. A more exotic (but more realistic) testbed could duplicate the fighter cockpit inside and even tie it to the testbed aircraft flight control systems. This approach must weigh the considerable installation complexity versus any additional minimizing of technical risks.

5.13.3 Radar Testbed Limitations

Most testbed aircraft will not approach the maximum speed capability of the production fighter. The tradeoff in testbed size may also mean a larger aircraft may provide even less speed capability, but may offer more time on station for testing. In this case, slower may be preferred. However, the doppler shift of the ground clutter return seen by the radar, and the processing to eliminate it, will be affected by a slower testbed. This slower speed may not adequately "stress" the radar system. Generally, the greater number of development flights attainable with the use of a testbed vehicle far outweigh the compromises made in speed and maneuverability.

The ECS and electrical loadings on the testbed may be severe (as commented on earlier) but may also provide a representative environment relative to the production aircraft. The EMI environment will likely be different, and could even be worse on the testbed if care is not taken in the planning and installation. With the use of multifunction displays requiring interfacing aircraft avionics MUXBUS controllers, the testbed results may not be the same as the production implementation if the testbed is set up dedicated to only the radar. Any differences between the radar data shown on the testbed versus that in the production installation must be accounted for. It is difficult to install a production radome on a testbed, although it has been done successfully in several instances. Even if one is installed, associated equipment such as pitot tubes/lines, other antennas, and anti-static lines should be installed or simulated to obtain the best production representation.

The primary objective of a ground simulation and test facility supporting an a/a radar flight test program is to help ensure the flight time is more efficient and productive. Prior to flight, the ground test capability can be used to check out proper system operation, the effects of configuration changes and the interaction of the radar with other avionics systems. This volume will herein refer to the radar ground simulation and test facility as a "lab." Use of a lab does not eliminate the need for flight testing, but affects the planning of in-flight conditions, since flight tests appropriately concentrate on areas of interest or problems as discovered in the lab. In this way, the lab can be very useful in planning the a/a radar flight tests. The radar flight test engineer needs to have knowledge of the radar system design and lab test limitations, and needs to participate in the lab tests in order to better observe and understand the radar performance characteristics. Section 6 is a description of what a lab could be used for in an a/a radar evaluation, rather than a detailed description of how a lab is built. This section is divided into subsections to address the lab uses, limitations, requirements, test methods, instrumentation and data requirements, data processing and data analysis. Much of the information in the following subsections on a/a radar ground simulation and testing is based on Reference 5.

6.1 Lab Uses

The lab should simulate the flight environment to the maximum extent practical and stimulate the radar as if it were in flight to obtain the most realistic test results. This can result in a significant reduction of flight hours dedicated to in-flight system development and check out. The lab can be used to further system development, investigate problems found during ground and in-flight testing, and to design, implement and evaluate fixes to those problems. Radar lab testing can be used to discover and correct system development (especially software) problems, optimize system performance prior to flight, and the results can be used to clear the system for flight. Lab tests can be used to determine the starting points for flight test, help identify the flight test conditions (i.e., areas to concentrate on or minimize), and obtain an indication of how the system will perform in flight under the same test conditions. Relative radar system performance can be obtained from lab tests and compared to operation in flight, rather than obtaining performance with respect to specification verification requirements. However, lab testing can give a good indication of how some modes (primarily those not requiring a clutter background) will perform in flight and confidence that the performance requirements will be met. In-flight data can be used to determine how representative the lab tests were for a given mode, and if statistically valid, the lab results could be used to add to the data base for evaluation. These comparisons of flight and lab simulation results should also be used to update the simulation to make it more realistic and representative of the in-flight situation to increase the users' confidence in its results.

The lab could actually start out with no radar hardware, only a large computer complex to design and check out the radar software such as that for the signal processor. Once the hardware is available, it can be added and the software then installed. This can greatly speed up development time since the software often takes longer to develop than the matching hardware. The lab is usually the first time the radar is connected to the other avionics LRUs where the interfaces can be verified for compatibility. This is an extremely important milestone to accomplish prior to flight test. The radar and interfacing systems hardware can be functionally equivalent to the production systems, but need not be constrained to be packaged for flight when the initial use is in the lab, since there is much more room available there than in the aircraft. Also, test points or data access points not accessible in flight can be used in the lab setup. The lab can dynamically exercise the radar OFP and assess the effects of any OFP changes on radar system performance. Radar software changes can also be evaluated for the effect of the changes on any associated avionic systems such as the HUD, weapons computer, and weapons systems.

The lab should be configured to play back radar data gathered in flight, and set up to stop and analyze the events which occurred during the test condition. This requires compatible instrumentation systems in the lab and radar test aircraft. This kind of lab configuration can be used to change the radar system design parameters or situation/environment parameters, and repeat the tests to observe the effects and radar sensitivity to the changes. A prime advantage of radar lab ground simulation and test is the ability to gather large sample sizes and test many system alternatives faster and with less expense than flight testing. Changes can be made to the system during the run conditions to investigate and evaluate the feasibility of alternative mechanizations, thereby allowing the most immediate comparisons to minimize unproductive flight time. The lab tests can be run at real-time speeds, but also should have the capability to run forward and reverse faster and slower than in real time, as well as the capability to "freeze" the action to read out internal data not otherwise obtainable. One possible advantage of running the simulation at greater than normal speed is to obtain more data faster when it does not affect the realism of the test condition.

Test costs in a radar lab are generally lower than in flight because simpler facilities can be used without tying up expensive test aircraft and associated support equipment, ranges and personnel. Schedules can be compressed because the lab equipment is available at any time and is not dependent on range scheduling or target availability. Test data are more repeatable and reliable because the test environment/situation is more controllable, i.e., testers are able to change one variable at a time to isolate its effects.

There are also a number of pilot/operator/crewmember activities which can be beneficial to the program if accomplished in a radar lab. While the radar lab is not usually configured as the true cockpit environment with all the surrounding visual cues, it can be useful for a number of functions. It can be used for pilot training on radar system operation, flight test engineer familiarization on system operation, and maintenance crew orientation prior to actual aircraft flight. Pilots could use the system to rehearse a mission prior to each flight, depending on the complexity of the test conditions, and be able to see the expected outcome in order to better determine in flight if the radar is performing properly. While the realism of the lab cockpit layout is not as important nor feasible for the radar tests (since these are more functionally oriented test objectives), the radar controls and displays must be maintained in the latest system functional configuration to match those on the aircraft. Even though the lab cockpit may not be identical in layout, some man-machine interface evaluations of radar displays and controls can and should be performed in the lab rather than relying totally on flight testing. As a minimum, these evaluations could point out potential in-flight problem areas early, or areas needing further investigation.

6.2 Lab Limitations

Air-to-air radar ground lab simulation and testing does have its limitations. It is a static environment for the radar system and may have very limited (or no) simulation capability for actual radar motion. Therefore, it would not be an adequate indicator of radar capabilities affected by aircraft radar system movement (such as the effects of moving clutter, shifts in the clutter spectrum based on antenna azimuth angle and/or aircraft maneuvering, or aircraft body bending). If the radar is transmitted outside the lab facility towards a real airborne target, significant data can be gathered, however the LOS rates available will be limited since the radar system is not moving. This will particularly limit the dynamic tracking performance evaluation. For the look-down modes, the simulation of ground clutter and its motion is very difficult and is a major limitation for realistic lab test results. The actual ground clutter in the radar FOV while it is on the ground is not representative of in-flight conditions due to its relative closeness, low grazing angle and high return signal strength which may affect the antenna main beam and sidelobes much differently than in flight. However, the look-up modes, when operated at a sufficiently high elevation angle, should not be significantly affected by operation in a lab close to the ground.

It is generally not practical or possible to duplicate the aircraft radar system environment (such as electrical power, electromagnetic, and vibration or acoustic from gunfire) in the lab. The airborne radar environment to be encountered is even more difficult to predict only from analysis. Trying to simulate this environment in a lab for a new aircraft which has never flown (while the radar is being developed and readied for flight test) is a formidable task. In order to represent the radar electromagnetic environment in the lab, a substantial portion of the aircraft structure and wiring is required. The electrical power environment simulation requires the loading effects of the other aircraft systems as well as power noise and instabilities present on the real aircraft. The lab radar installation may require separating some of the LRUs at substantially greater distances than in the aircraft. For example, the transmitter and receiver may be separated to achieve sufficient antenna height above the ground. This separation may involve a performance degradation since the additional cable or waveguide lengths may affect the system such as by introducing signal phasing differences.

Good representations of airborne targets are required for the lab test target generators. Many simulations have a steady target signal in a noise background, yet most real target returns are not actually steady signals, but rather, are fluctuating. This fluctuation introduces a further statistical uncertainty in the in-flight detection process which may not be modelled in the lab. It is also difficult to model target scintillation, glint, atmospheric propagation, and multipath reflections which occur in flight. The target generator is further required to model the target response by varying the target return signal amplitude as a function of target range and shift the doppler return frequency with relative target velocity to more realistically represent a true target. If a jamming source is used for lab tests of radar ECCM, the setup will usually not allow the radar to look down on the signal source, and it must be sufficiently far away from the radar to be outside the near field of the antenna.

The limitations discussed in this section should not be interpreted as discouraging the use of lab testing for a/a radar development and evaluation. Rather, they are intended to highlight the areas of differences between the lab and in-flight testing which need to be understood to assess the impact on the test results. As long as these limitations are realized and taken into account, much use can and should be made of the lab for an a/a radar test program.

6.3 Lab Requirements

The radar test lab facility must have the capability to: 1) provide dynamic interfacing and stimulation of the radar hardware and software, 2) provide head-up displays, radar and other cockpit displays, plus display an out-the-window scene for pilot reference and testing, 3) interact with aircraft avionics multiplex busses such as those based on MIL-STD-1553B, 4) provide generic simulation models and hardware interfaces capable of reconfiguration, 5) provide performance monitoring to evaluate both radar internal and traffic, 6) evaluate man-machine interfaces, 7) provide data reduction and analysis capabilities for test data, and 8) maintain documentation for each radar and avionics system configuration. The interfacing avionic systems may consist of actual LRUs and OFPs, may all be simulated, or may use a combination of actual equipment and simulators.

Equipment in a radar lab should include hardware (mounting racks, cables and panels) as similar as possible to that in the aircraft. It should also include (when available) the production radar support equipment so that its capabilities and effectiveness can be evaluated in conjunction with the radar testing. Wherever practical, the actual geometric relationship of aircraft components in the lab (such as cable runs and waveguides) should be the same as in the aircraft to minimize lab induced changes. The lab should have the same (or functionally compatible) instrumentation systems as are installed on the radar test aircraft, so that flight data can be played back in the lab and through the lab radar system. The type of lab addressed here is not a full-up dome type of system which includes a duplicate of the cockpit and all external visual and aural cues. That type of fully realistic simulation lends itself more to operational evaluations of the overall weapons system, rather than of only the a/a radar to be covered in this volume.

An a/a radar lab should provide a simulation of the aircraft dynamics, environment and interfacing avionics. This capability exercises the radar system through its various modes and functions, including alternative mode mechanizations and all backup or degraded mode configurations. Functions to be performed by the lab simulation include:

- System and simulation control, including a device to perform the functions of the MUXBUS controller, to monitor and simulate multiple remote terminals
- A scenario generation program to allow the input of data to define modes of operation, geometry and characteristics of target and test aircraft and to change system parameters. Typical target information to be input includes number of targets, target RCS, location, speed and direction
- Computation of aircraft dynamics to derive the aircraft attitude, attitude rates, position and velocity information, simulating the flight control system in automatic and manual operation
- Environment simulation using standard atmospheric models, gravitational models, and wind profiles to simulate the air data system and its sensors
- Other avionic subsystems simulations including the inertial navigation system, the fire control computer, infrared sensors and laser ranging devices as applicable
- Weapon system simulation including the stores management system computations of safe release zones, alignment of missile seekers, launch initialization data and weapon release discretes, and the weapon models to simulate missile trajectories and bomb scoring
- HUD simulation to provide the data and interface with the graphics system to display the HUD data and provide an out of the window background display
- Data processing to support the compilation and analysis of the test data, including data formatting, engineering unit conversion, and statistical analysis

The lab should provide for the transfer of data among avionic subsystems, the aircraft avionics MUXBUS interface to the radar syst m, and a simulation of the dynamic environment. Simulations of the other avionic subsystems (such as the INS, SMS and weapons) can be software modules contained in the computer complex and interfaced with the MUXBUS. The main simulation computer may host all of the software modules, control target generation (either digital simulations or RF target generators), and also initiate data collection as specified by the scenario. The lab should have the capability to intermix software simulations and the actual aircraft avionic subsystems hardware to form the lab "test aircraft". For each hardware subsystem included, the corresponding software simulation module would be eliminated. Another very useful capability in the lab is a scenario playback capability to control the simulation test environment using flight test data.

The a/a radar lab installation will require a "window" (transparent to the radar frequencies) in the building to radiate through in order to detect and track airborne targets. The facility should have the capability to operate the radar with and without the actual aircraft radome installed, and preferably have a good view of airborne targets of opportunity in addition to dedicated targets. The entire radar system, the antenna and transmitter, or just the antenna may be mounted on a moveable platform to go in or out of the window depending on weather, reflections from surrounding materials and security considerations. The lab should have the capability to operate the radar alone by simulating other avionics inputs to the radar, and also operate with the other interfacing avionics systems installed to simulate operation of the full aircraft suite. Targets can also be simulated through the use of radio frequency (RF) or intermediate frequency (IF) injection to provide maneuvers, target fade, multiple targets and ECM. Actual airborne targets--with and without ECM--can be used to provide the more realistic target return signal characteristics. If actual target aircraft are used, radio contact between the lab, the aircraft controlling and tracking facility, and the target aircraft is a necessity to ensure the test conditions are properly conducted. A tracking facility needs to be able to provide target tracking reference data, such as described in section 7 of this volume, and the lab facility should have the capability of receiving and processing data telemetered from the target aircraft, as applicable. A test plan should be written and approved for this type of testing just as if the radar were in an airborne aircraft. The fact that a lot of radar development and testing can be done in a lab without transmitting outside can also be of benefit from a security standpoint since it lessens the possibility of compromising signal emanations.

The radar lab should include a target generator with the capability to generate the RF and digital target signature data. In addition to static targets, the generator must have the capability to simulate doppler frequencies representative of a moving target, and to simulate the effects of ground clutter and jet engine modulation. External radar receivers can be used to determine radar antenna beam patterns, to characterize antennas (for example: test a sample of 10 antennas to obtain average value correction algorithms to put in the radar system), and to indicate surrounding aircraft structure or radome effects on the beam pattern.

The overall radar lab test facility can include wooden towers supporting remotely controlled antennas, receivers and transmitters. Additional signal generators, analysis equipment, power supplies and cooling could be located at the base of the towers. A typical installation would have the test radar mounted 60 to 75 feet above ground in the lab (or only the test radar antenna mounted that high and coupled to the remainder of the radar system through low-loss waveguides), with the towers located anywhere from several hundred to thousands of feet away. The tower-mounted antennas should be at least as high above ground as the test radar, but preferably higher to lessen the impact of ground reflections due to the radar horizon at longer ranges. Ground reflections can be further reduced by installing radar absorbent material (such as in fences) on the ground between the test radar and tower. To provide signals at multiple azimuth angles, multiple towers are required at approximately the same range but horizontally separated. Alternatively, multiple moveable antennas may be used to generate multiple azimuth signals. Radar ECM/ECCM tests can be conducted using fly-over aircraft carrying ECM equipment, or by transmitting ECM signals from the towers--either in the presence of a target aircraft, or in the presence of a simulated target which is also transmitted from a tower. The tower equipment can also include an ESM receiver/analyzer (as described in section 5.2) to determine what all the emitters are actually doing, and to sense the surrounding electromagnetic environment. Command and data transmission lines, and RF signal lines will be required between the towers and the radar lab to provide remote control of emitters and analyzers, to provide coherent radar signal data for simulated target generation, and for real-time data analysis. The remote controls for the tower-mounted systems should be located near those for the radar system in the lab for best test coordination. If the radar-equipped fighter aircraft is capable of carrying its own defensive jamming equipment, that system (such as a pod) can also be mounted in either the radar lab or on a tower to determine if any interference exists between it and the test radar.

6.4 Lab Test Methods

A radar lab can and should be used (within the limitations previously discussed) for all a/a radar modes, and can also be used to test integration of the radar with the aircraft avionics systems if the lab is so equipped. Testing in the radar lab should be conducted with the same test planning, scheduling, configuration management and procedural disciplines as actual flight test. Radar lab test and flight test methodologies and instrumentation systems should be as similar as is reasonably possible, including both the test scenarios and test configurations. This will provide several benefits, including: 1) the ability to better determine the correlation between flight test and lab test data, 2) preflying flight test missions in the lab will be more easily accomplished and more representative of in-flight system operation, 3) duplication of flight anomalies in the lab will be more readily achieved, and 4) similar data processing and analysis processes can be used for both lab and flight test data.

Effective testing in the lab requires carefully planned test scenarios. These scenarios input fighter information such as aircraft altitude, way points, radar fix points, and target information such as altitude, range, velocity, relative bearing and RCS. Scenarios, once constructed, can be retained in the lab for future use or modification. Frequent use of these "canned" scenarios will aid in insuring test repeatability, confirming satisfactory radar system operation after a configuration change, or duplicating standard flight test profiles. Also, scenarios permit adjusting one variable through the full range of values while holding other variables constant. For example, target characteristics can be changed as the radar is cycled through the automatic acquisition modes to determine what effect they have on mode performance, or ground clutter characteristics can be varied during look-down detection runs to evaluate effects on detection performance and false alarm rate. A matrix should be constructed of radar ground lab test requirements versus the scenario(s) to be used to fulfill the requirements. The completed matrix can be used to determine the need to generate new test scenarios, the potential to improve test efficiency by modifying scenarios to accommodate more test events, and to ascertain if all ground test requirements are met. A configuration management system, to include a comprehensive test documentation and records maintenance system is very important to have for radar lab testing. Much of this system can be automated but some manual elements will usually be required. Specific functions that this system should accomplish include: 1) configuration tracking of all hardware and software (software configuration tracking will include operating systems, application software and support utilities), 2) maintenance of a library of test documentation including test methods, support hardware and software, test procedures and test results, and 3) provide a comprehensive test data audit trail, e.g., test item configuration, test scenario used, test environment simulations, system stimuli, and test results.

Several methods of radar stimulation in the lab can be used. These can be used to play back situations encountered in flight (at real-time and slow motion speeds), and to develop new capabilities. Methods may include use of RF target horns to feed signals to the radar antenna, RF signal injection into the radar receiver, IF signal injection to the radar signal processor, digital signal simulation to the radar signal processor, or signal radiation to real airborne targets. Airborne targets may be either targets of opportunity or scheduled fly-by targets. The signal injection methods involve generating a signal with characteristics as similar as possible to those returned by a true target, in addition to simulated clutter returns and/or simulated and actual ECM. The type of signal used at any one time (RF, IF or digital) is usually not mixed with another due to the possibility of inducing signal timing and amplitude anomalies.

The most direct method to perform an end-to-end lab test of the radar is to feed an RF signal to the radar antenna and observe the processing and display of that target. This can be done using an RF horn positioned in front of the radar antenna. This horn is connected to a signal generator by a waveguide. The signal generator can receive transmitted radar pulses and output a similar signal which has RF content altered to provide the desired target characteristics (range, range rate, acceleration). The target signal dynamic characteristics can be controlled by manual settings or by computer control. Multiple targets can be generated by the use of multiple horns (and multiple signal generator outputs) or by generating additional targets in range. Clutter, noise, or ECM effects can also be simulated by dedicating one or more horns to these conditions or by combining these signals with the target signal. Angular motion can be simulated by physically moving the RF horn. Several advantages to the use of horns include:

- Detection, acquisition, and tracking functions can be tested end-to-end (from antenna to display)
- ECM and clutter signals can be generated using actual ECM transmitters and RF clutter generators respectively
- Test support equipment can be obtained relatively easily because the technique is widely used
- Angular discrimination of multiple targets can be evaluated using moveable horns

Use of an RF horn for a/a radar lab testing does have some limitations, such as:

- Horns are generally stationary, therefore the azimuth and elevation to the "target" are constant although the range and range rate are dynamic. Physical movement of the horns only provides a limited angular change
- Generation of multiple targets requires multiple horns or a complex switching capability
- A substantial amount of hardware and wiring are required
- Use of actual ECM transmitters for more sophisticated ECM techniques will introduce additional timing constraints
- The radar is at a fixed, low altitude and therefore problems with ground clutter and multipath returns will usually be apparent at certain elevation angles

Radio frequency signals can also be injected into the radar receiver. This technique is similar to the use of RF horns except that the antenna is bypassed and the waveguide and horn support structures are not needed. Computer control of the signal generator can simulate a relatively complex RF environment. Advantages of this method include:

- Detection, acquisition, and tracking functions can be tested end-to-end except for the antenna
- Dynamic target characteristics can be simulated relatively easily
- ECM and clutter signals can be combined with target signals prior to injection
- Test support equipment can be obtained relatively easily because the technique is widely used
- Multiple targets can be generated

Limitations of RF signal injection into the radar receiver include:

- Antenna functions are not checked
- Generation of a full range of dynamic target characteristics, particularly maneuverability, requires complex computer control
- A substantial amount of generation hardware is required for complex RF environments (such as multiple dynamic targets and clutter)

Intermediate frequency signals can be injected between the radar receiver and the signal processor (although another LRU is bypassed and the test is less than a complete system end-to-end test). This technique is advantageous since it can be used with real data collected from flight which is recorded at IF. Data of this type then includes actual ground clutter returns. However, limitations of this technique include:

- No testing of the radar RF section is achieved
- The recorded signals are specific radar system, altitude, aspect and terrain unique. Therefore, recordings for the radar system under test must be made in-flight prior to being able to accomplish the lab test
- Data fidelity is limited by the capabilities of the on-board instrumentation system used to record the data
- The IF injection point may not be readily accessible
- The ability to inject ECM signals is uncertain

Digital simulations of targets, clutter, and ECM can be computer generated and introduced at the radar signal processor. This method of stimulation provides the greatest latitude for dynamic testing in the ground environment because there are no physical restrictions. Although the RF and analog sections of the radar are bypassed, digital signals can be used to test one of the most complex portions of the radar--the digital section. The major limitation to digital simulations is the less direct applicability of data to the real world. Advantages to digital simulation and injection include:

- Thorough testing of changes made in the radar digital sections (usually the most frequently changed radar area)
- The technique is in general use
- Multiple, maneuvering targets can be generated much easier than by using some of the other methods

Limitations to the use of digital simulation include:

- Each radar system simulation is sufficiently different that the simulation may not be applicable to another situation
- The RF and analog sections of the radar system are not tested
- Digital simulation of sophisticated ECM capabilities combined with clutter and multiple targets is a highly complex task
- Clutter and ECM characteristics may be limited to relatively simplistic models due to simulation computer capacity limitations

The use of actual airborne targets, either targets of opportunity or scheduled fly-by aircraft, presents several advantages:

- ECM systems can be carried on-board the target aircraft and operated against the radar
- Actual aircraft and ECM systems provide the most realistic target and ECM representations
- End-to-end testing of detection, acquisition, and tracking functions is achieved

Limitations to the use of real airborne targets include:

- Clutter is not introduced into the test since testing is limited to look-up geometry due to possible interference or multipath returns for the ground
- Target aircraft position, rates, and maneuvers are less precise than simulations and not as easily repeated. Targets of opportunity are uncontrolled
- Relative maneuverability, such as is needed in ACM modes, cannot be achieved. (Maneuvering of the target aircraft is necessarily limited, and the radar is stationary)
- Flight time, particularly for multiple scheduled targets, is costly
- TSPI systems will be needed to gather reference system data for the aircraft

6.5 Lab Instrumentation and Data

A substantial amount of instrumentation will be required to support the a/a radar lab, and it should have considerable commonality with the airborne flight test instrumentation systems. The lab can also be used to perform a thorough checkout of the airborne instrumentation systems prior to flight. The determination of whether to use identical instrumentation systems for lab and flight tests can involve cost tradeoffs, but does result in overall savings since the same radar data analysis tools can then be used for both. For each a/a radar test or mission conducted in the lab, the capability should exist to record the entire aircraft avionics MUXBUS, internal radar data, TSPI data (or accept externally recorded TSPI data), simulator generated data, video display data, environment data such as ECM signals, and weapon interface signals. These data will be used for radar development, troubleshooting and performance evaluation.

Two data handling capabilities are required: real-time monitor capability and post mission analysis capability. The real-time monitor capability can allow considerable time savings in the areas of: initial operational checkout of the baseline lab configuration, initial checkout of the system with the radar installed, verification of mission scenarios, and monitoring of selected test data during actual testing. Real-time monitoring should include the capability to obtain and display some data (such as selected MUXBUS words) in engineering units. The post mission analysis capability can allow the quick reaction checkout of parameter time histories and the production of report quality plots. This interactive capability would include the generation of titles, legends, grids, grid marking, legends and comments for single or multiple plots. The MUXBUS carries most of the signals needed to evaluate overall radar performance in acquisition and track. However, when the radar is in search modes, the MUXBUS does not contain all the data needed to determine radar detection performance, and additional video or internal data is required. Similarly, for automatic acquisition, the radar display is blank before tracking begins, and not all the necessary data is on the MUXBUS. Consequently, internal radar data must be obtained to supplement the MUXBUS data. Internal radar data are needed to augment data available from the MUXBUS or radar display and to provide a more detailed examination of the radar design. These signals are used to assist in performing troubleshooting within the radar and for performance evaluation. Internal radar data can be used to evaluate data processing techniques associated with target and clutter signals, threshold settings, Fast Fourier Transforms (FFT), Kalman filtering, Constant False Alarm Rate (CFAR) settings, and various other algorithms.

Test environment data is the test environment (both simulated and real) seen by the radar under test. This data includes all the simulations used, the signals generated, and TSPI data. These test environment data are compared to the radar data to determine radar performance. Before the comparisons are made, the necessary coordinate transformations, time correlation and data processing must be performed to make the values comparable. There are two reference systems which may be used depending on the types of tests conducted. If actual airborne targets are used, the range TSPI system would serve as the reference system and coordinate transformations made using the location of the radar antenna with respect to the lab. If RF target generators or digital target simulations are used, the test environment and the radar system under test will use the same coordinate system defined by the simulation support computers and direct comparisons can be made.

6.6 Lab Data Processing

Radar and support systems data outputs can be categorized as real-time, near real-time, and post mission. Near real-time outputs are those that have gone through some data processing, usually conversion to engineering units, and are delayed from real time by generally not more than one to two seconds. The most useful real-time display of data is in engineering units. This almost always requires the conversion of output signals by use of high-speed computers and applicable calibrations and mathematical equations. These data can be output on CRT displays to produce multiple listings of selected parameters, time history plots, and cross plots of two parameters for a desired time period or event. The data system should be designed to provide versatility of data presentations, be interactive so that changes can be made rapidly, and have time correlation and hard copy capabilities. Also, recording all data in engineering units will reduce the post mission data processing requirements.

Display and recording of the radar display is required. Multiple repeater displays should be located away from the cockpit display to avoid crowding. Video recording and playback equipment should be compatible with the flight test equipment. The ability to add digital data (environmental and additional radar parameters) to the video repeater displays and recordings will greatly enhance real-time monitoring and data analysis. Non-engineering unit radar data display can be done as a back-up in the lab using analog strip charts. This requires digital-to-analog conversion of much of the data. When actual airborne targets are used with TSPI tracking, a repeater plotter should be located in the lab, with processing to provide the target data relative to the lab location. The plotter can also be used to plot the computer-generated tracks of the lab radar aircraft and targets during full simulation modes.

CRT displays of radar lab test data should be produced in near real time to aid the radar test engineers in test monitoring and preliminary analysis. These displays should be relatively uncluttered and should incorporate a means of highlighting out of limits performance. A two-level set of displays can be beneficial for the monitoring and flagging activity. The first level would be a series of time-tagged numerical values (in engineering units) of selected radar parameters and the error associated with each. Out of limits error magnitudes could be highlighted by several means (such as white background, using other colors or flashing alphanumeric characters). The second level set of displays would be selectable from the first level and would show a graphic representation of a single parameter shown in the first level display. Typically, the second level display would be a parameter that is out of tolerance or exceeds some preselected threshold value. The display should have a visual depiction of established thresholds or boundaries and should show present performance in relation to these boundaries. A series of special characters could show the most recent data and a blinking cursor could show the present error value. Second level displays should be selectable from the first level by a single key stroke and the first level heading should include prompts of the correct control key by parameter. Similarly, the second level display should include the key board entry to return to the first level. Also a message should be displayed on the second level display if an additional parameter should go out of tolerance while a second level display is being displayed. This would prompt the engineer or analyst to consider returning to the first level display. Each level of display should incorporate features which would allow the engineer to annotate the data for detailed post-mission analysis. Also, the capability to make a hard-copy print of any particular display should be incorporated. This would make selected data available for immediate post mission review.

6.7 Lab Data Analysis

The basic data analysis method common to all the radar test methodologies is to compare data from the radar with that obtained from a reference system and determine the differences. Data analysis of a/a radar lab tests should be quite similar to the analysis of flight test data. The same parameters should be evaluated, and the test scenarios should be much the same. The analysis procedures should be essentially the same and presentation of results should follow the same format. This will also allow comparisons of flight test and lab test results so that consistencies and differences can be identified, in order to determine the validity of the lab results and to update the simulation as required.

Both real time test data monitoring and post test review of data can be accomplished. The main sources of this data are the video recordings of the radar display, CRT displays and strip charts. A video display board can be used which is capable of superimposing alphanumeric characters and various graphics displays over the image of the radar display without interfering with displayed radar data. This allows the radar display and most of the real-time data to be placed on the same display. The normal data displayed could include all radar set control switch positions, AGC levels, digital readouts of angles and ranges, and environment cues. The independent target tracking position can be displayed as a box at the correct position on the radar display for ease of target identification and analysis. TSPI of multiple targets may be displayed in the same manner. The symbology generated by the instrumentation should be easily changeable and different sets of symbology kept on disk for different mission types. The radar display and instrumentation symbology should be recorded on video tape for post mission, frame-by-frame analysis, if needed.

7. INSTRUMENTATION AND DATA

A high degree of sophisticated in-flight instrumentation is required in order to properly evaluate the performance of an a/a radar system. The primary types include recording of video displays, recording of internal radar data and the interfaces with other avionics, operator comments, telemetry, on-board special controls and reference data. The radar test aircraft may not be the only one to be instrumented--the targets may need to be, as well as jamming aircraft, radar missiles, ground-based jammers and reference ranges. Sufficient data is required to develop and evaluate the radar performance, and determine whether or not the test objectives were met. Adequate data is required in a timely manner in order to determine if the next test condition (either during the same flight or for the next flight) should be accomplished. The data reduction and analysis schemes may very well drive the design and implementation of the instrumentation systems, especially for the recording of the radar internal and external interfaces. Standardized recording methods should be implemented so the many users can easily use the same data, especially when a/a radar tests include multiple ranges, targets and jammers. Time correlation amongst all the sources must be ensured, typically within 10 milliseconds for high accuracy radar tests such as target tracking.

The placement of on-board instrumentation systems in modern-day fighters is getting more difficult due to the limited "real-estate" available with the incorporation of so many aircraft and avionics systems. It often requires removal of systems which are not as critical to the radar evaluation, such as fuel tanks and other unrelated systems, or the addition of external pods to house the instrumentation systems. Care should be taken to ensure the aircraft instrumentation modifications do not affect the radar operating environment (such as equipment removal which changes the cooling or electrical power available to the radar) or the aircraft operating envelope needed for radar testing (such as an external pod restricting aircraft maneuvering). Also, any changes made to the radar system for instrumentation purposes which will not appear in production (such as including a digital readout of antenna tilt angle on the display) must be made so as not to affect the system evaluation.

A "shakedown" of the entire aircraft instrumentation and data processing capability--both on the ground and in flight--should be accomplished well before any radar flights requiring its use. This shakedown includes determining if the instrumentation system will properly record the data under all aircraft flight conditions, ensuring the compatibility of the recording and processing systems such that data will run through the reduction and analysis programs, and validating that reasonable data products are received. Some data from laboratory testing can be used to check out the data processing flow, as long as it is compatible. This checkout may also help to sort out and eliminate any non-useful parameters.

The advent of so many more radar modes, coupled with the increases in data available (both internal to the radar and with external interfaces) and rapid changes in system configuration and test conditions, has required the development of programmable instrumentation systems that are easily changeable prior to flight and even in flight. These systems have the capability to pre-define a set of parameters to be recorded for an event (such as a test condition for one mode), and then select a different set of parameters to be recorded for the next mode test condition. Typical characteristics are to have from three to eight different selectable sets available during a flight. While a/a radar system testing alone may not require all of them, the realities of many test programs forces the sharing of aircraft assets with concurrent testing of other aircraft and avionics systems. Even though increases in instrumentation capabilities allow substantial increases in the amount of data available, it should be noted that it can become easier to over-specify data requirements, thereby obtaining much never-used data at considerable expense. Sometimes data requirements are specified on a "what if" basis, i.e., it would be nice to have only if the unexpected occurs. Obtaining this much data can quickly overtax the data reduction and processing systems, as well as the radar analysis team's capability to analyze it. Further information on aircraft flight test instrumentation can be found in AGARDograph series 160, "Flight Test Instrumentation."

7.1 Video

Recording of the aircraft radar display is required for all test conditions and is normally done using a video tape recorder. This allows a quick-look postflight evaluation and can be a prime source of radar data. The preferred method is to tap off the video signal going to the display--especially if it is in a standard format which can be recorded directly. Some installations use a video camera (with a beam splitter to allow the pilot to still view the display) when a directly recordable signal is not available. The least preferred method is an over-the-shoulder mounted video camera which may provide a poorer recorded image but is still better than no recording at all. The main advantage of using a camera is that it will record what the pilot actually saw, including the effects of brightness and contrast settings, cockpit lighting, glare and parallax.

A helpful feature for shorter range radar evaluations (generally for airborne targets within five nm) is video recording through the HUD which has the symbology superimposed on the outside scene. The HUD displays a target symbol superimposed over the target being tracked by the radar, as well as on aircraft parameters such as altitude, airspeed, heading and attitude. Video recording of the HUD requires a camera with a wide dynamic light range to accommodate the large extent of exterior brightness levels encountered, especially the rapid changes that can occur during maneuvering flight. Experience has shown that the HUD symbology must be adjusted brighter than normal in order to adequately show up in the video recording against the exterior background. The preferred method of HUD video recording is to record the radar display and HUD together. This allows the postflight evaluators to observe both the exterior background and airborne target through the HUD, and directly compare it with the radar performance as observed on the radar display. Two most common methods for this combined recording use: 1) recording of interleaved HUD and radar display video frames and then separating them during playback on the ground to separate screens, and 2) split screen with one half for the radar display and the other for the HUD simultaneously. The interleaving method can induce some flicker on playback since the video update rate is cut in half, but may be preferable to split-screen since interleaving presents a larger view of each display. The on-board system should have the capability for the operator to select recording of the radar display only, the HUD only, or both.

Audio and time tracks are required on the video recording for pilot comments and time correlation with other data sources. Additional aircraft and radar data can be included in data blocks on the display or embedded in the non-viewable video lines. Data blocks on the display can obscure radar information, but have the advantage over the embedded approach in that the blocks will still be viewable if the video is put in slow motion or pause, whereas the decoder for stripping off embedded data or time code information may not operate at other than full-speed playback. Any time delays, such as between radar internal processing and actually displaying the information, need to be understood and must be accounted for when merging data streams. Some of the displayed data added for radar testing may be found to be operationally useful (such as the minimum and maximum search altitudes covered by the selected radar scan pattern at the cursor range, or an overlay of both a/a target detection range and velocity versus azimuth displays). These useful features may be incorporated in the production configuration.

Video recorders should be mounted so that they are accessible in flight for changing cassettes. This is especially desirable if the mission data length exceeds the record time of a cassette. Typical recording times are 20-30 minutes for the 3/4 inch cassette tape format, and 1-2 hours for the 1/2 inch VHS format. Normally, an on/off switch is provided in the cockpit so that recording can be limited to only data runs to conserve tape usage. Video recording is more desirable than film for the radar display since it is immediately viewable postflight (versus waiting for film to be processed), and it has a longer available recording time which requires less aircraft storage room for additional cassettes. However video resolution is generally less than that for film which can be a factor when attempting to view an airborne target through the HUD. If a film camera is used for the HUD, it typically runs at a standard 16 or 24 frames per second, and must include the capability to record time for correlation with other data. This can be done by recording pulses on the film or having time included in the HUD display field of view. The lesser resolution of video recording is usually not a limiting factor for analysis of a/a radar data from the radar display. A color video capability would be preferred when looking through HUD and would be required when color radar displays are used.

Proper video playback equipment is very important. It should have the capability for variable slow-motion in forward and reverse, and the ability to freeze (stop motion) video frames on command. It should have a good indexing mechanization in order to rapidly find areas of interest on the tape. Most installations do not use an actual aircraft radar display for playback due to its different power requirements and since it is generally smaller and the small screen makes analysis difficult. The primary reason for using the aircraft display for at least some of the playback is to be able to observe the displayed data as the pilot actually saw it, but is not as great a factor in a/a radar evaluation as it would be for a/g.

Some aircraft contain video recording systems as a part of the production configuration as a training aid and for historical combat data. While this installation may not be adequate for the detailed radar evaluation, it should be evaluated with respect to its suitability of operation.

7.2 Internal Radar Data

The radar can be modified to send out some additional internal data over the avionics interface, acting as a "data pump". This method may be sufficient for some development and evaluation applications, but does have its limitations in that it may overload the radar processor or aircraft avionics MUXBUS at the busiest (and therefore worst possible) times. An extensive radar development program will require full data recording of the internal radar busses and data ports. This will usually require a separate dedicated high speed recording system of one megabit per second or greater capacity. Newer radar systems may have substantially higher data rates which may force the recording of only a portion of the data, or require some form of on-board real-time data compression which doesn't substantially corrupt the data resolution or timing.

Internal radar data is used primarily for radar system development, troubleshooting and failure analysis. It can also be used for a/a radar evaluation, such as to gather target detection blip-scan data (the scan number, bar number, range, azimuth and time of each displayed detection) instead of manually reading it from the video display, and for false alarm determination. The instrumentation system configuration should be easily changeable, especially during radar development testing, to accommodate the numerous areas which will have to be investigated.

A typical internal radar instrumentation system will have the capability to record data from the following sources: 1) the internal bus which ties together all the radar LRUs, 2) the dedicated high speed bus between the radar computer and signal processor, 3) selected portions of the aircraft avionics MUXBUS which ties the radar system to the rest of the aircraft avionics, 4) internal radar processor data, 5) analog radar hardware temperature and vibration levels, 6) some aircraft instruments such as a/a TACAN range and bearing, 7) time code information, and 8) crew audio. It may have one or two recorders (depending on the tradeoffs made between recording capacity, available aircraft space, and amount of data to be recorded), a buffer to receive and format the data streams necessary for recording, and a control and indicator panel in the aircraft cockpit. It may contain a built-in radar digital data simulator to use for testing and verification of the instrumentation system. The recorder can be a standard 28-track instrumentation recorder, capable of 30 to 60-minute record time depending on the recording speed/data density required. At high data recording rates (one megabit per second and greater) the typical number of tracks required may be: 1 each for the radar internal bus, the aircraft avionics MUXBUS, temperatures, vibration levels, time code and audio, while several (typically 2-4) will be required for the dedicated radar computer/signal processor bus, and many (10-20) for internal radar processor data. This radar processor data will typically include data from radar processing routines or FFT data (the contents of the doppler filters and range gates matrix) which can be used to examine clutter rejection and target detection capabilities.

The radar instrumentation system controls and indicators should be provided in the aircraft cockpit. Controls should be installed to allow the crewmember to power the system on and off, start and stop the recorder(s), and select recording data streams or formats (as applicable and equipped). Indicators should be installed to show power on, tape motion, selected data or formats, amount of tape used, and low tape warning.

7.3 Avionics Interfaces

The recording of the radar interface with the other avionics (analog such as INS data, discretes and digital such as the MIL-STD 1553 type MUXBUS) is the source of most radar evaluation data, since the parameters of interest for evaluation are usually those sent to the rest of the weapons systems over these communications channels. This is true primarily in a/a radar target acquisition and tracking modes when the weapons system is dependent on radar target data for launch/delivery pointing and computations. Additionally, the radar may be modified to put added data out on the MUXBUS which is not normally required by the other avionics systems but which can aid in development and evaluation. Detailed information on each MUXBUS data word is normally included in a system interface control document. Typical data rates are 50 transmissions per second per digital word over a 1 megabit per second serial digital data bus along with analog data and discretes. A typical data recording system is a 14 or 28 track standard instrumentation recorder with 1-2 hours of record time. The serial digital data can be split across several tracks (typically 4-5) and other tracks used for analog, discretes, time code, and pilot audio.

The amount of data needed to be recorded, and the fact that there may be several aircraft multiplex busses of interest (such as avionics, display and weapons) depending on the radar modes under test, may require in-flight selection of the parameters to be recorded. This would require the prior definition of data formats by mode or test condition, and may also involve on-board data compression schemes to fit all the desired data. Some special techniques, such as coding data as to when an event actually occurred versus when it was recorded as it came on the bus, may be required in order to obtain sufficiently accurate time correlation with other data sources.

7.4 Telemetry

In addition to the test aircraft on-board recording capabilities, radar data can be transmitted to a ground station continuously during each test flight by means of a digital telemetry (T/M) link. The data can be recorded at the ground station on magnetic tape as a backup to the airborne recording. If the test aircraft on-board space is extremely limited, T/M could be used instead of on-board recording for some or all of the data. This does run the risk of losing data when noise, line-of-sight limits, and other factors disturb the T/M transmission. The T/M systems generally do not have sufficient bandwidth to transmit all the radar and interface data, therefore the testers need to prioritize what will be sent out on the basis that the on-board recorders will handle the remainder. There may have to be a means to select in flight between several pre-defined T/M formats depending on what testing is taking place.

Telemetry of the radar video display is highly desirable as it can impart a large amount of information on the current test, yet it poses a considerable problem due to its high bandwidth if it must be encrypted for security purposes.

Selected channels of the telemetered data can be displayed on the ground using strip chart recorders and cathode-ray tube (CRT) displays to evaluate radar functional performance. While it is highly desirable to observe radar data real time on the ground via T/M during the conduct of the test condition, the number of parameters may be limited by the T/M transmission bandwidth required, the ground monitoring capabilities and security considerations. Much of the a/a radar performance evaluation is accomplished by comparing radar data to reference data postflight, which does not require T/M. Some evaluations can be accomplished using T/M, such as determining if the radar maintains track or breaks lock under maneuvering conditions or in the presence of a jamming signal. Telemetered radar data can also be used to ensure the radar is in the correct mode configuration for the test, for real-time limit checking (such as indicating when specified accuracies are being exceeded, when track quality measures go beyond acceptable limits, or when antenna position rates become excessive), to obtain an early indication of problems, and to determine if the test should continue.

The aircraft T/M system should be compatible with all test ranges which may be used, unless program-unique T/M receivers, recorders and processors are transported wherever testing takes place. When T/M is desired during low-level test aircraft flights in the vicinity of rough terrain, a relay capability may be the only method of receiving the T/M signals. This may be accomplished using one or more other aircraft, or a satellite, to relay the data back to a ground station. If the data is encrypted, not only does the data error rate usually rise, but the range compatibility and relay issues can become considerably more complicated. If the aircraft has a production data link system installed, this could be used in lieu of some of the T/M data required, since it will likely only contain radar data normally on the aircraft avionics MUXBUS, and no internal radar parameters.

7.5 On-board Special Controls

The test aircraft radar installation may include special controls which can be very helpful by modifying radar performance in flight to investigate problem solutions. Special controls may also be used to make immediate in-flight comparisons to evaluate alternative mechanizations under the same flight conditions (as described in section 5.6 of this volume). The radar software can be temporarily programmed so that options can be selected via unused a/a radar controls or switch combinations for that test condition (such as using the selection for beacon mode to change the track coast time when in a/a mode, or ground map controls to change a/a ECCM techniques). Another option is to add a non-production keyboard and display tied directly to the radar computer to send commands and read out internal radar data. Alternatively, the system may be modified to accept a plug-in cartridge (containing some type of memory material such as magnetic tape or read-only memory) and then several cartridges containing different mechanizations could be carried and used in flight. Implemented properly, special controls can maximize the efficient use of flight time, especially during early system development of different radar processing schemes. This can be particularly useful and time-saving when compared to other means of changing radar mechanizations such as hardware replacement or software modification.

Special on-board controls must be implemented and used with care to ensure that other problems are not created. Since the radar is highly integrated with the other avionics systems, all versions of the in-flight radar modifications must be compatible with the interfacing systems. Also, the addition of special controls should not be allowed to affect the normal operation of other radar modes which may be developed and undergoing a final evaluation. Depending on the extent of the changes made to the radar system to implement the special controls, it may be necessary to use the production configuration radar for evaluation without the special controls installed, to ensure that the evaluation is of a truly representative system.

7.6 Reference Data

The major source of reference data used for a/a radar evaluations is ground-based time space position information (TSPI). This may include radars (to track the aircraft skin return or an aircraft mounted beacon), cinetheodolite cameras, laser trackers and interrogators/transponders. The use of each of these systems will depend upon the reference accuracy required and TSPI system limitations such as coverage area, coverage during maneuvering and tracking of multiple targets. Some a/a radar tests, when in look-down modes, will require reference data on the ground moving targets in the vicinity to evaluate the radar ground moving target rejection implementation.

7.6.1 Sources

The following factors need to be considered when using typical TSPI systems: 1) the aircraft must be equipped with a beacon transponder to reply to tracking radars (such as an FPS-16) to obtain higher accuracy, 2) cinetheodolite cameras require clear atmospheric conditions, have a limited range (typically within 25-40 nm) and require considerable coordination to have 3-4 cameras each tracking the radar-equipped aircraft and the target, 3) laser trackers usually require highlighted reflective areas on the aircraft which may be obscured during maneuvering, and 4) interrogators/transponders (with the interrogator on the aircraft and a layout of transponders on the ground at known locations) are limited to only the flight path which keeps the aircraft within range of the ground systems. All of these systems are limited in the number of targets that can be simultaneously tracked--generally only one target per tracking system--and may also be limited in their line-of-sight track ranges depending on the surrounding terrain. Mobile systems can be used to cope with some of the line-of-sight limitations, but are generally not quickly relocatable. It might be possible for a tracking radar such as an FPS-16 to be modified, using a computer-controlled receiver and multiple local oscillators, to multiplex the radar and enable it to track more than one aircraft at a time, each with different beams. This would require the use of some track smoothing algorithms and some memory, but may be able to provide multiple target tracking with acceptable accuracy. Most range tracking facilities have programs which can provide the user with the proper flight geometry relative to the tracking systems to obtain the best reference system accuracy available for each test condition.

The timeliness of the TSPI is also a factor in choosing which systems to use. Real-time TSPI system accuracy and postflight processing delays are important factors to be considered. Cinetheodolite film cameras require processing of the film and then manual scoring of target position within each film frame--although the advent of high resolution video cameras coupled with automatic scoring equipment will greatly shorten the processing time required. Some less accurate real-time position data can be obtained directly from the camera azimuth and elevation angles. The accuracy of this real-time data is generally on the order of that from an FPS-16 type radar, as long as the operators keep the cameras reasonably well pointed towards the aircraft. Laser trackers can provide more accurate real-time data, but still require postflight processing.

Not only is TSPI required for postflight evaluation, but it is used during the test conditions to provide aircraft vectoring for proper test set up and real-time aircraft data. These data are typically test aircraft and target position, altitude, range and velocity to initialize and maintain the correct test conditions within limits. When available, the Global Positioning System (GPS) satellite network can also be used as a source of TSPI for a/a radar testing. Some a/a radar tests will require the use of differential GPS (the inclusion of a ground-based GPS pseudo-satellite system and additional processing) to obtain the higher accuracies required. TSPI outputs are used in several formats--normally printouts, plots and data tapes which can then be merged with other data sources.

Reference data can also be acquired from an instrumented target (typically by recording the target's INS outputs to obtain time correlated attitude, velocity and acceleration data). Target aircraft attitude and body-relative data are not available from any of the TSPI sources mentioned previously. Another source of data can be an Air Combat Maneuvering Range (ACMR) which uses an external aircraft-mounted system and ground-based transponders to obtain position and attitude information on a number of targets in an operational scenario. This data is usually not sufficiently accurate for a highly quantitative a/a radar accuracy evaluation, but is very useful for OT&E.

Air-to-air TACAN can provide target position range and bearing reference data for radar tests such as measuring detection and lock-on ranges, and for target positioning to set up test conditions. Its advantage is in not requiring any ground station and therefore can be used wherever the test conditions necessitate. It would be advisable, if a/a TACAN is to be used extensively, to conduct a short evaluation of the accuracy of the systems and installations to be used by comparison with a more accurate reference system. Air-to-air TACAN has been measured to be as accurate as 0.1 nm between two aircraft. Most aircraft TACAN installations are designed with the prime consideration of communication with the ground (i.e., the antenna is mounted on the lower part of the aircraft) and therefore may be unreliable when communicating with another aircraft which is higher in altitude.

Tracking the aircraft telemetry stream (which contains aircraft latitude, longitude and altitude) is another option for obtaining reference data. The aircraft data could be used to aim the ground T/M antenna to track the aircraft T/M signal using a mobile positioning van with a broadband antenna. This mobile van could be transported with the test aircraft to deployed locations to provide the same displays, readouts and data processing schemes at all locations. The mobile capability could also be used to position the ground T/M receiving antennas to avoid terrain masking for low-level tests. Air-to-air radar evaluation reference data may also be obtained using a pod system mounted on the test aircraft which can measure target position. The pod could be carried externally and may have the capability to track multiple targets simultaneously. It may house a reference radar, RF transponder, data acquisition system, signal conditioner, telemetry transmitter, timing receiver, timing decoder, and associated antennas. An RF transponder, with the associated antenna and a telemetry antenna, could be mounted directly on the test aircraft. The reference data pod electronics packages could condition, format, and transmit test aircraft parameters such as altitude, roll, pitch, heading, airspeed, angle of attack, and target relative position, along with parameters from other on-board instrumentation. The data could be transmitted to a ground facility, and also recorded on board for backup. A timing signal is required to synchronize the time tagging of all the data as they are received at the ground facility. The pod reference radar could provide range, azimuth, elevation, and azimuth and elevation rate data with respect to a transponder located on the target. One disadvantage to this pod concept is its dependence on a unique ground processing site to receive the telemetered data, and it would therefore be limited to use only within that vicinity. Also, the requirement for a beacon in each target could be eliminated if the pod had a highly accurate radar system.

7.6.2 Data

The a/a radar test planning process should include a definition of the reference data accuracy and time correlation requirements, especially since they will usually be different for the various test conditions and radar system capabilities to be evaluated. High altitude versus low altitude test conditions may even require different tracking systems to follow the aircraft. The newer, more accurate a/a aircraft radar systems are forcing innovative uses and upgrades in existing reference tracking systems. Quite often, the reference system accuracy alone is not sufficient and requires postflight combinations of data outputs with substantial mathematical estimating and smoothing.

A single reference tracking radar (such as an FPS-16) using an aircraft-mounted beacon, can track at all typical a/a radar ranges, usually with an accuracy of +/- 20 feet depending on the geometry and range to the aircraft. Cinetheodolite data is usually accurate to +/- 3 to 5 feet depending on geometry, number of cameras on each aircraft (usually 3-4) and atmospheric clarity. The effective range is often limited to 25-40 nm. Laser trackers are generally accurate to within +/- 10 feet but are also limited in range. A test aircraft pod reference data system such as described in section 7.6.1 may be accurate to within 15 feet at ranges of less than 15 miles, and accurate to within 25 to 50 feet at ranges from 15 to 60 miles.

Much work has been done to increase reference system accuracies by the use of best estimate of trajectory (BET) computation processes which use data from more than one tracking source. This can be a variety of combinations of cameras, radars, and lasers, as well as using on-board aircraft navigation system data. The BET process usually uses a Kalman filter/optimal smoother to model errors of all data sources including those on board (such as altimeters and the INS). When on-board INS data is added to the process, aircraft velocity accuracy is better and smoother, with the greatest improvement being realized in a high-dynamic arena.

The methods and depth of a/a radar data analysis to be performed are dependent on the purpose(s) of the tests, such as functional checks, verification of corrections of system discrepancies, specification compliance, or operational evaluation. Functional checks may be only for the purpose of determining if the system is working satisfactorily in a general sense, and very little detailed analysis may be required other than monitoring the radar display. Verification of configuration changes, specification compliance, and operational testing all usually compare radar system performance against a baseline or standards. The analysis for these types of tests consists of performing the comparison and evaluating the results. The data analysis procedures and programs need to be specified during the test planning stages in a data analysis plan to ensure the analysis capability will be available when needed. The type of data analysis to be performed will also influence the type of instrumentation required and its configurations. As covered in section 7 of this volume, the very high data rates may necessitate flexible selective recording of parameters at various rates, compression algorithms and means of changing menus of recorded parameters in flight. The data processing and analysis schemes and the instrumentation requirements must be compatible, should be standardized as much as possible (such as standard data report formats), and must provide the user with the appropriate data sufficient to determine radar performance. The ground lab can be a useful source of data to validate the data processing and analysis techniques to further confirm their acceptability for the flight test data.

In addition to the detailed data analysis for radar performance measurement, some limited data processing and analysis is required on a quick turnaround basis for rapid decision making such as: clearance for the next flight, confirmation that the required data was gathered, or if a modification is required to the test setup or to the radar system itself. The typical process after a flight is to: 1) have a postflight debriefing with the flight test engineers and flight crew using the notes taken during the flight, 2) obtain the video recordings (and use them as part of the postflight debriefing), 3) use real-time and postflight quick-look data to make early performance assessments, and 4) decide what second generation data analysis will be required. During radar system development especially, when all participants (such as the radar designers) are not collocated with the test facility, it has been found that video teleconferencing is very useful in rapid dissemination of flight test results and planning. This requires an audiovisual link between all test-related personnel from a variety of geographical areas to promote the best sharing of thoughts and allowing the crew to explain the performance seen in flight.

The process of requesting data and performing data analysis should be automated as much as possible, especially in light of the enormous amounts of data which can be generated from even a single flight. The data processing and analysis system needs to be "user friendly," i.e., be easy for the test engineers to use and adaptable to changing requirements. A flexible system (such as one with an interactive ability to use different sets of data, and able to vary the analysis methods based on a number of resident statistical packages) will also reduce the unacceptably long lead times involved when actual flight test data is run and a need to change the analysis capability becomes apparent. This will also speed up the whole data analysis schedule, allowing flights which are dependent on the analysis outcome to proceed sooner.

Data processing capabilities can be broken down into several types: real-time, video, first generation, merging, and second generation. Some analysis can be performed at each step along the way, but the majority of the performance analysis is performed after the second generation processing has been accomplished. Real-time processing is usually defined as that which is performed during the flight as the data is being gathered, and [illegible] include the capabilities of processing some first generation data, limited merging [illegible] even some second generation processing.

Real-time data is used to better isolate and identify data time slices for further detailed postflight analysis, to make quick-look types of assessments, and to determine if there is a need for greater or fewer test runs on the current flight. For real-time data processing and analysis, the areas of display and calculation requirements, control room layout, and the duties of control room personnel must be well defined prior to the start of testing. Also, the processing which is needed in real time versus in near real time (shortly after occurrence) will need to be defined. Typical real-time display requirements include: 1) the radar or avionics system status indicators to be displayed (for example: green for radar lock-on, yellow for ECM detect, and red for break lock), 2) the required update rates, 3) the necessity for time history displays (i.e., what is needed to make a decision to go to the next test condition or run), 4) a radar system "health" display, 5) an indication of the currently selected radar and weapons system mode, 6) plot scale units and colors, 7) digital readouts, 8) pointers/flags/messages to be displayed and under what circumstances, and 9) limit lines to be drawn on data to indicate when a predetermined limit is about to be exceeded.

8.1 Video

Video data is obtained primarily from the radar display, and from the HUD for shorter range test conditions. Video data may also be obtained from the target aircraft (from its radar or ECM displays) and from an Air Combat Maneuvering Range. Video data is used for a quick look qualitative analysis to verify that the system is operational, to show what the pilot saw in flight, and to narrow down the areas of interest to be further processed and analyzed using data obtained from other sources. Data that can be initially obtained from the video, and then more accurately obtained from analysis including the reference system, are: 1) target azimuth and range or velocity for initial detection range and probability of detection, 2) detection range/velocity/azimuth accuracy, 3) false alarm rate, 4) multiple target resolution, and 5) indications of ECM. Initial estimates can also be made for: 1) time to lock on, 2) time to stable track, and 3) effects of ECM on tracking performance. If the radar video data is telemetered to the ground during the test flight, some of this analysis can be performed in real time. Video data is very handy to have during the postflight debriefing since it can help refresh the pilot's memory (particularly for a long flight with many test objectives and conditions), it can give a good overall view and understanding of the situation to the flight test engineers, help in early indication of anomalies or problem investigation, and present the data that was given to the pilot in case of any discrepancies with respect to the recorded digital and analog data. The video data also will be used to assess the radar display, and may be used to judge whether the use of the recording is satisfactory for training and combat history purposes in the field on production aircraft.

Detailed video data analysis will require playback equipment that can operate at normal speed, slow motion, and "freeze" (stop motion of a video frame). When the video tape includes time code and/or imbedded data, it would be helpful for the playback system to continue to display the last data prior to the stop motion. Most recording techniques in use, however, will not display time or imbedded data when the tape is played back in slow motion. Video display recordings normally are manually interpreted and the data entered as another file to be used by data analysis programs. Automatic scoring of video during playback, with the playback system keeping track of the range and azimuth of one or more a/a radar displayed targets, is a recent innovation though still difficult and expensive. A scoring system could determine parameters such as target range and azimuth and output the data on a data tape for use in further analysis routines. Video data is useful for a multitude of operational analyses, for example determining the ease of system use by the pilot's ability to place the cursor over the target in a timely manner. Video data is also useful for quantitative analysis such as measuring the number of successful lock-ons versus the number of attempts, and can be used to verify the internally recorded radar detection and false alarm data. The video data can also be used to help interpret other data, such as strip charts or recorded control room CRT displays, since sometimes "a picture is worth a thousand words."

8.2 First Generation

First generation data processing is usually defined as that processing which converts raw data measurements (both digital and analog) to engineering units (units such as feet, feet per second, and degrees) and can obtain reports of significant discrete radar or weapons system events (called "events reports"). First generation data can be in the form of listings and plots for quick look assessments, or data tapes which can be used as input to radar performance analysis programs. An events report is typically a time-oriented listing of the significant events that occurred during each test run (such as time of designate, time of lock-on, and time of breaklock) which can be used to refine the start and stop time periods of the digital data needed for further analysis, or to provide preliminary analysis of events.

A "smart" and fast data processing system is required to obtain quick-look data right after the flight, especially for the purpose of approving the next flight. The most rapid processing will use the data in whatever form it exists and will not spend extra time reformatting the data. This is especially important when the testing is being conducted in a remote area away from the main processing facility. This rapid processing is used to evaluate the quality of the data, to validate the data to ensure the instrumentation system is recording properly, and to provide a preliminary assessment of the success of each test condition. This includes determining if the correct modes were used and the test setup (such as target range, azimuth and speed, radar system PRF, and range scale) was proper. The quick look data to be used will depend on the test objectives, but may include performance parameters such as detection range, lock-on distance, lock-on time, and target closing speed, as well as fighter parameters such as altitude, speed, normal acceleration (g's), attitude and heading. Target parameters available from conventional flight instruments in the target aircraft (which may be hand-recorded by the crew or instrumented) include target altitude, speed and heading, and a/a TACAN distance and bearing. Hard copies of strip charts and CRT displays can be made from either analog or digital data streams, and can be used to graphically illustrate data such as the dwell times and walk-off rates during ECM tests. These sources of data are usually very adaptable to changes in data presentation.

The very large amounts of recorded data would be unwieldy during playback if formatted post-flight on a one-for-one basis. Rather, data are compressed using algorithms during the first generation processing to obtain engineering units in a greatly reduced data volume. A common compression algorithm outputs data for a parameter only when its value changes greater than a predetermined amount and also forces data out at a specified time interval (such as once per second) even if the value has not changed. The compression algorithm values and limits applied to each radar and weapons system parameter must be carefully chosen since there is a tradeoff between reducing the amount of data versus having sufficient data resolution available for analysis. Some high rate rapidly changing data, such as obtained during ECCM test conditions, may not readily lend itself to compression since every sample of all data may be required for analysis. With a very instrumented on-board aircraft avionics instrumentation system, on-board real-time compression may be used, thereby increasing the amount of data time available.

Some first generation data processing schemes include data smoothing routines, such as for TSPI data. If smoothing routines are found to be necessary due to "noisy" data, care must be taken to ensure the smoothing routines use the least number of points while properly tailoring the filter response to accommodate aircraft maneuvers. Since much a/a radar testing involves highly maneuvering aircraft, improper smoothing may impart an incorrect position or velocity for analysis purposes, since the smoothing routine may cause the data to unacceptably lag the actual aircraft performance. The radar flight test must ensure any smoothing algorithms used are compatible with aircraft and radar performance, and with the radar analysis routines.

The advent of more aircraft data busses, along with the newer storage technologies, results in even larger data bases which must be stored and catalogued for easy retrieval. This is a good area for which a management information system (as covered in section 3.7) can be very useful. Since much of the data is usually classified, an MIS can be used to track and control all sources. The great increase in data volume also points out the need for standardized formats of first generation data for use in multiple analysis programs.

8.3 Merging

Merging of data streams is required to combine various first generation data sources in order to accomplish data comparison and analysis. Some limited merging may be accomplished in real time during the flight, but this is dependent on the communication of the sources to a central data facility with sufficient data processing capability to handle such a complex task. When reference data are to be merged in real time, the reference data real-time accuracy must be taken into account, since it may be less than that obtainable post-flight. Real-time merging may be used to display or compute data such as: target velocity and range errors, selective aircraft avionics MUXBUS parameters, aircraft attitude, cockpit display parameters, and other weapons systems parameters.
Postflight merging of data will include all parameters, and may include data sources such as an Air Combat Maneuvering Range, tracking range reference data, instrumented target(s), other sources of target information via data link (other fighters or interceptors, airborne or ground-based early warning systems), threat ECM facilities (both airborne and ground-based), video and pilot comments. The typical means of merging data is based on time of occurrence, usually recorded on each source to a resolution of one millisecond. The typical means of providing time for each data source (especially for in-flight use) is by a separate time code generator which will normally have some inaccuracy in its initial setting which may drift over time. The correlation of time among all data sources can be accomplished in a variety of ways such as introducing a tone which is simultaneously recorded by all sources, or via telemetry of aircraft on-board time to the other sources. The radar data rates and accuracies at typical test aircraft speeds requires data timing correlation to within 10 milliseconds. Any time skew which is determined post-flight can be applied to the data during analysis. This points out the need to have data analysis programs which can accept an input of time deltas for the data sources, and apply these deltas during the processing.

The application of time correlation deltas to the data will require the use of interpolation algorithms, since not all data will be simultaneously sampled nor will it be sampled at the same rate. The type of algorithm selected may use straight line or weighted interpolation, and it may be necessary to change the interpolation algorithm based on the data sources, sample rates and the type of radar test being analyzed. The merging and correlation process must be carefully chosen in order to accommodate the variety of digital sampling rates, various filter characteristics, and compression techniques. The merging process also must not be allowed to discard any data (such as by filtering) without approval. Merged data will typically be put on a single type of data media, such as magnetic tape or disk, to allow easy access to all data within a given time segment.

8.4 Second Generation

Second generation processing uses as input the time-tagged engineering units data directly out of the real-time or first generation processing and performs additional processing and calculations on sets of parameters from the same time segment. The input can be in the form of a serial time history (data ordered by time of occurrence having each parameter defined at each time point) or a compressed serial time history (a data structure where the amount of data are reduced and must be reconstructed to perform the analysis). The output data from second generation processing is normally in the form of plots, tabular listings, time history data, and histograms of flight events which can be used for further analysis. Second generation processing may also include comparisons of in-flight radar performance with the results of computer-generated simulations and radar lab tests. Second generation processing will also include the merging of overall performance data for like test conditions from multiple flights to obtain overall performance with statistically meaningful results. The term "third generation" is sometimes used to describe the processing performed with data from several events or time slices from several flights using input from second generation software.

8.5 Analysis Techniques

Two methods of radar performance analysis are typically employed for the a/a radar flight test program. One uses only data originating from the radar system (including pilot comments, video, internal and MUXBUS) to perform: 1) in-depth analysis for development and troubleshooting (such as a detailed examination of clutter cancellation techniques, causes of false alarms from the doppler/range bin matrix, acquisition sequence and timing, ST/BIT failure validity, and simulation of the radar digital processor on the ground to see if it provides the same results as found in flight), 2) some performance analysis (such as detection and lock-on ranges), and 3) both subjective and quantitative operational analysis (such as the ability of the pilot to discern and lock on to his assigned target). The other analysis method is a comparison of the radar data to that of a reference system, primarily to obtain statistical performance results. For example, target range error can be calculated as a percentage of actual range and might be determined for a variety of aspect angles, in clutter and non-clutter conditions, in non-ECM and ECM environments, and for a wide range of opening and closing velocities.

The reference system must be sufficiently more accurate than the radar system under test. A "rule of thumb" is for the reference system to be a factor of 10 more accurate than the radar under test, although it can be shown statistically that factors between 3 and 6 may be sufficient to achieve acceptable confidence levels in the analysis. Coordinate rotation (putting the aircraft and reference data into a common coordinate frame of reference) is probably one of the most difficult parts of the analysis technique to implement. The reference data must be put into the same coordinate system as the radar-equipped aircraft body before comparisons are made of the a/a radar-derived versus reference system-derived target data. In addition to analysis of radar in-flight performance, comparisons can be made with ground lab data to update the simulation to ensure it is as close as possible to actual in-flight performance. This can be particularly useful when the simulation is used to predict performance under conditions which were not used during flight test.

Radar analysis typically operates on the assumption that radar performance statistics have a gaussian distribution. The error analysis should indicate values for minimum and maximum, mean, standard deviation, number of samples, ratios, and include confidence levels/bounds (the typical confidence level used is 90 percent). It is especially important to indicate the statistical meaning of the computed results. Sensitivity curves can be calculated for varying coefficients such as the effect of clutter or target type on a/a detection range. Detailed performance analysis should be emphasized when the flight test program has a limited number of samples. Sampling and statistical theorems should be employed for maximum confidence in the test results (for example, determining how well the flight test results represent the population and at what level of confidence). It should be noted that radar performance analysis is not an end in itself, but must consider how the results will be used, who will use them, the purpose of the test, the timeliness of the answers, and the type and format of the report.

Automated data processing should be used for much of the a/a radar data analysis. The analysis techniques may not be standardized for various systems, since specific radar system problem investigation may require unique analysis methods. If possible, standard methods of comparisons and presentations of data from previous tests on other similar systems should be developed. A fully automatic a/a radar performance analysis would be very difficult to implement. It would require a very complex algorithm (or expert system) to set thresholds for "good" versus "bad" performance. For example, how would the analysis routine judge a marginal lock-on (which could be called good in a different test scenario), or the reason for a breaklock, or judge an ECCM test where the radar maintained track but would have broken lock if...? The "whys" of the performance analysis cannot be reliably implemented automatically, but will require the skill and expertise of a data analyst. This is especially true when an operational analysis is being performed, and the results need to be interpreted from the perspective of the operator in a given combat situation. A management information system (as explained in section 3.7) can be of considerable use for data analysis to keep track of data, and may help identify trends in the results (for example increases in system performance and changes in failure rates).

Much of the a/a radar performance analysis will also be qualitative in nature. This applies especially to the operational judgments, wherein an assessment must be made of the system's ability to perform the intended mission regardless of whether it meets a particular performance specification requirement. Also, radar switchology, mode mechanizations and display adequacy will be evaluated qualitatively, based on pilot comments and answers to questionnaires. Some evaluation criteria may have both quantitative and qualitative analysis techniques employed, for example, the pilot's ability to lock on to his assigned target (in a multiple target engagement) may have a statistical result in terms of percentage of times the pilot locked on to the correct target, but is also highly subjective with respect to the ease and simplicity of achieving a successful lock-on.

Radar analysis techniques described in the following subsections are divided into two parts--detection, and acquisition and track. This covers the specific areas of evaluation described in section 4 and can also be used for the topics in section 5. For example, the analysis description for tracking includes the analysis for the acquisition portion, and can be used for evaluation of manual and auto acquisition performance as well as for TWS acquisition. Evaluation of other considerations such as ECCM will use type of analysis (such as track accuracy) for comparison between radar performance in a non-ECM versus ECM environment. The same holds true for comparisons to determine effects of the environment, EMC, and evaluation of alternative mechanizations. The tables and plots shown in this section are samples of how a/a radar data and results can be shown and analyzed--they do not contain actual data (to eliminate any sensitivity or classification of this volume). Not all results are shown in the form of a plot or table, since the explanation in the text is sufficient to describe what a table should contain and an additional layout of the table itself would be redundant. All data printouts and plots should contain headings to identify: date of processing, flight date(s) and number(s), run type and number(s), and the start and stop time of run. More specific test condition heading information can be included as appropriate, such for detection analysis: the number of detections (for each scan/bar if conducted in other than one-bar scan), symbols for each bar plot, and the average false alarm rate.

8.5.1 Detection Analysis

Detection data is available from radar system internal recordings and video tapes of the radar display. The preferred method of obtaining detection and false alarm data is from the internal recording to minimize the manual process of sorting through video tapes. The scan number, elevation bar number, range, azimuth and time are noted for every displayed target symbol during the test condition. These detections are then sorted into four categories (using reference data from either a/a TACAN or ground-based tracking systems): those on the target of interest, those on other airborne targets, those in the vicinity of a road which could be Ground Moving Targets (GMT), and the remainder as false alarms. The target detections are used to calculate the various detection results (such as detection ranges and consistency) and to compare with reference data to determine range and azimuth accuracy. If no internal radar data is available, the target range and azimuth read from the video tape will not be as accurate as desired, resulting in some uncertainties in distinguishing between false alarms, ground moving targets, other airborne targets and discrete non-moving ground targets. The P_D calculation is accomplished using a sliding window - usually 10 scans long if a slow closure rate run (fighter in trail of the target in a "tail-chase", closing on the target) and 5 scans long if a high closure rate run (fighter "head-on" to the target). When this window is moved inward in range looking at the detections on the target versus scans, the number of detections in the window is plotted as the P_D versus the target range at the center of the window. False alarm rate is a difficult parameter to analyze since so many variables and unknowns are involved.

For multiple target resolution runs, the video tape can be used to determine the points at which the two targets appeared to merge or separate. Reference data is then used to determine the range or angle resolution achieved.

Typical inputs to the a/a radar detection analysis routines are:

- Time delta - the time correlation difference between the on-board and reference data which must be applied during the processing
- Flight information - fighter tail number, flight date and flight number.
- Fighter versus target closing speed (knots)
- Fighter antenna scan rate (X.X seconds per scan)
- Window size and slide - the number of opportunities used to determine the ratio of hits to opportunities (blip-scan ratio) and how many opportunities to slide the window in range for each calculation
- Analysis type, run number and flight number
- Aircraft time, azimuth, range, scan number and bar number for each target detection or false alarm (does not need to include data on other aircraft and ground moving targets)
- Identification of whether the data is for a false alarm or a target detection (such as 1 for a false alarm, 0 for a target detection)
- MUXBUS and internal radar data tape identification
- MUXBUS and internal radar data such as: radar mode words, target range, target azimuth, antenna azimuth, antenna elevation, fighter altitude, fighter heading and fighter velocity
- Reference data tape identification

Typical analysis outputs include listings, tables and plots of all scans and bars showing the range and azimuth errors, tilt angle, fighter and target altitude/heading/velocities, the P_D and false alarm rates; and plots of P_D versus time, azimuth and range accuracy versus range, and false alarm rate. Following are examples of analysis outputs for detection evaluation with explanations for some of the more complex ones. Abbreviations used are: fighter fire control radar (FCR), fighter (FTR), target (TGT) and reference data (REF).

Explanation of Table 9:

- TIME - for each scan/bar combination starting with the first false alarm or detection
- SCAN/BAR - the program filled in all scan/bar combinations during the run for continuity. If there was no false alarm or detection for that bar in that scan, the data in the appropriate columns is zero. If a target detection and/or more than one false alarm occurred on a single scan/bar combination, there will be multiple entries in this column
- TGT AZIMUTH - radar azimuth (FCR) of the target or false alarm, target azimuth from reference data (REF) and the azimuth error (ERROR) between the reference and the fighter radar (corrected for the difference between reference system ground track

heading and fighter true heading) for target detections. If there was no target detection or false alarm for that scan/bar, the FCR and ERROR columns will contain Ø.Ø*

- TGT RANGE - radar range (FCR) of the target detection or false alarm, target range from reference data (REF) and the range error (ERROR) between reference data and the fighter radar for target detections. If there was no target detection or false alarm for that scan/bar, the FCR and ERROR columns will contain Ø.Ø*
- PD - indicates whether or not this entry was included in the probability of detection calculations - N if no (i.e., it was a false alarm), Y if yes (i.e., it was a target detection) and Ø if no entry for this scan/bar
- TILT - fighter radar antenna tilt (elevation) from MUXBUS data.
- ALT - differential altitude between fighter and target (DIFF), fighter MSL altitude (FTR) and target MSL altitude (TGT) from reference data
- HDG - heading of fighter (FTR) and target (TGT) from reference data
- VEL - velocity of fighter (FTR), target (TGT) and closing velocity between the two (CLOS) from reference data

Explanation of Table 1Ø:

- TIME and SCAN/BAR - same as for Table 9
- TGT RANGE - range of the target from reference data (REF) and radar range (FCR) of target or false alarm, Ø.Ø* if there were no detections
- TGT AZ - radar azimuth (FCR) of the target or false alarm, Ø.Ø* if there were no target detections or false alarms
- -6Ø through +6Ø is a tabular representation in azimuth versus time of all target detections and false alarms
- PD - whether or not this entry was included in the probability of detection calculations - N is no (false alarm), Y if yes (target detection) and Ø if no entry for this scan/bar
- FA - whether or not this entry was included in the false alarm calculations - N if no (i.e., it was a target detection), Y if yes (i.e., it was a false alarm) and Ø if no entry for this scan/bar

TABLE 9 DETECTION OUTPUT 1

FLIGHT DATE FLIGHT NO. RUN TYPE DETECTION RUN NO. START TIME

TIME HHMMSS.SSS	SCAN/ BAR	TGT AZIMUTH FCR DEG	TGT AZIMUTH REF DEG	TGT AZIMUTH ERROR DEG	TGT RANGE FCR NM	TGT RANGE REF NM	TGT RANGE ERROR NM	PD	TILT DEG	ALT DIFF FT	ALT FTR FT	ALT TGT FT	HDG FTR DEG	HDG TGT DEG	VEL FTR FPS	VEL TGT FPS	VEL CLOS FPS
1055.018	55/1	2.0	-3.5	.2	13.0	12.8	.2	Y	-3.4	-3432.	7329.	3787.	88.	274.	1490.	881.	-2314.
1055.518	55/2	0.0*	-4.1	0.0*	0.0*	12.7	0.0*	0	-3.3	-3502.	7341.	3839.	88.	269.	1491.	927.	-2350.
1056.018	56/1	3.0	-3.6	-.8	12.5	12.5	.0	Y	-3.3	-3236.	7355.	4119.	89.	258.	1499.	765.	-2167.
1056.518	56/2	0.0*	-3.7	0.0*	0.0*	12.3	0.0*	0	-3.3	-3336.	7360.	4024.	89.	265.	1501.	818.	-2325.
1057.018	57/1	3.0	-4.2	-.7	12.3	12.1	.2	Y	-3.3	-3446.	7386.	3940.	88.	274.	1489.	858.	-2309.
1057.518	57/2	0.0*	-3.5	0.0*	0.0*	11.9	0.0*	0	-3.4	-3353.	7399.	4046.	89.	262.	1505.	778.	-2234.
1058.018	58/1	2.0	-4.0	.5	12.0	11.7	.3	Y	-3.4	-3318.	7419.	4101.	88.	264.	1488.	780.	-2261.
1058.518	58/2	0.0*	-4.8	0.0*	0.0*	11.5	0.0*	0	-3.4	-3409.	7438.	4030.	88.	281.	1482.	951.	-2518.
1059.018	59/1	3.0	-3.7	-.9	12.0	11.3	.7	Y	-3.4	-3308.	7458.	4150.	89.	284.	1495.	1002.	-2432.
1059.518	59/2	3.0	-3.7	-.9	11.8	11.3	.5	Y	-3.4	-3308.	7458.	4150.	89.	284.	1495.	1002.	-2433.
1100.018	60/1	2.0	-4.0	.0	11.5	10.9	.6	Y	-3.3	-3233.	7497.	4265.	89.	256.	1491.	712.	-2163.
1100.018	60/2	3.0	-4.0	-1.0	11.3	10.9	.4	Y	-3.3	-3233.	7497.	4265.	89.	256.	1491.	712.	-2163.
1100.518	61/1	0.0*	-3.7	0.0*	0.0*	10.8	0.0*	0	-3.4	-3257.	7519.	4262.	89.	280.	1494.	901.	-2375.
1101.018	61/2	2.0	-3.8	-.0	11.0	10.6	.4	Y	-3.3	-3242.	7553.	4311.	89.	281.	1479.	916.	-2414.
1101.685	62/1	0.0*	-3.9	0.0*	0.0*	10.3	0.0*	0	-3.3	-3381.	7600.	4218.	89.	254.	1497.	742.	-2162.
1102.351	62/2	0.0*	-3.3	0.0*	0.0*	10.1	0.0*	0	-3.3	-3418.	7663.	4245.	90.	276.	1498.	873.	-2355.
1103.018	63/1	0.0	-3.8	0.0*	18.5	9.8	0.0*	N	-3.4	-3253.	7699.	4445.	89.	284.	1489.	986.	-2413.
1103.018	63/1	2.0	-3.8	0.0*	8.0	9.8	0.0*	N	-3.4	-3253.	7699.	4445.	89.	284.	1489.	986.	-2413.
1103.351	63/2	0.0*	-4.4	0.0*	0.0*	9.7	0.0*	0	-3.3	-3171.	7729.	4558.	88.	280.	1482.	906.	-2361.
1103.685	64/1	0.0*	-3.9	0.0*	0.0*	9.5	0.0*	0	-3.3	-3162.	7761.	4599.	89.	271.	1492.	785.	-2258.
1104.018	64/2	2.0	-3.7	-.0	9.0	9.4	-.4	Y	-3.4	-3253.	7782.	4529.	89.	273.	1489.	809.	-2245.
1104.518	65/1	0.0*	-3.8	0.0*	0.0*	9.2	0.0*	0	-3.4	-3232.	7803.	4571.	89.	288.	1486.	1015.	-2536.
1105.018	65/2	2.0*	-3.9	-.1	9.0	9.0	-.0	Y	-3.3	-3133.	7825.	4692.	89.	281.	1485.	913.	-2420.
1105.518	66/1	0.0*	-3.9	0.0*	0.0*	8.8	0.0*	0	-3.4	-3187.	7868.	4681.	89.	282.	1482.	897.	-2324.
1106.018	66/2	0.0*	-3.9	0.0*	0.0*	8.6	0.0*	0	-3.3	-3174.	7917.	4743.	89.	284.	1476.	928.	-2332.
1106.518	67/1	0.0*	-3.7	0.0*	0.0*	8.4	0.0*	0	-3.4	-3260.	7964.	4704.	89.	282.	1489.	937.	-2414.
1107.018	67/2	2.0	-4.0	-.3	8.0	8.3	-.3	Y	-3.3	-3470.	8006.	4536.	89.	278.	1481.	845.	-2285.

TABLE 10 DETECTION OUTPUT 2

FLIGHT DATE FLIGHT NO. RUN TYPE DETECTION RUN NO. START TIME

TIME HHMMSS.SSS	SCAN/ BAR	TGT REF NM	RANGE FCR NM	TGT AZ DEG	-60	-50	-40	-30	-20	-10	000	+10	+20	+30	+40	+50	+60	PD?	FA?
					•	•	•	•	•	•	•	•	•	•	•	•	•		
1055.018	55/1	12.8	13.0	2.0							•							Y	N
1055.518	55/2	12.7	0.0*	0.0*														0	0
1056.018	56/1	12.5	12.5	3.0							•							Y	N
1056.518	56/2	12.3	0.0*	0.0*														0	0
1057.018	57/1	12.1	12.3	3.0							•							Y	N
1057.518	57/2	11.9	0.0*	0.0*														0	0
1058.018	58/1	11.7	12.0	2.0							•							Y	N
1058.518	58/2	11.5	0.0*	0.0*														0	0
1059.018	59/1	11.3	12.0	3.0							•							Y	N
1059.018	59/2	11.3	11.8	2.0							•							Y	N
1100.018	60/1	10.9	11.5	2.0							•							Y	N
1100.018	60/2	10.9	11.3	3.0							•							Y	N
1100.518	61/1	10.8	0.0*	0.0*														0	0
1101.018	61/2	10.6	11.0	2.0							•							Y	N
1101.685	62/1	10.3	0.0*	0.0*														0	0
1102.351	62/2	10.1	0.0*	0.0*														0	0
1103.018	63/1	9.8	18.5	0.0*							•							N	Y
1103.018	63/1	9.8	8.0	2.0							•							N	Y
1103.351	63/2	9.7	0.0*	0.0*														0	0
1103.685	64/1	9.5	0.0*	0.0*														0	0
1104.018	65/2	9.4	9.0	2.0							•							Y	N
1104.518	65/1	9.2	0.0*	0.0*														0	0
1105.018	65/2	9.0	9.0	2.0							•							Y	N
1105.518	66/1	8.8	0.0*	0.0*														0	0
1106.018	66/2	8.6	0.0*	0.0*														0	0
1106.518	67/1	8.4	0.0*	0.0*														0	0
1107.018	67/2	8.3	8.0	2.0							•							Y	N

Figure 3 is a typical single scan probability of detection P_D plot showing a line for each bar in a two-bar scan detection run (a circle indicating the bar 1 target detections and a triangle indicating the bar 2 target detections). The plot would normally be self-scaling in range to account for the detection range differences on various test conditions. The P_D results can also be tabulated to list the target range P_D for each window calculated for each bar.

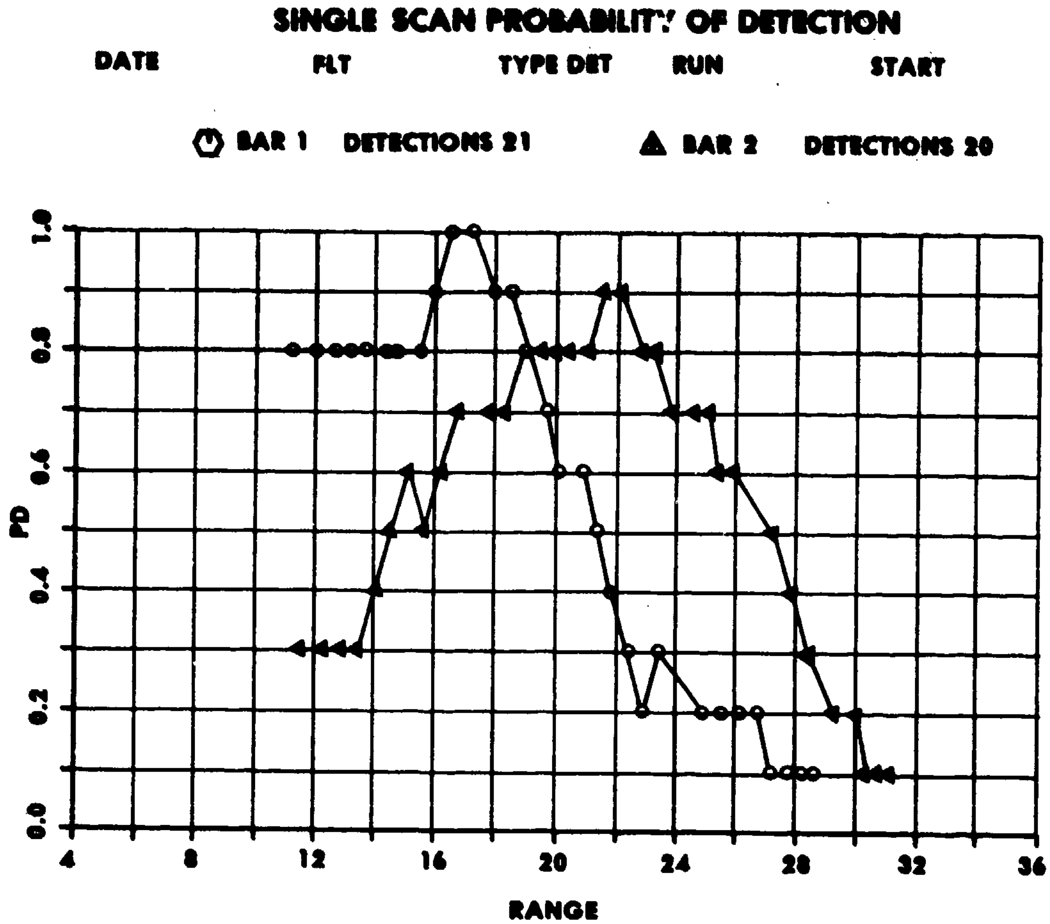


Figure 3 Single Scan Probability of Detection

The detection azimuth and range accuracies (as tabulated in the listing shown in Table 9) can be plotted versus target range. If internal radar data were not available, these plots are useful to verify that the correct points from the video tape were read accurately and used in the target detection range analysis (i.e., if a point shows a very large error when most do not, it may not have been a detection of the target and should be eliminated from the detection range analysis).

Table 11 is an example of how false alarm rate results could be presented. False alarm rate can also be plotted versus target range to determine if it is range dependent.

Table 11 False Alarm Rate

	Run No.	Run Time (minutes)	No. of GMTs	No. of Others	No. of False Alarms	False Alarm Rate
	XXXX	XX	XX	XX	XX	XX
	XXXX	XX	XX	XX	XX	XX
Total for all runs		XX	XX	XX	XX	XX

Some analysis results do not require unique tabular or plot formats, but can be organized and presented as the author sees fit or customer desires. Typically, they would be presented to show the effects of a variable, such as clutter. The types in this category include both DT&E and OT&E analyses of:

- Cumulative probability of detection (P_{CUM})
- Correlation of radar detections with IFF detections
- Scan-to-scan azimuth and range correlation
- Multiple target range and azimuth resolution
- Comparison of the useful operating ranges of low PRF and VS in the presence of clutter (FAR verses detection performance)
- Percentage each RWS mode option (azimuth scan width, elevation bar, range scale, target history, PRF, frequency) was used

An operational measure of detection performance is the frequency of radar detections (percentage of successful target detections out of the total number of occurrences where the pilot attempted to use the radar for target detection). A successful detection in this case could be defined as a target detection prior to visible contact or at greater than a specified range. This detection range is very dependent on pilot workload and combat situation. Reasons for no detection could include: the pilot was tracking other aircraft, or the pilot's efforts were concentrated on visual search or navigation. The results can be categorized and then plotted by mission role such as: PI - pure intercept, PAD - point area defense, FP - force protection, and AS - air superiority. The plot could be in the format as shown in Figure 4. This plot includes data at the mean (the point on the line) and also shows the confidence bounds (typically 90 percent). This type of plot can be used to compare many detection mode results, such as detection range by mission role, by pilot, by clutter background, and by target type.

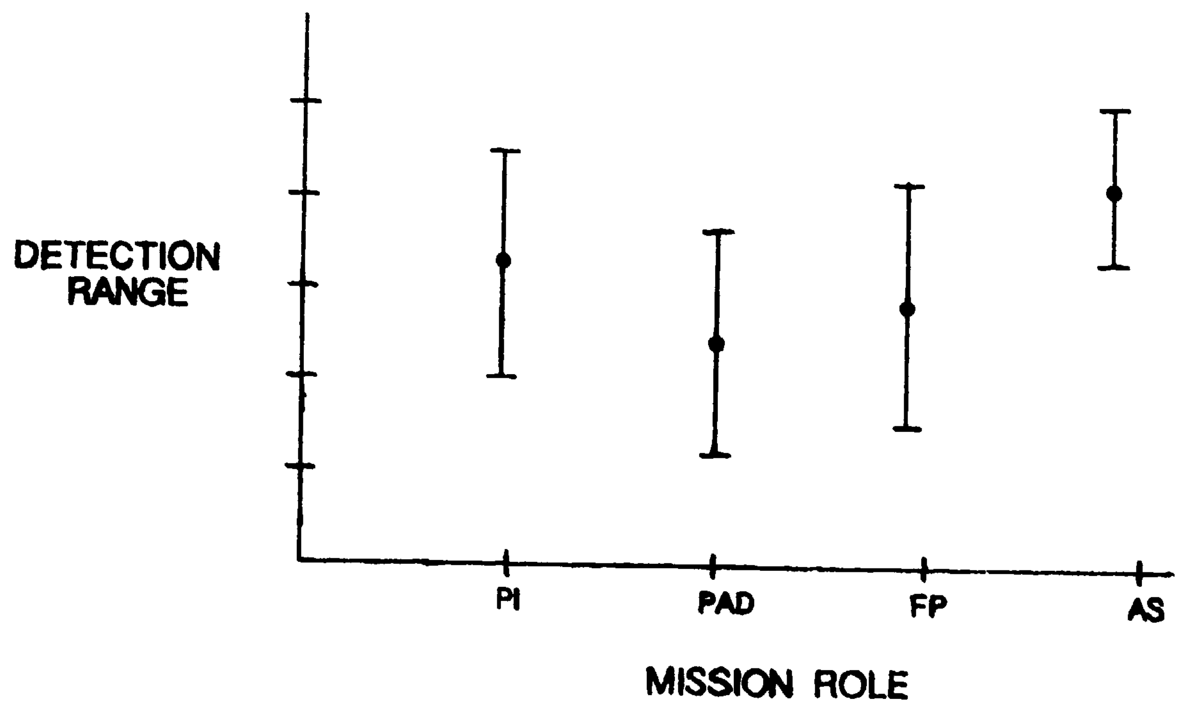


Figure 4 Detection Range Versus Mission Role

Additional operational analysis may include the determination of initial radar contact versus consistent contact (initial can be defined as the first time the target is displayed, and consistent as the third time the target is displayed--not necessarily consecutively). The frequency of resolution can be defined as the percentage of successful resolution of multiple targets (prior to visual contact) of the total number of occurrences the pilot obtained successful radar contact. Resolution range can also be sorted and plotted by mission type, pilot, target type, and whether another detection source was available to provide target information. Initial versus consistent resolution range can be determined, using the same type definitions of initial and consistent as for single target detections.

8.5.2 Acquisition and Tracking Analysis

The data streams, analysis methods, types of analysis outputs and overall results all incorporate both acquisition and tracking, therefore they are addressed together in this section. Postflight video tape playback can be used to confirm times of track coast, breaklocks and a qualitative analysis of tracking capabilities. The primary quantitative analysis of performance accuracies uses time-correlated MUXBUS data in comparison to reference data. Typical analysis outputs include printouts showing a time history of fighter and target altitude/heading/velocity, target range and range rate accuracy, fighter g's, target azimuth/elevation/angular error, velocity and acceleration magnitude/angle error and a statistical evaluation of each run. This can include the mean, standard deviation, and number of points for angle error, range error, relative target velocity vector and total target acceleration vector. Plots for errors versus elapsed time and versus range would include track angle accuracy, track azimuth accuracy, track elevation accuracy, track range accuracy and track range rate accuracy. The events report from MUXBUS data can be used to give detailed times of occurrence of radar events. Switchology and usefulness of radar target acquisition and tracking mechanization and displays will also be evaluated qualitatively through pilot comments.

Typical inputs to the a/a radar acquisition and tracking analysis routines are:

- Time delta - the time correlation difference between the on-board and reference data which must be applied during the processing
- Flight information - fighter tail number, flight date and flight number
- Start and stop time of run
- Analysis plot rate interval (usually in numbers of seconds)
- Allowance for specifying wild point limits for track analysis (usually will also have a default value if not specified)
- Analysis type, run number and flight number
- MUXBUS and internal radar data tape identification
- MUXBUS and internal radar data such as: radar mode words, target slant range, target range rate, antenna azimuth, antenna elevation, relative target velocity X, Y Z, relative target acceleration X, Y, Z, target azimuth, target elevation, fighter altitude, fighter normal acceleration (g's), fighter roll angle and roll rate, fighter pitch angle and pitch rate, fighter true heading, fighter velocity
- Reference data tape identification

Typical analysis outputs include listings, tables and plots of which several examples follow. Abbreviations used (FCR, FTR, TGT and REF) are the same as those used in the detection analysis output examples. Tables 12 through 14 are illustrations of detailed point-by-point analysis of radar tracking accuracy performance. The samples shown are based on the TSPI data rate of 20 samples per second. The tables show different types of analyses obtainable for a single run, and include elapsed time of the run to correlate with other data.

Explanation of Table 12:
- TIME - for each point of reference data (usually 10 or 20 points per second)
- L - blank if radar was locked on, otherwise an asterisk is placed beside each point during the time the radar was not locked on
- ALT - MSL altitude of fighter (FTR) and target (TGT) from reference data
- HDG - heading of fighter from fighter inertial navigation system (INS), fighter heading (FTR) and target heading (TGT) from reference data
- VEL - velocity of fighter (FTR) and target (TGT) from reference data
- TGT RANGE - range to the target from radar data (FCR), range to target from reference data (REF) and the error between the two (ERROR). If the radar was not locked on, FCR and ERROR columns would contain 0.0*
- TGT RDOT - range rate between the fighter and target from the fighter radar data (FCR), from reference data (REF) and the error between the two (ERROR). If the radar was not locked on, the FCR and ERROR columns would contain 0.0*
- FTR G - fighter normal acceleration (g's) as measured on-board
- C - indication of radar in coast - N if no, Y if yes
- R - indication of radar in reacquisition when radar is attempting to acquire or about to breaklock - N if no, Y if yes
- ET - elapsed time from start of run for reference to other data.

Explanation of Table 13:
- TIME - for each point of reference data (usually 10 or 20 points per second)
- L - blank if radar was locked on, otherwise an asterisk is placed beside each point during the time the radar was not locked on
- AZIMUTH - target azimuth as output directly from the radar (FCR), target azimuth from the radar rotated into the reference data coordinate system (XFCR), and target azimuth directly from the reference data (REF). The XFCR and REF columns are directly comparable
- ELEVATION - target elevation as output directly from the radar (FCR), target elevation from the radar rotated into the reference data coordinate system (XFCR) and target elevation directly from the reference data (REF). The XFCR and REF columns are directly comparable
- ANGULAR ERROR - resultant angle to target from the radar rotated into the reference data coordinate system (FCR), resultant angle to target from reference data (REF), and the error between the two (ERROR) in degrees and milliradians
- AZR - the radar antenna azimuth rate (not implemented in this example)
- ELR - The radar antenna elevation rate (not implemented in this example)

- LOS and XLOS - target line-of-sight rate (LOS) and target line-of-sight rotated into the reference data coordinate system (XLOS)--both calculated using AZR and ELR as inputs
- RSLTR - resultant angular rate to target from reference data
- LOSACL - target line-of-sight acceleration calculated using AZR and ELR as inputs
- FTR G - fighter normal acceleration (g's) as measured on-board
- C - indication of radar in coast - N if no, Y if yes
- R - indication of radar in reacquisition - N if no, Y if yes
- FCR - radar range to target
- ET - elapsed time from start of run

Explanation of Table 14:
- TIME - for each point of reference data (usually 10 or 20 points per second)
- L - blank if radar was locked on, otherwise an asterisk is placed beside each point during the time the radar was not locked on
- VV - blank if radar indicates target velocity data is valid, otherwise an asterisk if invalid
- VELOCITY MAGNITUDE - target relative velocity magnitude from radar data rotated into the reference data coordinate system (XFCR), target relative velocity magnitude from reference data (REF), and the error between the two (ERROR). If VV indicates radar data is invalid, XFCR and ERROR columns will contain 0.0*
- ANGLE ERROR - the error between the target relative velocity vector from radar data and reference data. If VV indicates radar data is invalid, the column will contain 0.0*
- VA - blank if radar indicates target total acceleration data is valid, otherwise an asterisk if invalid
- ACCEL MAGNITUDE - target total acceleration magnitude from radar data rotated into the reference data coordinate system (XFCR), target total acceleration magnitude from reference data (REF), and the error between the two. If VA indicates radar data is invalid, the XFR and ERROR columns will contain 0.0*
- ANGLE ERROR - the error between the target total acceleration vector from the radar and reference data. If VA indicates radar data is invalid, this column will contain 0.0*
- FTR G - fighter normal acceleration (g's) as measured on-board
- VG - blank if the aircraft indicates g data is valid, otherwise an asterisk beside each point if invalid
- C - indication of radar in coast - N if no, Y if yes
- R - indication of radar in reacquisition - N if no, Y if yes
- FCR - radar range to target
- ET - elapsed time from start of run

TABLE 12 TRACK OUTPUT 1

FLIGHT DATE FLIGHT NO. RUN TYPE TRACK RUN NO. START TIME

TIME HHMMSS.SSS	L	ALT FTR FT	ALT TGT FT	HDG INS DEG	HDG FTR DEG	HDG TGT DEG	VEL FTR FPS	VEL TGT FPS	TGT RANGE FCR FT	TGT RANGE REF FT	TGT RANGE ERROR FT	TGT RDOT FCR FPS	TGT RDOT REF FPS	TGT RDOT ERROR FPS	FTR G	C	R	ET MIN
154616.050		12752.	8477.	91.	87.	185.	449.	380.	83000.	82989.	11.	-483.	-464.	-19.	1.0	Y	N	.800
154616.100		12751.	8478.	91.	86.	184.	449.	382.	82976.	82966.	10.	-483.	-461.	-22.	1.0	Y	N	.801
154616.150		12750.	8479.	91.	86.	184.	449.	383.	82952.	82943.	9.	-481.	-458.	-23.	1.0	Y	N	.802
154616.200		12749.	8480.	91.	86.	183.	449.	385.	82928.	82920.	8.	-480.	-455.	-25.	1.0	Y	N	.802
154616.250		12748.	8481.	91.	86.	183.	450.	386.	82904.	82898.	6.	-479.	-453.	-26.	1.0	Y	N	.803
154616.300		12747.	8482.	91.	86.	183.	450.	388.	82872.	82875.	-3.	-478.	-450.	-28.	1.0	Y	N	.804
154616.350		12747.	8483.	91.	86.	182.	451.	389.	82848.	82853.	-5.	-476.	-448.	-28.	1.0	Y	N	.805
154616.400		12746	8484.	91.	85.	182.	451.	389.	82824.	82830.	-6.	-475.	-447.	-28.	1.0	Y	N	.806
154616.450		12745.	8484.	91.	85.	182.	451.	390.	82800.	82808.	-8.	-475.	-446.	-29.	1.0	Y	N	.807
154616.500		12744.	8484.	91.	85.	182.	452.	390.	82776.	82786.	-10.	-474.	-445.	-29.	1.0	Y	N	.807
154616.550		12743.	8485.	91.	85.	182.	452.	390.	82760.	82763.	-3.	-472.	-444.	-28.	1.0	Y	N	.808
154616.600		12742.	8485.	91.	85.	182.	452.	391.	82736.	82741.	-5.	-472.	-443.	-29.	1.0	Y	N	.809
154616.650		12742.	8486.	91.	85.	181.	452.	391.	82712.	82719.	-7.	-470.	-443.	-27.	1.0	Y	N	.810
154616.700		12741.	8487.	91.	85.	181.	452.	391.	82696.	82697.	-1.	-470.	-442.	-28.	1.0	Y	N	.811
154616.750		12740.	8488.	91.	85.	181.	452.	392.	82664.	82675.	-11.	-469.	-439.	-30.	1.0	Y	N	.812
154616.800		12740.	8488.	91.	86.	180.	452.	392.	82648.	82653.	-5.	-467.	-437.	-30.	1.0	Y	N	.813
154616.850		12740.	8489.	91.	86.	180.	451.	392.	82616.	82631.	-15.	-467.	-433.	-34.	1.0	Y	N	.813
154616.900		12739.	8489.	91.	86.	179.	451.	392.	82608.	32610.	-2.	-465.	-428.	-37.	1.0	Y	N	.814
154616.950		12739.	8490.	91.	86.	179.	450.	392.	82568.	82588.	-20.	-465.	-423.	-42.	1.0	Y	N	.815
154617.000		12738.	8491.	91.	86.	178.	450.	392.	82552.	82567.	-15.	-464.	-419.	-45.	1.0	Y	N	.816
154617.050		12738.	8491.	91.	87.	178.	450.	392.	82528.	82546.	-18.	-463.	-414.	-49.	1.1	Y	N	.817
154617.100		12737.	8492.	91.	87.	177.	450.	392.	82504.	82526.	-22.	-462.	-410.	-52.	1.1	Y	N	.817
154617.150		12737.	8492.	91.	87.	177.	450.	392.	82480.	82506.	-26.	-460.	-407.	-53.	1.1	Y	N	.818
154617.200		12737.	8492.	91.	86.	176.	450.	392.	82464.	82485.	-21.	-460.	-405.	-55.	1.1	Y	N	.819
154617.250		12736.	8492.	91.	86.	176.	450.	392.	82432.	82465.	-33.	-460.	-403.	-57.	1.1	Y	N	.820
154617.300		12736.	8493.	91.	86.	176.	450.	393.	82416.	82445.	-29.	-459.	-400.	-59.	1.1	Y	N	.821
154617.350		12736.	8492.	91.	86.	176.	450.	393.	82392.	82425.	-42.	-458.	-398.	-60.	1.1	Y	N	.822
154617.400		12736.	8492.	91.	86.	175.	449.	394.	82376.	82405.	-38.	-457.	-395.	-62.	1.1	Y	N	.822
154617.450		12736.	8493.	91.	86.	175.	449.	394.	82344.	82386.	-50.	-456.	-394.	-62.	1.1	Y	N	.823
154617.500		12736.	8493.	91.	87.	175.	448.	395.	82328.	82366.	-47.	-456.	-393.	-63.	1.1	Y	N	.824
154617.550		12735.	8493.	91.	87.	175.	448.	396.	82296.	82347.	-51.	-454.	-392.	-62.	1.1	Y	N	.825
154617.600		12735.	8493.	91.	87.	175.	447.	396.	82280.	82327.	-47.	-454.	-390.	-64.	1.1	Y	N	.826
154617.650		12735.	8493.	91.	87.	175.	446.	396.	82256.	82307.	-51.	-453.	-389.	-64.	1.1	Y	N	.827
154617.700		12735.	8494.	91.	87.	174.	446.	396.	82240.	82288.	-48.	-453.	-386.	-67.	1.1	Y	N	.827
154617.750		12735.	8494.	91.	87.	174.	445.	395.	82208.	82269.	-61.	-451.	-383.	-68.	1.1	Y	N	.828
154617.800		12735.	8494.	91.	87.	174.	445.	395.	82192.	82249.	-57.	-450.	-380.	-70.	1.1	Y	N	.829
154617.850		12735.	8494.	91.	87.	173.	444.	395.	82168.	82231.	-63.	-450.	-376.	-74.	1.1	Y	N	.830
154517.900		12734.	8494.	91.	87.	173.	444.	394.	82144.	82212.	-68.	-449.	-372.	-77.	1.1	Y	N	.831
154617.950		12734.	8495.	92.	87.	172.	443.	393.	82128.	82193.	-65.	-448.	-369.	-79.	1.1	Y	N	.832
154618.000		12734.	8495.	92.	87.	172.	442.	392.	82104.	82175.	-71.	-447.	-365.	-82.	1.1	Y	N	.832

TABLE 13 TRACK OUTPUT 2

FLIGHT DATE FLIGHT NO. RUN TYPE TRACK RUN NO. START TIME

TIME HHMMSS.SSS	L AZIMUTH FCR DEG	AZIMUTH XFCR DEG	AZIMUTH REF DEG	ELEVATION FCR DEG	ELEVATION XFCR DEG	ELEVATION REF DEG	ANGULAR ERROR FCR DEG	ANGULAR ERROR REF DEG	ANGULAR ERROR ERROR DEG	ANGULAR ERROR ERROR MILS	AZR DEG/S	ELR DEG/S	LOS DEG/S	XLOS DEG/S	RSLTR DEG/S	LOSACL D/S*2	FTR G	C	R	FCR	ET MIN
154613.050	.5	-4.6	-4.6	-10.0	-.9	-.7	4.7	4.6	.13	2.3	0.	0.	0.	1.	1.	0.	1.0	N	N	84600.	.75
154613.100	.5	-4.7	-4.6	-10.1	-1.0	-.6	4.8	4.7	.13	2.3	0.	0.	0.	2.	2.	0.	1.0	N	N	84568.	.75
154613.150	.5	-4.8	-4.7	-10.1	-.9	-.6	4.9	4.8	.13	2.3	0.	0.	0.	2.	2.	0.	1.0	N	N	84536.	.75
154613.200	.5	-5.0	-4.9	-10.1	-.9	-.6	5.1	4.9	.12	2.0	0.	0.	0.	3.	3.	0.	1.0	N	N	84512.	.75
154613.250	.5	-5.2	-5.1	-10.1	-.9	-.6	5.3	5.2	.09	1.5	0.	0.	0.	3.	3.	0.	1.0	N	N	84456.	.75
154613.300	.5	-5.3	-5.3	-10.2	-1.0	-.6	5.4	5.3	.09	1.6	0.	0.	0.	3.	3.	0.	1.0	N	N	84432.	.75
154613.350	.5	-5.5	-5.5	-10.2	-1.0	-.6	5.6	5.5	.11	1.9	0.	0.	0.	3.	3.	0.	1.0	N	N	84400.	.75
154613.400	.5	-5.6	-5.6	-10.2	-1.0	-.6	5.7	5.7	.07	1.3	0.	0.	0.	2.	2.	0.	1.0	N	N	84384.	.75
154613.450	.5	-5.8	-5.7	-10.3	-1.1	-.6	5.9	5.8	.03	2.0	0.	0.	0.	1.	1.	0.	1.0	N	N	84328.	.76
154613.500	.5	-5.7	-5.7	-10.3	-1.1	-.6	5.8	5.8	.05	1.2	0.	0.	0.	0.	0.	0.	1.0	N	N	84304.	.76
154613.550	.5	-5.7	-5.8	-10.3	-1.1	-.6	5.8	5.8	.03	.5	0.	0.	0.	-1.	-1.	0.	1.0	N	N	84272.	.76
154613.600	.5	-5.7	-5.7	-10.3	-1.0	-.5	5.8	5.7	-.01	.8	0.	0.	0.	-2.	-1.	0.	1.0	N	N	84248.	.76
154613.650	.5	-5.5	-5.6	-10.3	-.9	-.5	5.6	5.6	-.02	.5	0.	0.	0.	-2.	-2.	0.	1.0	N	N	84232.	.76
154613.700	.5	-5.4	-5.5	-10.3	-.9	-.4	5.5	5.5	.01	-.1	0.	0.	0.	-3.	-2.	0.	1.0	N	N	84208.	.76
154613.750	.5	-5.2	-5.3	-10.2	-.8	-.3	5.3	5.3	-.07	-.3	0.	0.	0.	-3.	-2.	0.	1.0	N	N	84168.	.76
154613.800	.5	-5.1	-5.2	-10.2	-.7	-.3	5.2	5.2	-.06	.1	0.	0.	0.	-2.	-2.	0.	1.0	N	N	84152.	.76
154613.850	.5	-4.9	-5.0	-10.2	-.7	-.3	5.0	5.1	-.04	-1.1	0.	0.	0.	-1.	-1.	0.	1.0	N	N	84120.	.76
154613.900	.5	-4.9	-5.0	-10.2	-.8	-.3	4.9	5.0	.03	-1.1	0.	0.	0.	-0.	-1.	0.	1.0	N	N	84080.	.76
154613.950	.5	-4.8	-5.0	-10.3	-1.0	-.4	4.9	5.0	.05	-.7	0.	0.	0.	1.	0.	0.	1.0	N	N	84064.	.76
154614.000	.6	-4.9	-5.0	-10.2	-1.0	-.5	5.0	5.0	.03	.6	0.	0.	0.	2.	1.	0.	1.0	N	N	84048.	.76
154614.050	.6	-5.0	-5.1	-10.2	-1.2	-.6	5.2	5.1	.05	.8	0.	0.	0.	2.	2.	0.	1.0	N	N	84008.	.77
154614.100	.6	-5.2	-5.2	-10.3	-1.4	-.8	5.4	5.3	.13	2.2	0.	0.	0.	3.	2.	0.	1.0	N	N	83984.	.77
154614.150	.6	-5.3	-5.4	-10.3	-1.5	-.9	5.5	5.5	.07	1.3	0.	0.	0.	3.	3.	0.	1.0	N	N	83952.	.77
154614.200	.6	-5.4	-5.5	-10.3	-1.7	-1.1	5.7	5.6	.07	1.3	0.	0.	0.	3.	3.	0.	1.0	N	N	83920.	.77
154614.250	.6	-5.5	-5.6	-10.2	-1.8	-1.3	5.8	5.8	.07	1.2	0.	0.	0.	2.	2.	0.	1.0	N	N	83888.	.77
154614.300	.6	-5.6	-5.7	-10.2	-1.9	-1.4	6.0	5.9	.07	1.3	0.	0.	0.	2.	2.	0.	1.0	N	N	83864.	.77
154614.350	.5	-5.7	-5.8	-10.1	-2.0	-1.5	6.0	6.0	.06	1.1	0.	0.	0.	1.	1.	0.	1.0	N	N	83840.	.77
154614.400	.6	-5.7	-5.8	-10.1	-2.1	-1.6	6.1	6.0	.06	1.0	0.	0.	0.	1.	0.	0.	1.0	N	N	83824.	.77
154614.450	.6	-5.7	-5.8	-10.1	-2.2	-1.7	6.1	6.0	.07	1.2	0.	0.	0.	-0.	-0.	0.	1.0	N	N	83800.	.77
154614.500	.6	-5.6	-5.7	-10.1	-2.3	-1.7	6.0	6.0	.07	1.2	0.	0.	0.	-1.	-1.	0.	1.0	Y	N	83784.	.77
154614.550	.6	-5.5	-5.6	-10.2	-2.4	-1.7	6.0	5.9	.12	2.1	0.	0.	0.	-1.	-1.	0.	1.0	Y	N	83752.	.78
154614.600	.6	-5.4	-5.5	-10.2	-2.4	-1.7	5.9	5.8	.10	1.8	0.	0.	0.	-1.	-1.	0.	1.0	Y	N	83728.	.78
154614.650	.6	-5.3	-5.4	-10.2	-2.4	-1.8	5.8	5.7	.12	2.0	0.	0.	0.	-1.	-1.	0.	1.0	Y	N	83696.	.78
154614.700	.6	-5.2	-5.4	-10.3	-2.4	-1.7	5.8	5.6	.11	2.0	0.	0.	0.	-0.	-0.	0.	1.0	Y	N	83680.	.78
154614.750	.6	-5.2	-5.3	-10.2	-2.3	-1.8	5.7	5.6	.09	1.5	0.	0.	0.	0.	0.	0.	1.0	Y	N	83648.	.78
154614.800	.6	-5.2	-5.4	-10.3	-2.5	-1.8	5.8	5.6	.13	2.3	0.	0.	0.	1.	1.	0.	1.0	Y	N	83624.	.78

TABLE 14 TRACK OUTPUT 3

FLIGHT DATE FLIGHT NO. RUN TYPE TRACK RUN NO. START TIME

TIME HHMMSS.SSS	L V V	VELOCITY MAGNITUDE XFCR FPS	VELOCITY MAGNITUDE REF FPS	VELOCITY MAGNITUDE ERROR FPS	ANGLE ERROR DEG	V A	ACCEL MAGNITUDE XFCR FPS*2	ACCEL MAGNITUDE REF FPS*2	ACCEL MAGNITUDE ERROR FPS*2	ANGLE ERROR DEG	F-16 G G	V G	C	R	FCR FT	ET MIN
154613.050		756.8	709.6	47.2	9.4		20.1	36.2	-16.1	62.2	1.0		N	N	84600.	.75
154613.100		752.2	709.0	43.2	8.7		20.1	27.8	-7.7	58.5	1.0		N	N	84568.	.75
154613.150		747.7	708.8	38.9	8.2		21.1	22.5	-1.4	50.4	1.0		N	N	84536.	.75
154613.200		742.2	709.2	33.0	7.6		21.1	21.1	-.0	39.4	1.0		N	N	84512.	.75
154613.250		733.5	709.4	24.1	6.5		21.1	23.3	-2.2	30.3	1.0		N	N	84456.	.75
154613.300		730.1	708.8	21.3	6.1		21.1	28.6	-7.5	26.3	1.0		N	N	84432.	.75
154613.350		723.9	708.2	15.7	5.3		21.1	35.9	-14.8	27.2	1.0		N	N	84400.	.75
154613.400		723.8	707.2	16.6	5.4		21.1	43.1	-22.0	29.3	1.0		N	N	84384.	.76
154613.450		721.4	705.5	15.8	5.3		21.1	48.9	-27.8	30.9	1.0		N	N	84328.	.76
154613.500		720.0	703.3	16.7	5.3		21.1	53.2	-32.1	33.1	1.0		N	N	84304.	.76
154613.550		717.3	701.0	16.3	5.8		20.1	55.7	-35.6	35.2	1.0		N	N	84272.	.76
154613.600		716.5	698.1	18.4	6.3		19.0	55.7	-36.6	34.1	1.0		N	N	84248.	.76
154613.650		716.8	695.1	21.7	7.0		18.0	53.9	-35.9	35.2	1.0		N	N	84232.	.76
154613.700		717.3	692.5	24.0	7.9		18.0	51.3	-33.3	35.3	1.0		N	N	84208.	.76
154613.750		718.5	690.2	28.3	8.6		16.0	48.3	-32.3	35.1	1.0		N	N	84168.	.76
154613.800		719.4	688.1	31.3	9.5		16.0	45.4	-29.3	33.1	1.0		N	N	84152.	.76
154613.850		722.7	686.3	36.4	11.2		15.0	43.3	-28.3	31.6	1.0		N	N	84120.	.76
154613.900		725.1	685.1	40.0	12.2		14.0	41.8	-27.7	30.0	1.0		N	N	84080.	.76
154613.950		726.6	684.3	42,3	13.0		13.0	41.3	-28.3	28.7	1.0		N	N	84064.	.76
154614.000		728.7	683.9	44.8	13.8		12.0	41.2	-29.1	27.5	1.0		N	N	84048.	.77
154614.050		731.4	683.9	47.5	14.5		12.0	41.3	-29.3	27.0	1.0		N	N	84008.	.77
154614.100		733.0	684.1	48.9	15.3		12.0	41.7	-29.7	26.0	1.0		N	N	83984.	.77
154614.150		736.8	684.1	52.6	16.6		10.0	41.7	-31.7	25.8	1.0		N	N	83952.	.77
154614.200		738.3	684.2	54.1	17.2		10.0	42.0	-32.0	25.4	1.0		N	N	83920.	.77
154614.250		739.7	684.4	55.4	17.7		9.1	42.0	-33.0	23.5	1.0		N	N	83888.	.77
154614.300		741.2	684.0	57.2	18.3		9.1	42.4	-33.4	21.3	1.0		N	N	83864.	.77
154614.350		742.5	683.6	58.9	18.7		9.1	43.2	-34.2	19.6	1.0		N	N	83840.	.77
154614.400		743.9	682.5	61.4	19.2		8.1	43.3	-35.2	18.4	1.0		N	N	83824.	.77
154614.450		746.6	681.2	65.3	20.1		8.1	42.2	-34.1	18.6	1.0		N	N	83800.	.77
154614.500		746.6	679.8	66.8	20.1		8.1	40.6	-32.6	20.3	1.0		Y	N	83784.	.77
154614.550		747.7	678.3	69.4	20.9		8.1	39.3	-31.2	24.4	1.0		Y	N	83752.	.78
154614.600		748.8	676.8	71.9	21.3		8.1	39.1	-31.0	29.3	1.0		Y	N	83728.	.78
154614.650		748.4	675.3	73.1	22.0		8.1	40.7	-32.6	35.3	1.0		Y	N	83696.	.78
154614.700		747.7	673.9	73.8	22.2		8.1	46.8	-35.7	40.6	1.0		Y	N	83680.	.78
154614.750		747.8	672.5	75.3	22.6		8.1	48.0	-39.9	44.1	1.0		Y	N	83648.	.78
154614.800		746.3	671.4	74.9	22.9		8.1	52.0	-44.0	46.5	1.0		Y	N	83624.	.78

Two means of tabulating track accuracies are shown in tables 15 and 16. Variations can be made, depending on the radar application and the analyst's prime areas of interest.

Explanation of Table 15:

- ANGLE ERROR ANALYSIS - statistical analysis of radar target angular error for low, medium and high LOS angle and LOS rate conditions (as pre-defined in the radar requirements). Each category has the number of points analyzed, the mean and standard deviation of the errors, interval (the lower and upper bounds of the confidence level used), and the percentage of points within one, two and three sigma (to give an indication of the validity of the mean and standard deviation calculations--this can also be indicated as skewness and kurtosis as in Table 16).
- RANGE ERROR ANALYSIS - statistical analysis of radar target range error at short range (less than a predetermined range) and long range (greater than a predetermined range). Each category has the number of points analyzed, the mean and standard deviation of the errors (can be in units of feet for short range and a percentage of range for long range), interval (the lower and upper bounds of the confidence level used), and the percentage of points within one, two and three sigma
- RELATIVE TARGET VELOCITY VECTOR - statistical analysis of radar relative target velocity vector error for short and long target ranges. Each category has the number of points analyzed, the mean and standard deviation of the magnitude (units of feet per second (FPS) at short range and a percentage of range at long range) and angle errors, interval (the lower and upper bounds of the confidence level used), and the percentage of points within one, two and three sigma
- TOTAL TARGET ACCELERATION VECTOR - statistical analysis of radar total target acceleration vector error for short and long target ranges. Each category has the number of points analyzed, the mean and standard deviation of the magnitude (units of FPS squared at short range and a percentage of range at long range) and angle errors, interval (the lower and upper bounds of the confidence level used), and the percentage of points within one, two and three sigma

Explanation of Table 16:

- RANGE - the radar target range error--both in terms of slant range, and the individual X, Y, and Z components. Each category has listed the mean and standard deviation in units of feet and in percent of range, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis (to give an indication of the validity of the mean and standard deviation calculations)
- ANGLE - the mean and standard deviation of radar target LOS angle accuracy in units of mils, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis. The two letters in the LOS column (ML, HL and HM) are for the various categories of maneuvers, with the first letter indicating the angle and the second the rate (i.e., ML is medium LOS angle and low LOS rate, HL is high LOS angle and low LOS rate, and HM is high LOS angle and medium LOS rate)
- ELEVATION - the elevation component of the ANGLE accuracy, with the same type of data as for ANGLE
- AZIMUTH - the azimuth component of the ANGLE accuracy, with the same type of data as for ANGLE
- RANGE RATE - the mean and standard deviation (in units of FPS) of the radar target range rate, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis
- VELOCITY - the overall magnitude and the individual X, Y, and Z components of the radar target velocity error. Each category has listed the mean and standard deviation in units of feet per second and in percent of velocity, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis
- ACCELERATION - the radar target acceleration error--both in terms of the magnitude and the individual X, Y, and Z components. Each category has listed the mean and standard deviation in units of feet per second squared and in percent of acceleration, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis
- HEADING - the mean and standard deviation of the radar target heading error in degrees, interval (the lower and upper bounds of the confidence level used), the number of samples, the skewness and kurtosis

Table 15 Track Output 4

FLIGHT DATE	FLIGHT NO.	RUN TYPE	RUN NO.	START TIME	TOTAL TIME
		TRACK			1.181

ANGLE ERROR ANALYSIS

LOW LOS							MED LOS							HIGH LOS						
PTS	MEAN MILS	STDEV MILS	INTERVAL MILS	1SIG PCT	2SIG PCT	3SIG PCT	PTS	MEAN MILS	STDEV MILS	INTERVAL MILS	1SIG PCT	2SIG PCT	3SIG PCT	PTS	MEAN MILS	STDEV MILS	INTERVAL MILS	1SIG PCT	2SIG PCT	3SIG P
619	1.6	2.7	0.7TO2.1	72.86	94.35	98.71	793	4.4	3.4	2.1TO5.7	74.31	94.01	99.00	0	0.0	0.0	0.0TO0.0	0.00	0.00	0.00

RANGE ERROR ANALYSIS

SHORT RANGE						
PTS	MEAN FT	STDEV FT	INTERVAL FT	1SIG PCT	2SIG PCT	3SIG PCT
0	0.	0.	0.TO 0.	0.00	0.00	0.00

LONG RANGE						
PTS PCT	MEAN PCT	STDEV PCT	INTERVAL PCT	1SIG PCT	2SIG PCT	3SIG PCT
1417	-.0	.1	-.1TO.1	89.98	97.74	98.24

RELATIVE TARGET VELOCCITY VECTOR ERROR ANALYSIS

SHORT RANGE

MAGNITUDE						
PTS	MEAN FPS	STDEV FPS	INTERVAL FPS	1SIG PCT	2SIG PCT	3SIG PCT
0	0.	0.	0.TO 0.	0.0	0.0	0.0

ANGLE						
PTS	MEAN DEG	STDEV PCT	INTERVAL PCT	1SIG PCT	2SIG PCT	3SIG PCT
0	0.0	0.0	0.TO 0.	0.0	0.0	0.9

LONG RANGE

MAGNITUDE						
PTS	MEAN FPS	STDEV FPS	INTERVAL FPS	1SIG PCT	2SIG PCT	3SIG PCT
1370	.046	.130	.017TO.170	74.5	94.4	97.6

ANGLE						
PTS	MEAN DEG	STDEV PCT	INTERVAL PCT	1SIG PCT	2SIG PCT	3SIG PCT
1370	31.2	29.0	18.1TO 57.3	85.9	95.4	96.6

TOTAl TARGET ACCELERATION VECTOR ERROR ANALYSIS

SHORT RANGE

MAGNITUDE						
PTS	MEAN FPS	STDEV FPS	INTERVAL FPS	1SIG PCT	2SIG PCT	3SIG PCT
0	0.	0.	0.TO 0.	0.0	0.0	0.0

ANGLE						
PTS	MEAN DEG	STDEV PCT	INTERVAL PCT	1SIG PCT	2SIG PCT	3SIG PCT
0	0.0	0.0	0.0TO 0.0	0.0	0.0	0.0

LONG RANGE

MAGNITUDE						
PTS	MEAN FPS	STDEV FPS	INTERVAL FPS	1SIG PCT	2SIG PCT	3SIG PCT
1300	-.48	.027	-.058TO-.013	76.1	94.8	97.5

ANGLE						
PTS	MEAN DEG	STDEV PCT	INTERVAL PCT	1SIG PCT	2SIG PCT	3SIG PCT
1300	63.0	31.9	49.2TO80.9	66.2	96.5	99.8

NOTE: PTS IS POINTS.

TABLE 16 TRACK OUTPUT 5

FLIGHT DATE FLIGHT NO. RUN NO. START TIME END TIME TOTAL TIME

RANGE TRACK MODE	RANGE	MEAN (FT) (PCT)	STDEV (FT) (PCT)	INTERVAL (FT) (PCT)	SAMPLES	SKEWNESS	KURTOSIS
	SLANT						
	X						
	Y						
	Z						
ANGLE TRACK MODE	LOS	MEAN (MILS)	STDEV (MILS)	INTERVAL (MILS)	SAMPLES	SKEWNESS	KURTOSIS
	ML						
	HL						
	HM						
ELEVATION TRACK MODE	LOS	MEAN (MILS)	STDEV (MILS)	INTERVAL (MILS)	SAMPLES	SKEWNESS	KURTOSIS
	ML						
	HL						
	HM						
AZIMUTH TRACK MODE	LOS	MEAN (MILS)	STDEV (MILS)	INTERVAL (MILS)	SAMPLES	SKEWNESS	KURTOSIS
	ML						
	HL						
	HM						
RANGE RATE TRACK MODE	DERIVED	MEAN (FPS)	STDEV (FPS)	INTERVAL (FPS)	SAMPLES	SKEWNESS	KURTOSIS
	DOPPLER						
VELOCITY TRACK MODE	VELOCITY	MEAN (FPS) (PCT)	STDEV (FPS) (PCT)	INTERVAL (FPS) (PCT)	SAMPLES	SKEWNESS	KURTOSIS
	MAG						
	X						
	Y						
	Z						
ACCELERATION TRACK MODE	ACCEL	MEAN (FPS2) (PCT)	STDEV (FPS2) (PCT)	INTERVAL (FPS2) (PCT)	SAMPLES	SKEWNESS	KURTOSIS
	MAG						
	X						
	Y						
	Z						
HEADING		MEAN (DEG)	STDEV (DEG)	INTERVAL (DEG)	SAMPLES	SKEWNESS	KURTOSIS

Typically, plots of acquisition and track data are made of each parameter (such as range error) versus elapsed time (of the track run) and versus target range. Both are helpful in analysis - elapsed time to note when significant events occurred (such as designate, coast, reacquisition, or start and end of ECM), and range to note any effects on the errors with respect to target range. Radar track data normally plotted includes: accuracy of a/a track range, range rate, acceleration, angle, elevation, azimuth and heading. Figure 5 is a typical plot for track acquisition time analysis and Figure 6 is a typical plot for track accuracy analysis.

Explanation of Figure 5:
- The plot time starts at the time of pilot designate (commanding lock-on)
- Two errors are plotted on the upper half - range error and range rate error versus time
- The lower portion of the plot indicates events. In this case, the first line (DESIG) indicates designate has occurred, the second line (REACQ) indicates the radar is not in reacquisition, and the third line (COAST) indicates the radar is not in coast
- The fourth through sixth lines are to analyse time to stable track. All three are set up so that the line will indicate when that error (RC for range error, LOSC for LOS angle error and RRC for range rate error) is within the two sigma value of its steady-state accuracy requirement. Since time to stable track can be defined as when all three of these parameters are within two sigma, this plot will then show when that happens

Explanation of Figure 6:
- The plot time starts at the time of pilot designate (commanding lock-on)
- Two errors are plotted on the upper half - range error and range rate error versus time
- The lower portion of the plot indicates events. In this case, the first line (ENTER) shows when the radar entered track (the circled dot), the second line (DESIG) indicates when designate occurred (the circled dot), the third line (REACQ) indicates the radar is not in reacquisition, and the fourth line (COAST) indicates the radar is not in coast. The last four lines can be used to indicate any other significant events, as applicable.

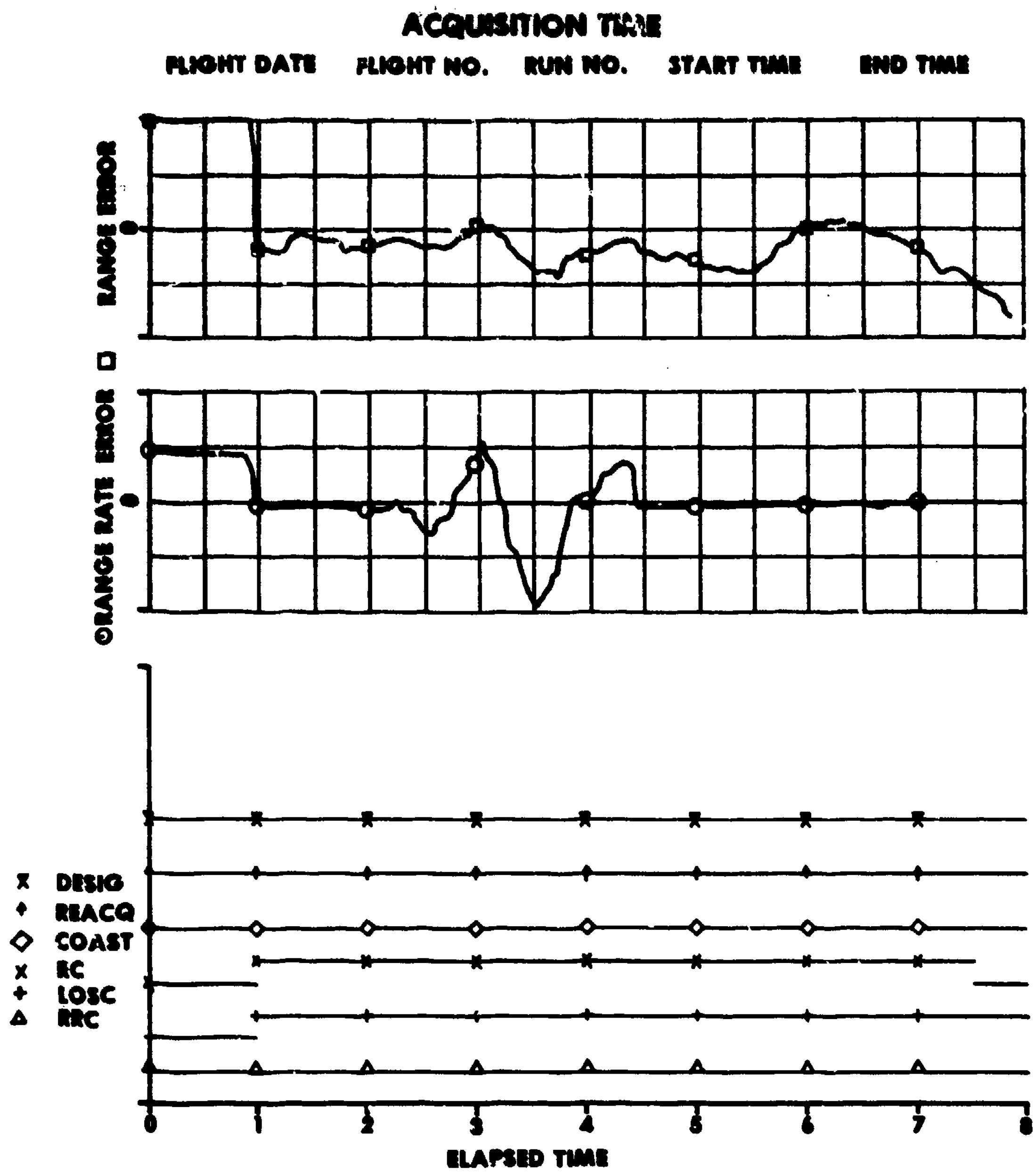


Figure 5 Acquisition Time Analysis

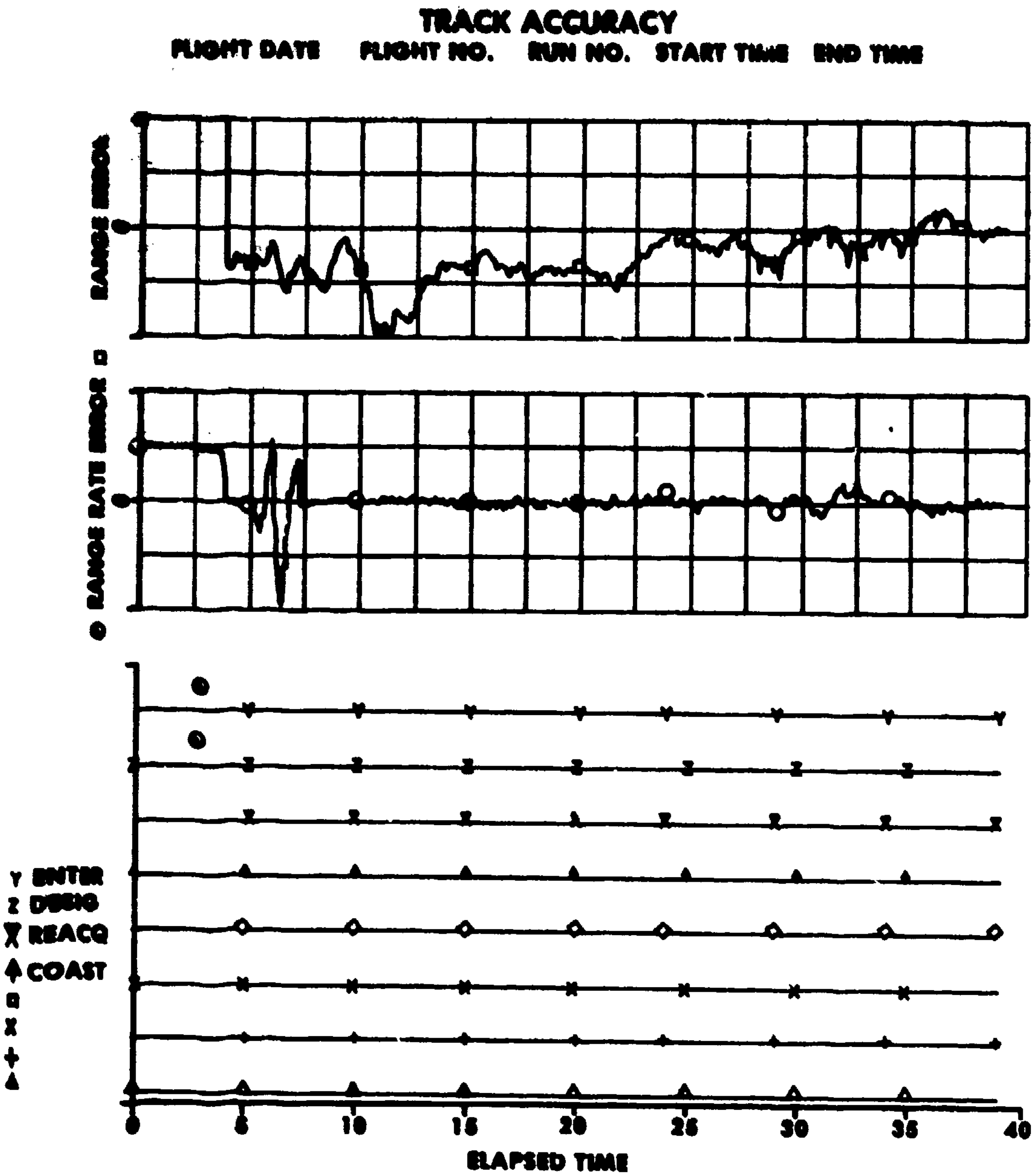


Figure 6 Track Accuracy Analysis

Some track analysis results do not require unique tabular or plot formats, but can be organized and presented as the author sees fit or customer desires. Typically, tracking results (both DT&E and OT&E) could be tabulated to show:

- Maximum lock-on range (for both manual and automatic acquisition)
- Time to stable track (for both manual and automatic acquisition)
- Manual acquisition ability (such as in a 2v2 engagement) - the pilot's ability to lock on to the assigned target. The result could be expressed in terms of percentage of times the pilot caused the radar to lock on to the correct target, but is also highly subjective with respect to the ease and utility of doing so
- Frequency of successful lock-ons - the percent of successful lock-ons (not false) out of the total number of lock-on attempts. A criteria should be established when to have the pilot attempt a lock-on such as: when three or more target detections have been displayed
- Percent of successful tracks, i.e., radar did not break lock
- Percent of time auto acquisition locked on to the correct target in a multiple target environment
- Angle at which track transfer occurred when in STT in a multiple target crossing maneuver

Track analysis for TWS will generally use the same (or slightly modified) accuracy analysis methods and formats as previously described for single target detection, acquisition and track. Some additional analysis will include the automatic lock-on false alarm rate (the radar falsely declared a target was present based on incorrectly correlating detections, and started tracking it), target maximum detection range, track file initiation range, maximum lock-on range, and acquisition time.

9 REPORTING

This section contains a brief description of what the reporting requirements should be for a/a radar flight testing. Report requirements can include status reports made throughout the test program, service reports to formally identify performance anomalies, and final reports which present an overall evaluation of the radar system performance. The report requirements (what the test "customer" wants to see) should be the starting point for test planning, and will often dictate the course of the entire test program. The final report can be used to provide information to help design the aircraft or weapons simulator, provide information on system performance, deficiencies and suggested improvements, and be an historical document for comparisons with future test programs. Much of the discussion in the many reviews of a report before it is distributed centers around the reviewers' perception of the reader's technical level and for what purpose the information will be used (e.g., to design a simulator, to make production decisions, or for further research and development). A good test program will have the report format and methodology prepared before the start of the test program, often in a printed guide, as well as a defined timetable for preparation and approval. This should also include a proposed distribution list, again in order to better target the report to the appropriate readers. Proper emphasis should be put on the necessity of a final report, since the urge often exists to reassign the flight test personnel at the end of the testing, before an adequate report is prepared. Typically, DT&E and OT&E reports will be published separately, due to the major differences in test objectives, methods, and results. It is essential that the report give a balanced overview of radar system performance, as there is a natural tendency to focus on the details of problem areas. While detailed coverage of problems is necessary to help the decision process for fixing or accepting them, the report should give an overview which emphasizes the positive features as well as any negative ones.

Substantive quick look reports to verify the validity of the data obtained should be required shortly after each mission or major test event. These reports can provide timely feedback regarding qualitative system performance, and quantitative instrumentation performance to avoid testing with instrumentation problems. Timely and effective feedback is required to permit assessment of test progress and diagnosis of system problems in order to provide the customer with the most current and accurate information possible. Quick look and status reports should be constructed so as not to present only a small portion of the testing out of context, but should provide the correct audience with test status and results that are put in the proper context of the stage of radar system development or maturity.

Careful tracking of radar performance anomalies is extremely important throughout the entire test program. Initial indications of anomalies (sometimes called watch items) can be kept in a data base in order to help determine if it was a one-time occurrence, or if there is a pattern or trend developing. This data base (as further explained in section 3.7) can be very useful to recall information in order to write a service report, and can also be used to track and prioritize proposed fixes. Service reports (also called deficiency reports, avionics problem reports or software deficiency reports) serve to formally identify, evaluate and track system deficiencies which may adversely impact the performance capability or operational suitability and supportability of the radar system. Early identification of these deficiencies is very important. This allows decisions on fixes to be made and any corrections to be tested prior to program decision milestones. Both watch items and service reports can be written whether the anomaly is in the hardware or software. In fact, the source or cause may not be apparent when the anomaly is detected and the service report written. Service reports can be categorized with respect to the urgency of needed corrective action and with respect to safety impacts. Typically, the radar flight test engineers will initiate service reports, whereas the program management agency will conduct the reporting program and will direct the radar system designer to correct the problem as necessary. Once a correction has been made, the designer will explain it and its impact to the testers, and the testers will then plan and conduct tests to verify the problem has been corrected and the solution has not adversely affected other radar modes or capabilities. A typical service report should address:

- Detailed description of what happened
- Description of what radar functions or modes are affected
- The specific part numbers or software release number (to include any software "patches")
- Any resultant test restrictions which should be imposed until a resolution is found
- Any suggestions on how to correct the anomaly (this is optional and usually requires considerable knowledge of the system design)

After the service report is processed, it should then contain:

- An explanation of why the anomaly occurred
- Resolution (either a detailed description of the corrective action taken and the verification completed, or an explanation of why no action was taken)
- Recommendations for further testing, as applicable (lab, ground or flight)
- Closing status (whether now closed, or to be closed pending further action)

Any radar test restrictions imposed as a result of a service report (such as not using a particular mode or capability) should be part of the preflight briefings and annotated on the run cards for any hardware/software configuration to which it pertains.

A typical a/a radar final report should include the following subjects (not necessarily in the exact order shown):

- Preface: relationship of this report to other reports and other work in progress
- Executive Summary: a summary of the report with a brief description of the objectives, testing accomplished, conclusions and recommendations
- Table of Contents
- List of Illustrations
- List of Tables
- Introduction
    - Background: historical information such as: if other applicable tests preceded this one, why this test program was accomplished, who asked for it, authorized it and directed it
    - General: which test plan(s) are covered by this report, who were the test participants, what test phases were accomplished, tests planned versus actual tests accomplished, total missions flown, significant milestones, critical issues and questions
    - Test Objectives: whether objectives were completed and if not, why not
    - Test Limitations: any limitations which precluded testing
    - Test Item Description: brief description of the vehicle which carried the tested radar system, brief description of the tested radar including the configurations used (refer to an appendix for a detailed description), brief description of the instrumentation system (refer to a reference document or an appendix for a detailed description)
- Test and Evaluation (usually covered by mode, i.e., one subsection per mode with each subsection including):
    - Specific Test Objective(s)
    - Mode Description (brief)
    - Test Description: how the mode was tested, what was done, how data was obtained
    - Test Results: summaries of mode performance (refer to an appendix for run-by-run data, if necessary to be in the report at all); what worked and what did not; findings and analysis of the findings; presentations of summary tables, charts, plots and pictures as applicable; include not just final results, but also confidence levels and tolerances involved in the data; draw conclusions and make recommendations as appropriate; discuss need for further testing (if required); reference applicable service reports
- Conclusions and Recommendations: compilation of all significant conclusions and recommendations made in the body of the report
- References: applicable documents such as the Required Operational Capability, the aircraft flight manual, the system specification or design requirements and objectives, any temporary operating limitations, the configuration description, and any other appropriate technical publications or other published reports
- Appendices (may contain some or all of the following, as necessary depending on customer desires and readers being addressed):
    - Detailed Radar Description and Configuration Summary
    - Instrumentation System Description
    - Cockpit Controls and Displays
    - Test Profiles
    - Sortie/Mission Summary
    - Data Reduction Methods
    - Detailed Test Results and Data
    - Summaries of Service Reports
- List of Abbreviations and Symbols
- Distribution List

The more automated the radar status tracking and data analysis systems are, the more automated the report preparation can be. For example, if the analysis routines can process multiple runs from multiple flights and output summary data in a report-ready format, much time will be saved when it comes time to prepare the final report. An operational final report can also contain test results with respect to the intended operational environment, and recommend improvements (as applicable) by addressing benefits versus cost. Some results may be stated in different terms--such as concluding that a radar mode is effective inside a particular range and azimuth combination, and is not usable outside this combination. An operational report is not only required to provide information for program decisions, but should also be readable by the typical operational pilot to allow him to get the best possible performance from the system.

10. CONSIDERATIONS FOR THE FUTURE

This section is an estimate of the impacts on future a/a radar flight testing as a result of radar and weapons systems advances. It is not an in-depth survey of all possible future radar technologies. These advances may be the result of specific pre-planned product improvement (P^3I) programs or technology advances such as in the area of increased radar digital system memory and processing speeds. One of the problems that can surface is the radar system (especially the processing memory and capability) may not have been sized in the original design to readily accept improvements (whether pre-planned or not). This can necessitate substantial retest or additional tests to ensure the new implementation (which may have been accomplished using shortcuts to "squeeze in" the changes or improvements) has not adversely affected the entire radar system operation. The topics presented in this section are not in chronological order nor are they prioritized, since it is difficult to predict when and on what systems they will be incorporated.

The next generation of a/a radars will probably have all solid-state electronically-scanned phased-array antennas containing anywhere from 1,000 to 3,000 individual active elements. These elements would each be an active aperture with a low-noise amplifier, and would combine transmit/receive, phase shifters and antenna all in one unit. As a part of the substantial improvements in reliability and maintainability, this type of radar design will also result in graceful degradation of radar system performance (i.e., a number of elements can fail while the radar remains fully capable, and failure of even more elements will not necessarily render the radar inoperable, but will only decrease performance). Graceful degradation will require even greater and more in-depth instrumentation capabilities in order to measure the remaining radar performance, and to determine what elements have failed. Graceful degradation will also impose requirements to identify to the crew current in-flight radar capabilities through ST/BIT, and may cause changes in the way faults are detected, reported, isolated and corrected after the flight.

Another future a/a radar implementation will have a single shared aperture (multi-function array) for multiple sensors such as radar, electronic support measures, electronic countermeasures, IFF and communications systems. This sharing may have to be limited over some narrow parameters, but will surely increase the possibilities of electromagnetic interference when more than one system is in operation simultaneously. Testing will require providing more complex stimulus (such as a threat to cause the ECM system to respond) during radar system test conditions in order to be able to realistically measure radar performance. The single aperture configuration will likely give way to multiple conformal antennas shared with multiple avionics systems, mounted at many locations around the aircraft to give up to 360-degree visibility. This will naturally vastly increase the amount of flight time required to check radar performance as compared to that now required for the typical current radar coverage of 120 degrees. Many more multiple target scenarios will be required, since the radar processing to detect and acquire multiple targets at all azimuths will be highly exercised. If the radar is composed of multiple phased array antennas, its ability to track while transitioning among the multiple antennas in azimuth and elevation will need to be evaluated, as well as its track accuracies at different angles with respect to the fighter.

Bistatic a/a radar systems will require a larger test arena since the transmitter and receiver are no longer collocated. Also, the RCS of the target is harder to determine and control in a bistatic situation, and may need to be measured prior to use. It also may be more difficult to extrapolate the test results to obtain estimated performance versus an actual threat, depending on the complexity of the target and threat shapes. A millimeter wave a/a radar system will most likely be a cued system (receive target pointing commands from another on-board or external source) since it will likely have a narrower field of view, and a narrow beam. Since it will also be of smaller physical size, it may be located at other than typical current aircraft radar installations, and there may be multiple radar systems installed on one aircraft. This multiple azimuth visibility will impose changes in test methods as previously described for the multiple conformal arrays.

Advances in system processing can result in the capability of a single radar system having 30 or more radar operating modes, with the likelihood that modes will begin overlapping. Required data rates, word size, and processing speeds will also grow. Higher resolution and faster analog-to-digital converters will increase potential radar range resolution as well as distant target detection. Programmable signal processors employing very large scale integrated circuits will be incorporated, as well as an expert system to aid in the target detection and tracking processes. Automatic mode interleaving and simultaneous multi-mode functions (such as interleaving a/a and a/g modes for situational awareness) may decrease pilot workload, but may require an expert system to dynamically determine which modes will be interleaved depending on the combat situation. The expert system may not only select the radar mode(s), but may well vary the displayed radar data or formats depending on the situation as there may be too much data for an individual pilot to try to assimilate. The radar may also be mechanised to take pointing commands from other on-board sensors (or data linked from external sources such as other fighters or interceptors, airborne or ground-based early warning systems) and then reshape the beam or change scan patterns accordingly. The radar data may be integrated with a digitally generated moving map display, and may be controllable by interactive voice commands. The advances in radar modes may also cause development of common modes among various aircraft, thereby minimizing duplication of development and evaluation effort. This could result in more generic hardware and software, commonality among test plans, instrumentation, data processing and analysis methods and systems.

New avionics systems will make use of sensor integration (also referred to as data fusion) which is the combination of data from several sensors such as threat warning, optical and infrared with radar data to help detect and identify the target. This will require a target which is more representative of the threat in all areas such as RCS, scintillation characteristics, infrared spectrum, target signal emanations, jet engine modulation, and maneuvering performance. Future threats will likely be substantially lower in RCS, necessitating the targets used for radar testing also have a lower RCS, since extrapolation techniques may not be valid in the look-down situation where the low RCS target is competing with the clutter return. This may add a requirement to calibrate the targets in advance of testing to ensure they are fully representative and have consistent characteristics.

Future radars will have the means to automatically reconfigure themselves using expert systems and artificial intelligence architectures to change radar parameters to cope with the situation, or to work around system failures. Failures can be dealt with through the use of multiple processors which can take over for each other, thereby providing little or no degradation in system performance. This will also result in improved system reliability, maintainability, and availability. This sharing of multiple processors can then be applied to the full aircraft avionics suite, reducing the overall mean time between failures of the suite by reconfigurability through resource sharing of the system elements. If the individual systems, such as radar, electro-optic sensor, and threat warning are integrated, a monitor unit could assess the status of all subsystems and reconfigure them accordingly in response to one or more subsystem failures. This reconfiguration capability among several subsystems will place further demands on the flight testing of degraded and backup modes, as well as complicate the instrumentation requirements, since the sources and destinations of data will change whenever the system reconfigures.

The incorporation of expert systems, data fusion and radar system and aircraft avionics suite real-time reconfigurability will substantially impact the environment required for radar testing. A much more complex ground test lab and flight test environment will be required to exercise radar variables such as: 1) automatic mode changing, 2) interleaving of modes, 3) dynamically changing radar parameters (such as scan volume, scan rate, PRF, clutter processing, target detection and tracking) depending on the type of mission (such as interception, point area defense, or a/g), 4) complex clutter, 5) weather effects, and 6) the presence of an electromagnetic pulse or ECM. This may have to include an on-board simulation to inject part of the environment into the radar system in flight to augment the actual limited flight test environment. The more automated radar systems that can rapidly change modes or radar parameters may be more difficult to test since they may have to be artificially constrained to not allow the system to change these variables. For example, a DT&E a/a detection test condition may be invalid if the radar were to vary operating parameters in mid-run, whereas OT&E type test conditions would want to allow the radar to change. Not only will an environment dependent radar system increase the OT&E test requirements, it could mean that the OT&E tests may obtain significantly different radar performance test results. A radar system with a/a and a/g mode interleaving capability may require two sets of DT&E detection test conditions--one with the radar constrained to only a/a, and the other repeated under the same conditions but mode interleaved to determine any performance differences. Considerable flight testing may be required to optimize the reconfiguration algorithms with respect to the many possible operating environments and scenarios which, unless given careful consideration, could lead to enormous flight test matrices. A portion of this algorithm optimization could be performed in a ground lab, as long as the environment simulations are upgraded to effectively simulate the many environment factors.

In addition to the test environment impacts on radar test ranges, improvements in a/a radar performance (such as increased detection range, greater tracking accuracies, and multiple azimuth visibility up to 360 degrees) are often outpacing improvements in the capabilities of the range reference systems against which the radar is compared to measure system performance. Reference data systems for radar testing need to be improved to track the radar-equipped and target aircraft at longer ranges and in larger test arenas, track more airborne targets simultaneously (to include during high rate maneuvers) and track ground moving targets in the presence of clutter and ECM.

As threat ECM capabilities become more agile and sophisticated, a/a radar system ECCM methods will have to improve, requiring more sophisticated threat simulators in the lab and in flight. Multiple ECM sources will be required, especially in the case of the previously discussed multiple array 360-degree coverage radar systems. Test matrices will grow since there will likely be a greater number of ECCM test conditions to compare with radar performance in a non-ECM environment. This will be further complicated by radar mode interleaving, and could require multiple simultaneous a/a and a/g mode threat ECM systems.

Future aircraft will have increasingly sophisticated cockpits with systems such as: three-dimensional sound and holographic displays, voice and vision activation of systems, rapid reconfiguration of cockpit controls and displays, pilot state monitoring, and a helmet-mounted display. The a/a radar display will be a color display (as opposed to the current monochrome displays) which will allow improvements in highlighting important data such as: ECM, higher priority targets in TWS, and on aircraft detected targets versus those received via data link from other sources. These developments will require improvements and whole new methods of recording radar information for later analysis, ranging from the addition of color video recorders to a means of reproducing holographic displays.

The incorporation of color multifunction displays and the increases in system computational power and memory, can also be used to improve test efficiency by adding on-board MFD-displayed run cards. An MFD could be devoted to displaying the required test condition to avoid the use of manual run cards. It could also display test condition limits and warnings, and highlight or announce when these limits are about to be exceeded. This may require an expert system to dynamically determine what the limits should be, and it may be able to include target limits as perceived by the radar system. The test conditions and associated limits should not have to be manually entered, but could be done so via test input cartridges or some other means of rapid information transfer to the on-board avionics system.

Radars may include an in-flight training mode which will require exercising and testing this mode for realism and validity during the radar test program. For example, this mode could present combinations of simulated targets and ECM, and then evaluate the pilot's ability to determine the presence of a target and lock on to it. This training mode may even include simulated data from other on-board sensors, and may integrate the radar with on-board weapons to the point of simulating launch conditions. The a/a radar flight test program will need to duplicate the training mode conditions in flight to ensure the training mode is correctly designed to indicate and respond to the simulated situation in the same manner as the "real thing."

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1 — Test and Evaluation, US Air Force Regulation 80-14, 3 November 1986

2 — Test Plans, US Air Force Flight Test Center Regulation 80-1, 5 November 1985

3 — Safety Planning for AFFTC Tests, US Air Force Flight Test Center Regulation 127-3, 15 September 1983

4 W L Long — Effect of Peak Sidelobes on System False Alarm Rate, Technical Memo, 5 April 1983

5 — IFAST Test Methodology, Air-to-Air and Air-to-Ground Radars, November 1982

Annex 1

AGARD FLIGHT TEST INSTRUMENTATION AND FLIGHT TEST TECHNIQUES SERIES

1. Volumes in the AGARD Flight Test Instrumentation Series, AGARDograph 160

Volume Number	*Title*	*Publication Date*
1.	Basic Principles of Flight Test Instrumentation Engineering by A.Pool and D.Bosman (to be revised in 1989)	1974
2.	In-Flight Temperature Measurements by F.Trenkle and M.Reinhardt	1973
3.	The Measurement of Fuel Flow by J.T.France	1972
4.	The Measurement of Engine Rotation Speed by M.Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E.Bennett	1974
6.	Open and Closed Loop Accelerometers by I.Mclaren	1974
7.	Strain Gauge Measurements on Aircraft by E.Kottkamp, H.Wilhelm and D.Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C.van der Linden and H.A.Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G.van Nunen and G.Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R.Ferrell	1980
11.	Pressure and Flow Measurement by W.Wuest	1980
12.	Aircraft Flight Test Data Processing — A Review of the State of the Art by L.J.Smith and N.O.Matthews	1980 1980
13.	Practical Aspects of Instrumentation System Installation by R.W.Borek	1981
14.	The Analysis of Random Data by D.A.Williams	1981
15.	Gyroscopic Instruments and their Application to Flight Testing by B.Stieler and H.Winter	1982
16.	Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications by P.de Benque d'Agut, H.Riebeek and A.Pool	1985
17.	Analogue Signal Conditioning for Flight Test Instrumentation by D.W.Veatch and R.K.Bogue	1986

Volume Number	*Title*	*Publication Date*
18.	Microprocessor Applications in Airborne Flight Test Instrumentation by M.J.Prickett	1987

At the time of publication of the present volume the following volume was in preparation:

Digital Signal Conditioning for Flight Test Instrumentation
by G.A.Bever

2. Volumes in the AGARD Flight Test Techniques Series

Number	*Title*	*Publication Date*
AG 237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes will be published as a sequence of Volume Numbers of AGARDograph 300.

Volume Number	*Title*	*Publication Date*
1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A.Lawford and K.R.Nippress	1983
2.	Identification of Dynamic Systems by R.E.Maine and K.W.Iliff	1985
3.	Identification of Dynamic Systems — Applications to Aircraft Part 1: The Output Error Approach by R.E.Maine and K.W.Iliff	1986
4.	Determination of Antenna Patterns and Radar Reflection Characteristics of Aircraft by H.Bothe and D.Macdonald	1986
5.	Store Separation Flight Testing by R.J.Arnold and C.S.Epstein	1986
6.	Developmental Airdrop Testing Techniques and Devices by H.J.Hunter	1987
7.	Air-to-Air Radar Flight Testing by R.E.Scott	1988
8.	Flight Testing under Extreme Environmental Conditions by C.L.Hendrickson	1988

At the time of publication of the present volume the following volumes were in preparation:

Identification of Dynamic Systems. Applications to Aircraft
Part 2: Nonlinear Model Analysis and Manoeuvre Design
by J.A.Mulder and J.H.Breeman

Flight Testing of Digital Navigation and Flight Control Systems
by F.J.Abbink and H.A.Timmers

Aircraft Noise Measurement and Analysis Techniques
by H.H.Heller

Flight Testing of Terrain Following Systems
by C.Dallimore and M.K.Foster

Store Ballistic Analysis and Testing
by R.Arnold and H.Reda

Annex 2

AVAILABLE FLIGHT TEST HANDBOOKS

This annex is presented to make readers aware of handbooks that are available on a variety of flight test subjects not necessarily related to the contents of this volume.

Requests for A & AEE documents should be addressed to the Defence Research Information Centre, Glasgow (see back cover). Requests for US documents should be addressed to the Defence Technical Information Center, Cameron Station, Alexandria, VA 22314 (or in one case, the Library of Congress).

Number	*Author*	*Title*	*Date*
NATC-TM76-ISA	Simpson, W.R.	Development of a Time-Variant Figure-of-Merit for Use in Analysis of Air Combat Maneuvring Engagements	1976
NATC-TM76-3SA	Simpson, W.R.	The Development of Primary Equations for the Use of On-Board Accelerometers in Determining Aircraft Performance	1977
NATC-TM-77-IRW	Woomer, C. Carico, D.	A Program for Increased Flight Fidelity in Helicopter Simulation	1977
NATC-TM-77-2SA	Simpson, W.R. Oberle, R.A.	The Numerical Analysis of Air Combat Engagements Dominated by Maneuvering Performance	1977
NATC-TM-77-1SY	Gregoire, H.G.	Analysis of Flight Clothing Effects on Aircrew Station Geometry	1977
NATC-TM-78-2RW	Woomer, G.W. Williams, R.L.	Environmental Requirements for Simulated Helicopter/ VTOL Operations from Small Ships and Carriers	1978
NATC-TM-78-1RW	Yeend, R. Carico, D.	A Program for Determining Flight Simulator Field-of-View Requirements	1978
NATC-TM-79-33SA	Chapin, P.W.	A Comprehensive Approach to In-Flight Thrust Determination	1980
NATC-TM-79-3SY	Schiflett, S.G. Loik'th, G.J.	Voice Stress Analysis as a Measure of Operator Workload	1980
NWC-TM-3485	Rogers, R.M.	Six-Degree-of-Freedom Store Program	1978
WSAMC-AMCP 706-204	—	Engineering Design Handbook, Helicopter Performance Testing	1974
NASA-CR-3406	Bennett, R.L. and Pearsons, K.S.	Handbook on Aircraft Noise Metrics	1981
—	—	Pilot's Handbook for Critical and Exploratory Flight Testing. (Sponsored by AIAA & SETP — Library of Congress Card No.76-189165)	1972
—	—	A & AEE Performance Division Handbook of Test Methods for assessing the Flying Qualities and Performance of Military Aircraft. Vol.1 Airplanes	1979
A & AEE Note 2111	Appleford, J.K.	Performance Division: Clearance Philosophies for Fixed Wing Aircraft	1978
A & AEE Note 2113 (Issue 2)	Norris, E.J.	Test Methods and Flight Safety Procedures for Aircraft Trials Which May Lead to Departures from Controlled Flight	1980

Number	Author	Title	Date
AFFTC-TD-75-3	Mahlum, R.	Flight Measurements of Aircraft Antenna Patterns	1973
AFFTC-TIH-76-1	Reeser, K. Brinkley, C. and Plews, L.	Inertial Navigation Systems Testing Handbook	1976
AFFTC-TIH-79-1	—	USAF Test Pilot School (USAFTPS) Flight Test Handbook Performance: Theory and Flight Techniques	1979
AFFTC-TIH-79-2	—	USAFTPS Flight Test Handbook, Flying Qualities: Theory (Vol.1) and Flight Test Techniques (Vol.2)	1979
AFFTC-TIH-81-1	Rawlings, K., III	A Method of Estimating Upwash Angle at Noseboom-Mounted Vanes	1981
AFFTC-TIH-81-1	Plews, L. and Mandt, G.	Aircraft Brake Systems Testing Handbook	1981
AFFTC-TIH-81-5	DeAnda, A.G.	AFFTC Standard Airspeed Calibration Procedures	1981
AFFTC-TIH-81-6	Lush, K.	Fuel Subsystems Flight Test Handbook	1981
AFEWC-DR-1-81	—	Radar Cross Section Handbook	1981
NATC-TM-71-ISA226	Hewett, M.D. Galloway, R.T.	On Improving the Flight Fidelity of Operational Flight/ Weapon Systems Trainers	1975
NATC-TM-TPS76-1	Bowes, W.C. Miller, R.V.	Inertially Derived Flying Qualities and Performance Parameters	1976
NASA Ref. Publ. 1008	Fisher, F.A. Plumer, J.A.	Lightning Protection of Aircraft	1977
NASA Ref. Publ. 1046	Gracey, W.	Measurement of Aircraft Speed and Altitude	1980
NASA Ref. Publ. 1075	Kalil, F.	Magnetic Tape Recording for the Eighties (Sponsored by: Tape Head Interface Committee)	1982

The following handbooks are available in French and are edited by the French Test Pilot School (EPNER Ecole du Personnel Navigant d'Essais et de Réception ISTRES — FRANCE), to which requests should be addressed.

Number EPNER Reference	*Author*	*Title*	*Price (1983) French Francs*	*Notes*
2	G.Leblanc	L'analyse dimensionelle	20	Réédition 1977
7	EPNER	Manuel d'exploitation des enregistrements d'Essais en vol	60	6ème Edition 1970
8	M.Durand	La mécanique du vol de l'hélicoptère	155	1ère Edition 1981
12	C.Laburthe	Mécanique du vol de l'avion appliquée aux essais en vol	16	Réédition en cours
15	A.Hisler	La prise en main d'un avion nouveau	50	1ère Edition 1964
16	Candau	Programme d'essais pour l'évaluation d'un hélicoptère et d'un pilote automatique d'hélicoptère	20	2ème Edition 1970
22	Cattaneo	Cours de métrologie	45	Réédition 1982
24	G.Fraysse F.Cousson	Pratique des essais en vol (en 3 Tomes)	T1 = 160 T2 = 160 T3 = 120	1ère Edition 1973
25	EPNER	Pratique des essais en vol hélicoptère (en 2 Tomes)	T1 = 150 T2 = 150	Edition 1981
26	J.C.Wanner	Bang sonique	60	
31	Tarnowski	Inertie-verticale-sécurité	50	1ère Edition 1981
32	B.Pennacchioni	Aéroélasticité — le flottement des avions	40	1ère Edition 1980
33	C.Lelaie	Les vrilles et leurs essais	110	Edition 1981
37	S.Allenic	Electricité à bord des aéronefs	100	Edition 1978
53	J.C.Wanner	Le moteur d'avion (en 2 Tomes) T 1 Le réacteur .... T 2 Le turbopropulseur	 85 85	Réédition 1982
55	De Cennival	Installation des turbomoteurs sur hélicoptères	60	2ème Edition 1980
63	Gremont	Aperçu sur les pneumatiques et leurs propriétés	25	3éme Edition 1972
77	Gremont	L'atterrissage et le problème du freinage	40	2ème Edition 1978
82	Auffret	Manuel de médicine aéronautique	55	Edition 1979
85	Monnier	Conditions de calcul des structures d'avions	25	1ère Edition 1964
88	Richard	Technologie hélicoptère	95	Réédition 1971

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