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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

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**RTO AGARDograph 300**

**Flight Test Techniques Series – Volume 16**

# Introduction to Airborne Early Warning Radar Flight Test

(Introduction aux essais en vol des radars aéroportés d'alerte lointaine)

*This AGARDograph has been sponsored by the SCI-055 Task Group, the Flight Test Technology Team of the Systems Concepts and Integration Panel (SCI) of RTO.*

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# Introduction to Airborne Early Warning Radar Flight Test

(Introduction aux essais en vol des radars aéroportés d'alerte lointaine)

edited by

J.M. Clifton
F.W. Lee

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# Introduction to Airborne Early Warning Radar Flight Test

## (RTO AG-300 Volume 16)

# Executive Summary

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

This book is intended as an introductory document to the subject of Airborne Early Warning radar flight testing. The first chapter provides a detailed discussion of the content and utility of the book. Chapter two is a discussion of the taxonomy and theory of AEW radars. Chapter three describes the instrumentation used in AEW radar testing and provides a detailed description of one sample system. Chapters four and five examine each of the subcategories of AEW radars and focus on the basic test techniques used for each. Specific examples of test techniques are provided for sample (and fictional) systems. The book ends by making some conclusions and providing recommendations.

# Introduction aux essais en vol des radars aéroportés d'alerte lointaine

## (RTO AG-300 Volume 16)

# Synthèse

Malgré la diminution actuelle des budgets militaires et la réduction de la taille des flottes aériennes qui en résulte, l'achat de systèmes rentables, susceptibles d'augmenter l'efficacité des systèmes d'armes existants, reste envisageable. Une meilleure connaissance de la situation des forces et une meilleure gestion du champ de bataille offertes par les radars aéroportés d'alerte lointaine (AEW), représentent un exemple de ces « multiplicateurs de force ». La fonction principale d'un avion AEW est la détection lointaine de cibles aériennes. Compte tenu des importantes menaces aériennes nouvelles, telles que les missiles de croisière à basse altitude, qui nécessitent des temps de réaction de plus en plus courts de la part des systèmes de défense aériennes classiques, l'intérêt des capacités de surveillance à longue distance d'un système AEW, qui permettent de compenser cette perte de temps, est évident. Essentiellement, ces nouvelles cibles mettent en question les principales capacités opérationnelles des capteurs radar AEW, qui devront atteindre de nouvelles performances pour pouvoir contrer cette menace sophistiquée. Ces nouveaux besoins ont entraîné des activités considérables dans le monde entier dans le domaine du développement de versions améliorées des radars équipant les avions AEW existants, tels que le E-2C Hawkeye de la Marine US et le E-3A AWACS de l'Armée de l'air US, ainsi que de nouvelles plates-formes et de nouveaux systèmes tels que le ERIEYE de l'Armée de l'air suèdoise. La sensibilité et la résolution accrues qui sont demandées, ainsi que les débits binaires nécessaires pour assurer ces améliorations de performance auront une influence très marquée sur leur exploitation et leurs performances dans différents environnements. Au fur et à mesure de l'évolution de ces systèmes de plus en plus performants, les radars AEW devront assumer d'autres missions et réaliser d'autres fonctions de surveillance dans la poursuite d'une connaissance de la situation des forces qui permettrait de dominer le champ de bataille. Malheureusement, peu ou point de littérature existe sur les techniques souvent uniques qui sont demandées pour réaliser les essais en vol des systèmes composant ces nouveaux radars AEW. D'une manière générale, les procédures ont été transmises d'une personne à une autre sans aucune documentation de base. Ce volume a pour objectif de documenter la théorie et les procédures nécessaires à la réalisation des essais de développement en vol de plusieurs grandes catégories de radars AEW.

Cet ouvrage est une introduction au sujet des essais en vol des systèmes radar aéroportés d'alerte lointaine. Le premier chapitre présente une discussion approfondie du contenu et de la finalité de l'ouvrage. Le chapitre deux examine la taxonomie et de la théorie des radars AEW. Le chapitre trois décrit les appareils de mesure utilisés pour les essais des radars AEW, avec la description détaillée d'un système échantillon. Les chapitres quatre et cinq examinent chacune des sous-catégories de radars AEW, en privilégiant les techniques de base de chaque essai. Des exemples spécifiques de techniques d'essais sont donnés pour des systèmes échantillon et des systèmes théoriques. L'ouvrage se termine par un certain nombre de conclusions et de recommandations.

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# Preface

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

# Foreword

This book is intended as an introductory document to the subject of Airborne Early Warning (AEW) radar flight testing. The first chapter provides a detailed discussion of the content and utility of the book. Chapter two is a discussion of the taxonomy and theory of AEW radars. Chapter three describes the instrumentation used in AEW radar testing and provides a detailed description of one sample system. Chapters four and five examine each of the subcategories of AEW radars and focus on the basic test techniques used for each. Specific examples of test techniques are provided for sample (and fictional) systems. The book ends by making some conclusions and providing recommendations.

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# Acronyms, Symbols and Abbreviations

| | |
|---|---|
| a | acceleration |
| Ae | antenna effective aperture, $m^2$ |
| ADC | Analog-to-Digital Converter |
| AEW | Airborne Early Warning |
| AGARD | Advisory Group for Aerospace Research and Development |
| AGC | Automatic Gain Control |
| ALT | ALTitude |
| AMTI | Airborne Moving Target Indicator |
| AWACS | Airborne Warning and Control System |
| | |
| BIT | Built In Test |
| $B_n$ | bandwidth of the receiver |
| BPF | Band Pass Filter |
| BSR | Blip/Scan Ratio |
| | |
| c | speed of light, 161,875 nm/sec |
| CA-CFAR | Cell Averaging CFAR |
| CBSR | Composite Blip/Scan Ratio |
| CFAR | Constant False Alarm Rate |
| COHO | COHerent Oscillator |
| COMO | COherent Master Oscillator |
| CPI | Coherent Processing Interval |
| $C_R$ | clutter loss term |
| CRT | Cathode Ray Tube |
| | |
| db | decibel |
| DCCS | Data Collection and Conditioning System |
| DEG | DEGree |
| DGPS | Differential GPS |
| DPS | Data Processing System |
| DR | Dead Reckoning |
| DRS | Data Recording System |
| $D_{sf}$ | spurious free dynamic range |
| DU | Data Unit |
| DX | Data Extraction |
| | |
| ECM | Electronic Counter-Measures |
| EMI | Electro-Magnetic Interference |
| FAA | Federal Aviation Administration |
| | |
| $f_c$ | output of COHO |
| $f_d$ | target or clutter induced doppler frequency |
| FFT | Fast Fourier Transform |
| $f_l$ | output of STALO |
| FL | Flight Level |
| $f_{min}$ | the minimum doppler shift below which the radar cannot discern between a real moving target and clutter |
| $F_n$ | noise figure of the receiver |
| $F_o$ | center frequency of target returns |

| | |
|---|---|
| G | directive antenna gain |
| GPS | Global Positioning System |
| H | altitude of aircraft in feet |
| I | In-phase |
| ICS | Internal Communication System |
| IFF | Interrogator Friend or Foe |
| k | Boltzman's constant=1.38 X $10^{-23}$ J/deg |
| K | 1,000 |
| KTS | Knots |
| LNA | Low Noise Amplifier |
| LO | Local Oscillator |
| LSB | Least Significant Bit |
| MAG | MAGnetic |
| MDS | Minimum Discernable Signal |
| MOPA | Master Oscillator Power Amplifiers |
| MSL | Mean Sea Level |
| MTI | Moving Target Indicator |
| N | north |
| NATO | North Atlantic Treaty Organization |
| nm | nautical mile |
| NRB | the number of range bins for each pulse repetition interval |
| $P_{av}$ | average transmit power |
| PCM | Pulse Code Modulation |
| $P_d(X)$ | Probability of Detection equal to X |
| $P_{dc}(X)$ | Composite Probability of Detection equal to X |
| $P_{fa}$ | probability of false alarm |
| PPI | Planned Position Indicator |
| PRF | Pulse Repetition Frequency |
| PRI | Pulse Repetition Interval |
| $P_t$ | transmitted power, watts |
| Q | Quadrature |
| R | Range |
| $R_a$ | the ambiguous range for each pulse |
| $R_c(I)$ | the ith candidate unambiguous range |
| RCU | Remote Control Unit |
| RF | Radio Frequency |
| RFI | Radio Frequency Interference |
| $R_h$ | range to radar horizon |
| $R_o$ | desired range |
| $R_{max}$ | radar maximum range |
| $R_{max\ adj}$ | maximum detection range of target of interest for which detection data has not been directly measured |
| $R_{max\ test}$ | maximum detection range of target for which radar detection data has been directly measured |
| $R_{max\ unamb}$ | maximum unambiguous radar range |
| $R_{min}$ | minimum range |
| RU | Recorder Unit |

| | |
|---|---|
| Sec | second |
| $S_{min}$ | minimum detectable signal, watts |
| $(S/N)_{min}$ | minimum signal to noise ratio necessary for detection |
| SPD | speed |
| STALO | STAble Local Oscillator |
| STAP | Space Time Adaptive Processing |
| STC | Sensitivity Time Control |
| SWT | Scan-While-Track |
| TACCAR | Time Averaged Clutter Coherent Airborne Radar |
| $T_{cpi}$ | time between samples |
| $T_o$ | temperature of the receiver in deg K |
| TWS | Track-While-Scan |
| v | velocity |
| W | West |
| $\alpha$ | alpha constant |
| $\beta$ | beta constant |
| $\sigma$ | radar cross section |
| $\sigma_{desired}$ | radar cross section of target of interest for which detection data has not been directly measured |
| $\sigma_e$ | effective target radar cross section |
| $\sigma_{test}$ | radar cross section of target for which radar detection data has been directly measured |
| $\lambda$ | wavelength |
| $\tau$ | transmit pulse width |
| $\theta$ | angle between the velocity vector and the clutter patch |
| $\eta$ | number of pulses per dwell |
| $\varepsilon_i(\eta)$ | integration efficiency for $\eta$ pulses |
| $\tau_c$ | compressed pulse width |

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**14. Abstract**

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

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