

RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036-4001, USA

**Minimum Operational Performance Standards (MOPS)
for Electro-Optical/Infrared (EO/IR) Sensor Systems for
Traffic Surveillance**

RTCA DO-387
June 17, 2021

Prepared by: SC-228.
© 2021, RTCA, Inc.

Copies of this document may be obtained from:

RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036-4001, USA

Telephone: 202-833-9339
Facsimile: 202-833-9434
Internet: www.rtca.org

Please visit the [RTCA Online Store](#) for document pricing and ordering information.

FOREWORD

This document was prepared by Special Committee 228 (SC-228) and approved by the RTCA Program Management Committee (PMC) on June 17, 2021.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Standards Development Organization and develops consensus based recommendations on contemporary aviation issues. RTCA's objectives include, but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity, and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders.

Since RTCA is not an official agency of the United States Government, its recommendations may not be regarded as statements of official government policy unless so enunciated by the U.S. government organization or agency having statutory jurisdiction over any matters to which the recommendations relate.

DISCLAIMER

This publication is based on material submitted by various participants during the SC approval process. Neither the SC nor RTCA has made any determination whether these materials could be subject to valid claims of patent, copyright or other proprietary rights by third parties, and no representation or warranty, expressed or implied is made in this regard. Any use of or reliance on this document constitutes an acceptance thereof "as is" and is subject to this disclaimer.

REVISION HISTORY

Rev. Level	Description	Date	Effective Sections
-	Draft for Phase 2 RAC – limited to SC-228 WG 1	07/24/20	All
-	Draft for FRAC	11/27/20	All
-	Editorial Review	12/19/20	All
-	Final post-FRAC editorial review	03/16/21	All

EXECUTIVE SUMMARY

This document contains Minimum Operational Performance Standards (MOPS) for Electro-Optical/Infrared (EO/IR) Sensors for Traffic Surveillance.

The EO/IR sensor system is a surveillance source for non-cooperative intruders for a Detect and Avoid (DAA) system used in Unmanned Aircraft Systems (UAS) transiting through Class B, C, D, E and G airspace and performing extended operations higher than 400' Above Ground Level (AGL) in Class D, E (up to Flight Level 180 (FL180)), and G airspace. It includes equipment to enable UAS operations in Terminal Areas during approach and departure in Class C, D, E and G airspace and off-airport locations. It does not apply to small UAS (sUAS) operating in low-level environments (below 400') or other segmented areas. Likewise, it does not apply to operations in the Visual Flight Rules (VFR) traffic pattern of an airport or to surface operations.

The intended function of the EO/IR sensor system is to detect and generate tracks for all airborne traffic within the EO/IR sensor system detection volume. The onboard EO/IR sensor system complements other airborne surveillance sensors by providing detection of non-cooperative traffic. The track should be established at sufficient range and with sufficient accuracy to enable the remote pilot to plan and execute a maneuver to keep the Unmanned Aircraft (UA) well clear of other traffic and avoid collisions.

This document has the detailed performance and environmental requirements of the EO/IR sensor system along with their verification methods. Verification includes bench tests, flight tests and environmental tests. Recommendations and flight tests for installed performance are also provided.

This Page Intentionally Left Blank

TABLE OF CONTENTS

1	PURPOSE AND SCOPE.....	1
1.1	Introduction.....	1
1.2	DAA System Overview	2
1.2.1	DAA System Description – Unmanned Aircraft	2
1.2.2	DAA System Description – Control Station.....	3
1.2.3	DAA EO/IR Sensor System Overview	4
1.2.4	System Limitations	5
1.3	Document Hierarchy.....	6
1.4	Intended Function	6
1.5	Operational Goals	6
1.6	Assumptions.....	6
1.6.1	Operational Assumptions.....	6
1.6.2	Atmospheric Conditions Assumptions.....	7
1.6.3	Protective Windows Assumptions	7
1.6.4	EO/IR Sensor System Class Assumptions	8
1.6.5	Sensor/Ownship Misalignment Budget Assumptions.....	8
1.6.6	Ownship State Data Assumptions.....	8
1.7	Test Procedure Overview.....	9
1.8	Definition of Terms and Acronyms	10
1.8.1	EO/IR Sensor System Field of Regard (FOR) Definitions	11
1.8.2	Track Definitions	11
1.8.3	Range (R) Definitions.....	12
1.8.4	Intruder Categories.....	13
1.8.5	Intruder Signatures.....	13
1.9	Aircraft Equipment Information Vulnerabilities.....	14
2	EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES	17
2.1	General Requirements.....	17
2.1.1	Airworthiness.....	17
2.1.2	Intended Function	17
2.1.3	Federal Communications Commission (FCC) Rules.....	17
2.1.4	Fire Protection.....	17
2.1.5	Operation of Controls	17
2.1.6	Accessibility of Controls.....	17
2.1.7	Effects of Test.....	17
2.1.8	Design Assurance.....	17
2.1.9	Harmful Interference and Hazards.....	18
2.2	Equipment Performance Requirements– Standard Conditions.....	18
2.2.1	Introduction.....	18
2.2.2	DAA EO/IR Sensor System Input/Output	18
2.2.2.1	Ownship State Data.....	18
2.2.2.2	EO/IR Sensor System States and Control	18
2.2.2.2.1	Number of States.....	18
2.2.2.2.2	Off State	19
2.2.2.2.3	Standby State.....	19
2.2.2.2.4	Operational State.....	19
2.2.2.2.5	Failure State.....	20
2.2.2.2.6	Emitting Systems.....	20
2.2.2.3	EO/IR Sensor System Data Output to the DAA Processor	20

2.2.2.3.1	Minimum Track Report Rate	21
2.2.2.3.2	Persistence of Track ID	21
2.2.2.3.3	Detect-to-Output Latency.....	21
2.2.2.3.4	Track Format	21
2.2.2.4	EO/IR Sensor System Status Reporting	21
2.2.3	EO/IR Sensor System Wavelengths.....	22
2.2.4	Applicable Atmospheric Conditions.....	22
2.2.5	EO/IR Sensor System Day and Night Operations.....	22
2.2.6	EO/IR Sensor System Field of Regard	22
2.2.7	EO/IR Sensor System Tracks.....	23
2.2.7.1	EO/IR Sensor System Track Accuracy	26
2.2.7.2	EO/IR Sensor System Track Uncertainty.....	27
2.2.7.3	EO/IR Sensor System Tracker Lag and Peak Error	28
2.2.7.4	EO/IR Sensor System False and Ground Tracks.....	30
2.2.8	EO/IR Sensor System Health Monitoring.....	30
2.2.9	EO/IR Sensor System Calibration.....	30
2.2.10	EO/IR Sensor System Sun Saturation.....	31
2.2.11	EO/IR Sensor System Ice Protection/De-misting	31
2.2.12	Lens & Protective Window Degradation	31
2.3	Equipment Performance – Environmental Conditions	31
2.3.1	Use of Special Purpose Software	31
2.3.2	DAA Airborne Equipment – Environmental Conditions.....	32
2.4	Equipment Test Procedures	36
2.4.1	Definitions of Terms and Conditions of Test.....	36
2.4.2	Required Test Equipment.....	37
2.4.2.1	EO/IR Simulator Requirements.....	37
2.4.2.2	Ground Test Setup -Optronic Test Bench	38
2.4.2.3	Ground Test Setup -Image Database Test Bench.....	39
2.4.2.4	Ground Test High-Level Description.....	40
2.4.2.5	Flight Test Setup	40
2.4.2.5.1	Flight Test Equipment and Configuration.....	48
2.4.3	Detailed Test Procedures	51
2.4.3.1	Ownship State Data (Subparagraph 2.2.2.1)	51
2.4.3.2	EO/IR Sensor System States and Control (Subparagraph 2.2.2.2).....	51
2.4.3.3	EO/IR Sensor System Data Output to the DAA Processor (Subparagraph 2.2.2.3)	52
2.4.3.4	EO/IR Sensor System Status Reporting (Subparagraph 2.2.2.4)	54
2.4.3.5	EO/IR Sensor System Wavelengths (Paragraph 2.2.3)	54
2.4.3.6	Applicable Atmospheric Conditions (Paragraph 2.2.4)	55
2.4.3.7	EO/IR Sensor System Day and Night Operations (Paragraph 2.2.5).....	55
2.4.3.8	EO/IR Sensor System Field of Regard (Paragraph 2.2.6).....	55
2.4.3.9	EO/IR Sensor System Tracks (Paragraph 2.2.7)	56
2.4.3.9.1	EO/IR Sensor System Track Accuracy (Subparagraph 2.2.7.1)	60
2.4.3.9.2	EO/IR Sensor System Track Uncertainty (Subparagraph 2.2.7.2).....	60
2.4.3.9.3	EO/IR Sensor System Tracker Lag and Peak Error (Subparagraph 2.2.7.3).....	61
2.4.3.9.4	EO/IR Sensor System False and Ground Tracks (Subparagraph 2.2.7.4).....	61
2.4.3.10	EO/IR Sensor System Health Monitoring (Paragraph 2.2.8)	61
2.4.3.11	EO/IR Sensor System Calibration (Paragraph 2.2.9).....	62
2.4.3.12	EO/IR Sensor System Sun Saturation (Paragraph 2.2.10)	63
2.4.3.13	EO/IR Sensor System Ice Protection/De-misting (Paragraph 2.2.11).....	64
2.4.3.14	Lens & Protective Window Degradation (Paragraph 2.2.12).....	64
2.4.4	Traceability	64
2.4.4.1	Test Procedure-to-Requirements Traceability.....	64
2.4.4.2	Requirements-to-Test Procedure Traceability.....	65

3	MANUFACTURER CONSIDERATIONS FOR INSTALLED EQUIPMENT	67
3.1	Equipment Installation.....	67
3.1.1	Accessibility.....	67
3.1.2	Aircraft Environment.....	67
3.1.3	Display Visibility.....	67
3.1.4	Dynamic Range.....	67
3.1.5	Failure Protection.....	67
3.1.6	Interference Effects.....	68
3.1.7	Inadvertent Turnoff.....	68
3.1.8	Aircraft Power Source.....	68
3.1.9	Safety Precautions.....	68
3.2	Installed Equipment Performance Considerations.....	68
3.2.1	Protective Window and Effective FOR.....	68
3.2.2	Installation Accuracy.....	68
3.2.3	Environmental Checks.....	68
3.3	Installed Equipment Tests.....	69
4	AIRCRAFT OPERATIONAL PERFORMANCE CHARACTERISTICS	71
5	MEMBERSHIP	73
	APPENDIX A WAVELENGTHS FOR DAA EO/IR SENSOR SYSTEMS	A-1
A.1	Bandwidth Consideration.....	A-1
	APPENDIX B EO/IR DECLARATION RANGE ANALYSIS AND ALERTING PERFORMANCE SIMULATIONS	B-1
B.1	Objective.....	B-1
B.2	Declaration Range Assumptions and Data Generation.....	B-1
B.3	Declaration Range Results.....	B-4
B.4	Modified Declaration Ranges and Validation.....	B-8
	APPENDIX C PROBABILITY OF AN INTRUDER ENTERING THE EO/IR SENSOR SYSTEM FIELD OF REGARD WITHIN THE EO/IR DR + 25 SECONDS	C-1
C.1	Introduction.....	C-1
C.2	Low-Size, Weight, and Power (SWaP) Encounter Set.....	C-1
C.3	Low-SWaP RDR Candidates.....	C-3
C.4	Event Filtering & Additional Assumptions.....	C-4
C.5	Results.....	C-5
C.6	Encounter Categorization.....	C-9
C.7	Using the Final Entry into FOR/DR for the Time Margin.....	C-12
C.8	Conclusions.....	C-14
	APPENDIX D INTRUDER SIGNATURES AND GUIDELINES FOR DESIGN AND PERFORMANCE JUSTIFICATION	D-1
D.1	Introduction.....	D-1
D.2	Intruder Categories.....	D-1
D.3	Relevant Operational Assumptions.....	D-1
D.4	Intruder Signatures.....	D-3
D.5	Background Characteristics.....	D-9
D.6	Atmosphere Parameters.....	D-14
D.7	Proposed Simulation to Model Scenes and Derive Intruder Images at the Sensor Level.....	D-17

D.8	References.....	D-24
-----	-----------------	------

**APPENDIX E SAFETY AND OPERATIONAL SUITABILITY ANALYSIS USING AN
ELECTRO-OPTICAL/INFRARED SENSOR..... E-1**

E.1	Introduction	E-1
E.2	EO/IR Sensor System Model Description and Characteristics.....	E-1
E.3	Analysis Setup.....	E-3
E.4	Simulation Setup	E-5
E.5	Metrics.....	E-6
E.6	Results	E-9
E.7	Conclusions	E-17
E.8	References	E-17

APPENDIX F TRACKER DESCRIPTION..... F-1

F.1	Introduction.....	F-1
F.2	Assumptions	F-1
F.3	Tracker.....	F-1
F.4	Tracker Analysis.....	F-11

APPENDIX G ACRONYMS AND ABBREVIATIONS.....G-1

LIST OF FIGURES

Figure 1-1	Major Elements of the DAA System onboard the Aircraft.....	3
Figure 1-2	Major Elements of the DAA System in the Control Segment.....	4
Figure 1-3	EO/IR Sensor System Block Diagram.....	5
Figure 1-4	EO/IR Range Definitions.....	12
Figure 2-1	EO/IR Sensor System State Machine.....	19
Figure 2-2	Optronic Test Bench for EO/IR Sensor System Tests.....	38
Figure 2-3	Image Database and Tracking Test Bench for EO/IR Sensor System Tests.....	39
Figure 2-4	DAA EO/IR Sensor System Track Accuracy Test Setup.....	49
Figure A-1	Typical Transmission at Sea Level across a 1-km Path.....	A-1
Figure A-2	Atmospheric Transmission as a Function of Altitude.....	A-2
Figure B-1	Geometric Constraint.....	B-3
Figure B-2	Encounter Geometry.....	B-3
Figure B-3	Example MCR Curve.....	B-5
Figure B-4	MCR by UA Airspeed – Bearing 0 deg.....	B-6
Figure B-5	MCR by UA Airspeed – Bearing ± 30 deg.....	B-7
Figure B-6	MCR by UA Airspeed – Bearing ± 60 deg.....	B-7
Figure B-7	MCR by UA Airspeed – Bearing ± 90 deg.....	B-8
Figure B-8	Polar Plot of Modified DR Correction Factors.....	B-9
Figure B-9	UAS and VFR Traffic Speed and Altitude.....	B-11
Figure C-1	Low-SWaP Encounter Speed Distribution.....	C-2
Figure C-2	Low-SWaP Encounter Altitude Distribution.....	C-2
Figure C-3	Event Filtering Process Flow Diagram.....	C-4
Figure C-4	Capturing the FOR/DR Entry Time Margin.....	C-5
Figure C-5	Effect of Elevation FOR on Pop-up Encounter Density.....	C-7
Figure C-6	Weighted Time Margin PDF, Pop-up Intruders.....	C-8
Figure C-7	Pop-up Categorization by Entry Beyond Az or El FOR, 10-sec Response Time.....	C-10
Figure C-8	Pop-up Categorization by Entry Beyond Az or El FOR, 17-sec Response Time.....	C-11
Figure C-9	Pop-up Categorization by Entry Beyond Az or El FOR, 25-sec Response Time.....	C-12
Figure C-10	Extra Density of Pop-ups, by Final Entry into FOR/DR, 25-sec Response Time.....	C-13
Figure C-11	Midair Collision Fault Tree.....	C-15
Figure D-1	Minimum Intensity in Vertical Planes for Anti-Collision Lights (AC20-74B).....	D-7
Figure D-2	Minimum Intensity in Horizontal/Vertical Planes for Position Lights (AC20-74B).....	D-8
Figure D-3	Angles defining the Position of the Sun and a Sky Element.....	D-11
Figure D-4	Sky Aspects for the Sky Type defined in Table D-6.....	D-13
Figure D-5	Directional Spectral Radiance of Clear Sky – Mid-Latitude Summer Atmosphere.....	D-14
Figure D-6	Flow Chart for Calculating Intruder IR SNR on a Detector.....	D-17
Figure D-7	Cessna 206 3D CAD Model Adapted for Thermal Calculation.....	D-18
Figure D-8	IR Signature Calculation.....	D-19
Figure D-9	Background Scene Modeling Example.....	D-19
Figure D-10	Sensor-Level Images: without Sensor Errors (L)/including Sensor Errors (R).....	D-21
Figure D-11	Sensor Signal Evolution with Time.....	D-22
Figure D-12	Definition of the EO/IR Sensor System MTF.....	D-23
Figure E-1	Range Estimation Error Plots.....	E-2
Figure E-2	Encounter Characteristics.....	E-3
Figure E-3	Risk Ratios.....	E-9
Figure E-4	LoWC Ratios.....	E-10
Figure E-5	Split Alert Probability.....	E-11
Figure E-6	Expected Number of Split Alerts.....	E-12
Figure E-7	Reversal Probability.....	E-12
Figure E-8	Expected Number of Guidance Reversals.....	E-13
Figure E-9	Pilot Workload.....	E-14
Figure E-10	System Operating Characteristics.....	E-15

Figure E-11	Metrics for Variable Time Correlation of Angular Rate Error	E-16
Figure E-12	Metrics for Variable Time Correlation for Range and Range Rate Error.....	E-16
Figure F-1	Measured Parameters	F-1
Figure F-2	Tracker Architecture	F-3
Figure F-3	Accuracy Analysis Results	F-13

LIST OF TABLES

Table 1-1	Ownship State Data (Note 1)	9
Table 1-2	LWIR Intruder Signatures.....	14
Table 1-3	EO Intruder Signatures	14
Table 2-1	Track Output Data	20
Table 2-2	EO/IR DR Corrections per Intruder Bearing Angle.....	25
Table 2-3	Reported Uncertainties	27
Table 2-4	EO/IR Tracker Lag Test Requirements	29
Table 2-5	DAA Airborne Equipment Environmental Test Requirements	33
Table 2-6	Statistical Encounter Scenarios or Flight Test Scenarios.....	42
Table 2-7	Individual Encounter Scenarios or Flight Test Scenarios	45
Table 2-8	Test Procedure-to-Requirements Matrix.....	64
Table 2-9	Requirements-to-Test Procedure Traceability Matrix	65
Table 3-1	Installed Performance Flight Tests	69
Table A-1	Qualitative Effect of Weather Conditions on Atmospheric Transmission.....	A-2
Table A-2	Qualitative Indications on Strengths and Weaknesses per Band of Operation.....	A-3
Table B-1	Aircraft Performance Parameters.....	B-1
Table B-2	Geometric Constraint.....	B-2
Table B-3	Reference Slant Range (Head-on) in NM.....	B-5
Table B-4	DR Correction Factors	B-6
Table B-5	Modified Reference Slant Range (Head-on) in NM.....	B-8
Table B-6	Modified DR Correction Factors	B-9
Table B-7	C20+C21 Metric for the DRs from Tables B-5 and B-6.....	B-13
Table B-8	C20+C21 Metric for the DRs from Tables B-3 and B-4.....	B-13
Table C-9	Summary of Unmitigated Separation.....	C-3
Table C-10	Low-SWaP DR Candidates with Correction Factors.....	C-3
Table C-11	Weighted Probability of Pop-up Intruders, Based on First Entry into FOR/DR	C-5
Table C-12	Weighted Probability of Encounters Affected by 5-sec Track Acquisition Time	C-6
Table C-13	Weighted Probability of Encounter Categories	C-9
Table C-14	Weighted Probability of Pop-up Intruders, Based on Final Entry into FOR/DR.....	C-12
Table D-15	Illuminance for Daylight Conditions	D-2
Table D-16	Illuminance for Night Conditions	D-2
Table D-17	Intruder IR Signatures.....	D-4
Table D-18	Aircraft Size and Albedo per Signature Category and Aircraft Type.....	D-5
Table D-19	Potential Non-cooperative Intruder Dimensions.....	D-9
Table D-20	Background IR and EO Characteristics	D-10
Table D-5-21	Value of Parameters for Typical Sky Luminance Distribution.....	D-12
Table D-5-22	Extinction Coefficient for Different Types of Atmosphere.....	D-15
Table D-5-23	Mean Atmospheric Transmission for the 8-12 μm Band and Various Altitudes.....	D-16
Table E-24	Analysis Configurations	E-4
Table E-25	SC-228 Pilot Model Update Delay Times	E-6
Table E-26	Safety Metrics	E-7
Table E-27	Operational Suitability Metrics.....	E-8
Table F-28	Lag Analysis.....	F-14

This Page Intentionally Left Blank

1 Purpose And Scope

1.1 Introduction

This document contains Minimum Operational Performance Standards (MOPS) for Electro-Optical/Infrared (EO/IR) sensors for traffic surveillance.

The EO/IR sensor system is a surveillance source for non-cooperative intruders for a Detect and Avoid (DAA) system used in Unmanned Aircraft Systems (UAS) transiting through Class B, C, D, E, and G airspace and performing extended operations higher than 400' Above Ground Level (AGL) in Class D, E (up to Flight Level (FL180)), and G airspace. It includes equipment to enable UAS operations in Terminal Areas during approach and departure in Class C, D, E and G airspace and off-airport locations. It does not apply to small UAS (sUAS) operating in low-level environments (below 400') or other segmented areas. Likewise, it does not apply to operations in the Visual Flight Rules (VFR) traffic pattern of an airport or to surface operations.

These standards specify the characteristics of the EO/IR sensor system that should be useful for designers, manufacturers, installers and users of the equipment. Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under the conditions specified herein. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

This document sets performance standards for EO/IR sensor systems for non-cooperative traffic surveillance as part of a DAA system. Separate MOPS were developed for the DAA system adapted to low-power ownership.¹ The RTCA MOPS for DAA Systems (hereafter referred to as the “DAA MOPS”) refer to these MOPS (hereafter referred to as the “EO/IR sensor system MOPS” or “these MOPS”) to satisfy surveillance requirements for non-cooperative intruders adapted to a low-power Unmanned Aircraft (UA). The basic functions of the EO/IR sensor system, e.g., Power On/Off, are controlled by the Remote Pilot in the Control Station (CS). Similarly, the EO/IR sensor system provides its status to the CS during operation. The CS sends commands to the EO/IR sensor system and receives status from it. Tracks generated by the EO/IR sensor system are sent to the DAA system for further processing.

Section 1 of this document provides information needed to understand the rationale for the equipment characteristics and requirements in Section 2. It describes typical equipment operations and operational goals as envisioned by the members of RTCA Inc. Special Committee (SC)-228, and establishes the basis for the standards stated herein. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2 contains the performance requirements for the equipment. These standards specify the required performance under standard environmental conditions. Also included are recommended bench test procedures necessary to demonstrate equipment compliance with the stated minimum requirements.

Section 3 describes the performance required of installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4 contains aircraft operational performance characteristics.

¹ Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems, RTCA DO-365B