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RTO AGARDograph 300
Flight Test Techniques Series – Volume 26

AG-300-V26

Airborne Laser Systems Testing and Analysis

(Essais et analyse des systèmes laser embarqués)

This AGARDograph has been sponsored by the
Systems Concepts and Integration Panel.

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- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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AGARDograph Series 160 & 300

Soon after its founding in 1952, the Advisory Group for Aerospace Research and Development (AGARD) recognized the need for a comprehensive publication on Flight Test Techniques and the associated instrumentation. Under the direction of the Flight Test Panel (later the Flight Vehicle Integration Panel, or FVP) a Flight Test Manual was published in the years 1954 to 1956. This original manual was prepared as four volumes: 1. Performance, 2. Stability and Control, 3. Instrumentation Catalog, and 4. Instrumentation Systems.

As a result of the advances in the field of flight test instrumentation, the Flight Test Instrumentation Group was formed in 1968 to update Volumes 3 and 4 of the Flight Test Manual by 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, it was decided that further specialist monographs should be published covering aspects of Volumes 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group (FTTG) was established to carry out this task and to continue the task of producing volumes in the Flight Test Instrumentation Series. The monographs of this new series (with the exception of AG237 which was separately numbered) are being published as individually numbered volumes in AGARDograph 300. In 1993, the Flight Test Techniques Group was transformed into the Flight Test Editorial Committee (FTEC), thereby better reflecting its actual status within AGARD. Fortunately, the work on volumes could continue without being affected by this change.

An Annex at the end of each volume in both the AGARDograph 160 and AGARDograph 300 series lists the volumes that have been published in the Flight Test Instrumentation Series (AG 160) and the Flight Test Techniques Series (AG 300) plus the volumes that were in preparation at that time.

Airborne Laser Systems Testing and Analysis

(RTO-AG-300-V26)

Executive Summary

Recent developments in the field of electro-optics have led to innovative concepts in the mission management of current and next generation ground attack aircraft. Particularly, tactical laser systems including LIDAR, range finders (LRF) and target designators (LTD) are used today by most military forces in the world and new promising laser technologies are being explored. Most laser systems are active devices that operate in a manner very similar to microwave radars but at much higher frequency (e.g., LIDARS, LRF). Other devices (e.g., LTD, Beam-riders) are used to precisely direct laser guided weapons (LGW) against ground targets. A combination of both functions is often encountered in modern integrated airborne navigation-attack systems. Compared to similar microwave devices, the higher frequency of laser systems has the beneficial effect of smaller components and remarkable angular resolution values. On the other hand, laser systems performance are much more sensitive to the vagaries of the atmosphere and are thus generally restricted to shorter ranges in the lower atmosphere than microwave systems.

For aircraft experimental activities with laser systems, it is important to optimise test missions taking into account the tactics of employment of the systems in different operational scenarios and to verify the performance of the systems in realistic environments at the ranges. Also important for test/training purposes is the definition of laser safety criteria, since most systems currently in service operate in the near infrared with considerable risk for the naked human eye. Therefore, it is essential to define methods for predicting and evaluating the performance of laser systems operating in the infrared, with different operational and environmental conditions, taking into account laser safety issues.

The objective of this AGARDograph is to present the main results of the PILASTER (**PI**SQ **LAS**er **T**est and **E**valuation **R**ange) research and development program, conducted by the Italian Air Force Flight Test Centre in collaboration with the Defence Academy of the United Kingdom (Cranfield University – RMCS). Particularly, the AGARDograph describes state-of-the-art methods for evaluating the performance of laser systems operating in the infrared (including flight test, modelling and simulation), with different operational and environmental conditions. Present laser technology status and future technology trends are investigated, in order to determine the relative strengths and weaknesses of the most promising laser technologies when applied to airborne systems. Suitable mathematical models for laser beam propagation, geometric analysis, target reflectivity and detection are identified. Safety issues are deeply analysed in the light of the operational requirements for airborne systems (including guided weapons), and the technical characteristics of the PILASTER range instrumentation (designed for current and likely future laser systems test/training operations) are identified. Finally, the requirements associated with tactical and test/training mission planning are defined, together with the kernel algorithms of suitable simulation programs capable to assist aircrews and flight test engineers in the determination of optimal aircraft flight profiles for operations at the ranges.

Essais et analyse des systèmes laser embarqués

(RTO-AG-300-V26)

Synthèse

Les développements récents dans le domaine de l'optronique ont conduit à des concepts innovants dans la gestion des missions des avions d'attaque au sol actuels et de prochaine génération. En particulier, les systèmes laser tactiques comprenant les télémètres LIDAR (LRF) et les systèmes de désignation d'objectifs LIDAR (LTD) sont utilisés actuellement par la plupart des forces armées dans le monde et des technologies laser nouvelles prometteuses sont à l'étude. La plupart des systèmes laser sont des dispositifs actifs qui fonctionnent d'une manière très similaire aux radars à micro-ondes mais avec une fréquence beaucoup plus élevée (par exemple, LIDARS, LRF). D'autres dispositifs (par exemple, le LTD, le guidage sur faisceau) sont utilisés pour diriger avec précision les armes à guidage laser (LGW) contre les cibles terrestres. On rencontre souvent une combinaison des deux fonctions dans les systèmes intégrés modernes d'attaque et de navigation embarqués. Comparés à des dispositifs similaires à micro-ondes, la fréquence plus élevée des systèmes laser a pour effet bénéfique de comporter des composants plus petits et des valeurs de résolution angulaires remarquables. D'autre part, les performances des systèmes laser sont bien plus sensibles aux caprices de l'atmosphère et sont, de ce fait, généralement limitées à des portées plus courtes en basse altitude que les systèmes à micro-ondes.

Pour les expériences aéronautiques avec des systèmes laser, il est important d'optimiser les missions d'essais en prenant en compte la tactique d'emploi des systèmes dans différents scénarios opérationnels et de vérifier les performances des systèmes dans des environnements réalistes sur les ranges. La définition des critères de sécurité laser est également importante pour les essais et la formation, car de nombreux systèmes en service actuellement fonctionnent dans le proche infrarouge avec des risques considérables pour la vision humaine sans protection. De ce fait, il est essentiel de définir des méthodes de prévision et d'évaluation des performances des systèmes laser fonctionnant en infrarouge, avec des conditions opérationnelles et environnementales différentes prenant en compte les questions de sécurité laser.

L'objectif de cet AGARDographe est de présenter les principaux résultats du programme de recherche et de développement du polygone d'essai et d'évaluation PILASTER (**PI**SQ **LAS**er **T**est and **E**valuation **R**ange) conduit par le Centre d'Essais en Vol de l'Armée de l'Air Italienne en collaboration avec la Defence Academy du Royaume-Uni (Université de Cranfield – RMCS). En particulier, l'AGARDographe décrit l'état de l'art des méthodes d'évaluation des performances des systèmes laser fonctionnant en infrarouge (comprenant les essais en vol, la modélisation et la simulation) dans différentes conditions opérationnelles et environnementales. L'état actuel de la technologie laser et les orientations technologiques futures sont étudiés afin de déterminer les forces et les faiblesses relatives des technologies laser les plus prometteuses appliquées aux systèmes embarqués. Les modèles mathématiques adaptés aux propagations à faisceau laser, l'analyse géométrique, la réflexion des cibles et la détection sont identifiés. Les questions de sécurité sont analysées en profondeur à la lumière des besoins opérationnels concernant les systèmes embarqués (dont les engins guidés), et les caractéristiques techniques de l'instrumentation du polygone PILASTER (conçu pour les opérations d'essais et de formation pour les systèmes laser actuels et vraisemblablement futurs) sont identifiées. Finalement, les besoins associés à la planification des missions d'essais et de formation sont définis avec les algorithmes fondamentaux des programmes de simulation adaptés capables d'aider les équipages et ingénieurs d'essais en vol dans la détermination des profils de vol optima des avions pour les opérations sur les champs de tir.

Acknowledgements

We would like to express our deepest gratitude to the RSV Commanders, PISQ Commanders and CSV Commanders who strongly supported the PILASTER project since its earliest stages.

We would also like to thank the Officers of the Italian Air Staff Logistics Branch for supporting ideas, giving suggestions and encouraging our work since the beginning of the project.

Great thanks go to the Italian Air Force Flight Test Engineers of the RSV Technical Group, to the Experimental Test Pilots of the 311th Flight Group, to the PISQ Technical Direction Officers, and to the Personnel of the 185th RAO of the Italian Army, that contributed to the PILASTER program.

Many thanks go to the technical personnel of Alenia-Aerospazio Flight Test Department, Selex Communications and LOT-Oriel Italia, for their support to the PILASTER program.

Preface

Major Roberto Sabatini is a Senior Flight Test Engineer and C4ISR Acquisition Manager in the Italian Air Force. He entered the Air Force in 1990 as an Engineering Officer (Avionics) and, after completion of the Officer's training, he was posted to the Italian Air Force Research and Flight Test Centre (Divisione Aerea Studi Ricerche e Sperimentazioni / Centro Sperimentale di Volo – Reparto Sperimentale Volo) in Pratica di Mare AFB (Rome). Major Sabatini graduated with a PhD in Electro-Optics with a Thesis on Airborne Laser Systems and Infrared Sensors (Cranfield University – UK) and a Doctor of Engineering Degree in Astronautical Engineering (Summa Cum Laude) with a Thesis on Satellite Navigation Systems (University of Rome "La Sapienza"). He also obtained an MSc in Navigation Technology (Nottingham University – UK) and a Diploma of Telecommunications Engineering with Full Grades ("Enrico Fermi" Industrial Engineering Institute of Rome). Furthermore, he received the qualifications of Aerosystems Graduate (ASG) with Distinction (Academic Lead), NATO Electronic Warfare Officer and Weapons Employment Officer (EWO/WEO) from the Royal Air Force (UK), and the license of Flight Test Engineer (Avionics) from the Italian Air Force.

During his Flight Test Engineering assignment, he served as Chief of the Electro-Optics Section, Chief of the Armament Section, and Head of the Communications, Navigation & Identification Section in the Avionics and Armament Test & Evaluation Branch of Reparto Sperimentale Volo. In 2006, Major Sabatini was appointed to the US Navy Program Executive Office for C4I and Space (PEO C4I & Space), Airborne Networking and Integration Program Office – PMW 780 (successively integrated in the US DoD Joint Program Executive Office Joint Tactical Radio System – JPEO JTRS), serving as the Italian Platform Representative at the Multifunctional Information Distribution System International Program Office (MIDS IPO) in San Diego, CA (USA). In his career, Major Roberto Sabatini was responsible for numerous development and flight test programs (Italian TORNADO Mid-Life-Update, EF-2000/TYPHOON Navigation and Landing Systems, AM-X Avionics Update, MB-3399CD Avionics Developments and Flight Testing, Development of a Laser Test Range for the Italian Air Force, FLIR/Laser Pods/Night Vision Imaging Systems Integration on various Fixed and Rotary Wing Aircraft, etc.), and is now in charge for MIDS Low Volume Terminal (LVT) Integration on Italian Military Platforms (Italian TORNADO IDS/ECR, TYPHOON, Navy and Army Platforms) and for the MIDS Joint Tactical Radio System (JTRS) developments for Italy. Furthermore, between 2006 and 2009, Major Sabatini has served as the MIDS European Logistics Manager and, since 2009, as the MIDS Software Engineering and Block Cycle Manager. In this role, Major Sabatini acts as the main point of contact for MIDS Software Operational and Technical Requirements implementation (Functional, Performance and Interoperability Requirements), Software Engineering Developments, Systems Engineering and Integration (SE&I) Support and Related Test, Evaluation and Certification Activities performed in the 5 MIDS nations (US, France, Italy, Germany and Spain) and in more than 30 MIDS third party sales nations and NATO agencies (over 70 different types of military platforms and 5500 MIDS terminals delivered worldwide).

Major Sabatini has written several peer-reviewed journal and conference papers on Aerospace Electronics and Electro-Optics systems. He is the author of NATO RTO AGARDograph volumes and books on Avionics Systems and has taught this subject on various occasions, including academic courses organized by Universities and the Italian Ministry of Defence.

Dr. Richardson is the Head of Electro-Optics Group at the Defence Academy of the United Kingdom, Shrivenham. He has a BSc with First Class Honours in Physics (from Imperial College – London) and is an Associate of the Royal College of Science. He also obtained an MSc with Distinction in Applied Optics (from Imperial College – London), a Diploma of Imperial College, and a PhD in Infrared Physics from Cranfield University.

He has been at the Defence Academy of the United Kingdom, Shrivenham since 1989, as a member of the lecturing staff. His main teaching duties are to postgraduate courses, in particular Defence Technology, Guided Weapons and Electronic Warfare MSc's. He also lectures in the United States on various EO&IR courses and seminars, and has taught EO&IR to the Australian Technical Staff Officers Course at the Australian Defence Force Academy in Canberra on six occasions. He has also taught EO&IR Electronic Warfare at the Finnish School of Military Electronics in Riihimaki.

Prior to joining the Defence Academy, he spent five years at GEC-Marconi working as a Professional Engineer/Senior Engineer/Section Leader and was concerned with all aspects of research, design, simulation and fabrication of thermal imaging sighting systems.

His research work is in the fields of Infrared Signature Simulation & Modelling and EO&IR Countermeasures. He has written numerous classified and unclassified papers on these subjects, and holds a Classified Patent on a novel Infrared camouflage material. He is the editor and principal author of a book on battlefield surveillance technology and has acted as a consultant and defence analyst, on numerous occasions, to both the UK Ministry of Defence and commercial industry.

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List of Acronyms

A-BHA	ALS Beam Hazard Area
ABL	Airborne Laser
A-BZ	ALS Buffer Zone
ADU	Analog Digital Unit
A-EBZ	ALS Extended Buffer Zone
A-EVP	ALS Eye-safety Verification Program
AGT	Air Force Ground Troops
AIRF	ADU/Integrated Radiance Response Function
ALL	Airborne Laser Laboratory
ALS	Airborne Laser System
ALS-MPP	ALS Mission Planning Program
A-LTD	Airborne LTD
AMCF	Atmospheric Model Correction Function
AP	Percentage of Acquired Pulses
APD	Avalanche Photodiode
ARTIMLR	Artillery Thermal Imager Module Long-Range
ATGT	Acquisition Training Target
BER	Bit Error Rate
BIT	Built-In Test
BRC	Bomb Release Corridor
BRDF	Bidirectional Reflectance Distribution Function
BTB	Bang-to-Bang Guidance
BZE	Effective G-BZ
CAD	Computer Assisted Design
CCD	Charge Coupled Device
CCG	Computer Control Group
CD	Coherent Detection
CDF	Cumulative Frequency Distribution Functions
CDU	Cockpit Display Unit
CEP	Circular Error Probable
CITE	Cinetheodolite
CLDP	Convertible Laser Designation Pod
COIL	Chemical Oxygen Iodine Laser
COS	Cinetheodolites Operator Sight
CP	Control Panel
CPU	Central Processing Unit
CSV	Centro Sperimentale di Volo
CT	Control Technique
CW	Continuous Wave
DAS	Digital Acquisition System
DC	Direct Current
DEA	Array of Detectors
DEST	Destroyable Target
DEW	Directed Energy Weapon
DGPS	Differential Global Positioning System

DPU	Detector Processing Unit
DRS	Display and Recording Station
DUH	Detector Unit Housing
ECR	Electronic Combat and Reconnaissance
EF-BZ	G-BZ Elliptical Footprint
EGEA	Extended GEA
EHAS	Extended HAS
EMD	Engineering Manufacturing and Development
EMT	Extinction Measurement Technique
EO	Electro-Optics
EOHD	Extended Ocular Hazard Distance
EPA	Energy Pointing Accuracy
EPIM	Energy Pixel Intensity Matrix
EPU	Electronic Processing Unit
Er:fiber	Erbium Fiber (Laser)
ESLM	Elder Strong Langer Middleton (Propagation model)
EVP	Eye-safety Verification Program
FAC	Forward Air Controllers
FAR	False Alarm Rate
FASCODE	FASt atmospheric signature CODE
FCS	Fire Control System
FIR	Far Infrared
FLIR	Forward Looking Infrared
FPA	Focal Plane Array
FRCT	Fast-recoverable Target
FTA	Folding Tail Assembly
FWHM	Full Width at Half Maximum
FXDT	Fixed Target
GaAlAs	Gallium Aluminum Arsenide
GaAs	Gallium Arsenide
G-BHA	GLS Beam Hazard Area
GBU	Guided Bomb Unit
G-BZ	GLS Buffer Zone
GEA	Ground Evacuation Areas
G-EBZ	GLS Extended Buffer Zone
G-EVP	GLS Eye-safety Verification Program
GLS	Ground Laser System
GLTD	Ground Laser Target Designator
GPA	Geometric Pointing Accuracy
GPIM	Grey-scale Pixel Intensity Matrix
GPS	Global Positioning System
HAS	Hazard Air Space
HC	Heading Change
HDD	Head-Down Display
He-Ne	Helium Neon (Laser)
HITRAN	HIgh resolution TRANsmission code
HMI	Human Machine Interface
HUD	Head-Up Display
HW	Hardware

I/O	Input/Output
I/P-I	Input Interface
ID	Incoherent Detection
IDS	Interdiction and Strike
IGB	Infrared Guided Bomb
INS	Inertial Navigation System
INST	Installation Mode (LTM)
IR	Infrared
IREF	IR Reference Target
ItAF	Italian Air Force
IVC	International Visibility Code
IWF	Impact Warning Function
LADAR	Laser Radar
LAN	Local Area Network
LATOA	Laser Activation Time Signal
LBP	Laser Beam Profiling
LCOM	Laser Communication Systems
LCS	Laser Cross-Section
LCU	LOAS Control Unit
LDI	LOAS Debugging Interface
LDP	Laser Designation Pod
LDV	Laser Doppler Velocimetry
LEM	Laser Energy Meter
LEMS	Laser Energy Measurement System
LGB	Laser Guided Bomb
LGW	Laser Guided Weapons
LIDAR	Light Detection and Ranging
LLLGB	Low Level Laser Guided Bomb
LOAS	Laser Obstacle Avoidance System
LOE	Laser Output Energy
LOS	Line Of Sight
LOWTRAN	LOW spectral resolution TRANsmission code
LPDB	Laser Propagation Data Base
LR	Lethal Range
LRF	Laser Range Finder
LSM	Laser Scatter-Meter
LSO	Laser Safety Officer
LSU	Laser Seeker Unit
LTD	Laser Target Designator
LTM	Laser Tracking and Monitoring system
LWR	Laser Warning Receiver
MC	Main Computer
MCU	Missile Control Unit
MDED	Minimum Detectable Energy Density
MDPD	Minimum Detectable Power Density
MIR	Mid Infrared
MODTRAN	MODerate spectral resolution TRANsmission code
MPA	Mission Planning and Analysis
MPE	Maximum Permissible Exposure

MRTD	Minimum Resolvable Temperature Difference
MSU	Monitoring and Control Station Unit
ND	Neutral Density
Nd:YAG	Neodymium Yttrium Aluminum Garnet (Laser)
NEP	Noise Equivalent Power
NFH	NATO Frigate Helicopter
NFOW	Narrow Field Of View
NHC	Navigator Hand Control
NIR	Near Infrared
NOHD	Nominal Ocular Hazard Distance
NVG	Night Vision Goggles
O/P-I	Output Interface
OD	Optical Density
OF	Optical Fibre
OHD	Ocular Hazard Distance
OPR	Operational Mode (LTM)
OU	Optical Unit
P/A	Pod-Aircraft
PAS	Pneumatic Actuation System
PC	Personal Computer
PCC	PISQ Control Centre
PD	Pulse Duration
PDF	Probability Density Functions
PDRR	Program Definition and Risk Reduction
PE	Pointing Error
PEP	Pyroelectric Probe
PG	Proportional Guidance
PILASTER	PISQ LASer Test and Evaluation Range
PIM	Pixel Intensity Matrix
PISQ	Poligono Interforze del Salto di Quirra
PLD	Portable Laser Designator
PPS	Precise Positioning Service
PRF	Pulse Repetition Frequency
PTD	Pulse Train Duration
PVT	Position-Velocity-Time
RAO	Reggimento Acquisizione Obiettivi
RC	Remote Control
RH	Relative Humidity
RP3	Range Performance Prediction Program
RS	Reference Station
RSS	Root Sum Squared
RSV	Reparto Sperimentale Volo
RX	Receiver
SA	Selective Availability
SDP	Spot Distortion Parameter
SHU	Sensor Head Unit
SK	Soft Key

SM	Safety Margin
SNR	Signal-to-Noise Ratio
SPA	Safe Positioning Area
SPS	Standard Positioning Service
SR	Slant-Range
SRTOA	Synchronous Signal
STANAG	NATO STANdardized AGreement
STU	Sensor Tracking and Measurement Unit
SW	Software
TAC	Area Correlation Tracking
TAS	True Air Speed
TC	Tactical Computer
TIC	Image Contrast Tracking
TLR	Target Lethal Range
TO	Trial Officer
TRF	Transfer Mode (LTM)
TSPI	Time and Space Position Information
TTH	Tactical Transport Helicopter
TTPF	Target Transfer Probability Function
TU	Traversing Unit
TV	Television
TX	Transmitter
UHF	Ultra High Frequency
UR	User Receiver
VHF	Very High Frequency
WAN	Wireless Area Network
WFOV	Wide Field Of View
WMO	World Meteorological Office
WMS	Wireless Meteorological Station
WSO	Weapon System Operator

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Absorption	Detector	Laser test range
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BRDF	Laser performance	Reflectivity
Electro-optical systems	Laser range finder	Scattering
Flight test techniques	Laser safety	Transmittance
Infrared camera	Laser target designator	

14. Abstract

This AGARDograph presents state-of-the-art methods for evaluating the performance of laser systems operating in the infrared with different operational and environmental conditions. Results of the PILASTER (**PI**SQ **LAS**er **T**est and **E**valuation **R**ange) research and development program, conducted by the Italian Air Force Flight Test Centre in collaboration with the Defence Academy of the United Kingdom (Cranfield University) are presented. For aircraft experimental activities with laser systems, it is important to define test missions representative of different operational scenarios and to verify systems performance in realistic environments. Laser technology status and future technology trends are investigated, in order to determine the relative strengths and weaknesses of these technologies when applied to airborne systems. Mathematical models for laser beam propagation, mission geometry analysis, target reflectivity and detection are identified. Safety issues are analysed in the light of the operational requirements and human eye safety for airborne laser systems and guided weapons. Technical characteristics of the PILASTER range instrumentation are identified. Finally, the requirements associated with tactical and test/training mission planning are defined with the kernel algorithms of suitable simulation programs capable to assist aircrews and flight test engineers in the determination of optimal aircraft flight profiles.

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