



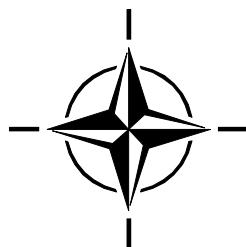
RTO TECHNICAL REPORT

TR-HFM-162

## Rotary-Wing Brownout Mitigation: Technologies and Training

(Remèdes contre le phénomène de brownout  
sur les appareils à voilure tournante :  
Technologies et entraînement)

This Report documents the findings of Task Group HFM-162 (2008 – 2011) that investigated the training and technologies employed by member NATO Nations to mitigate the impact of brownout on rotary-winged operations.



Published January 2012





RTO TECHNICAL REPORT

TR-HFM-162

# Rotary-Wing Brownout Mitigation: Technologies and Training

(Remèdes contre le phénomène de brownout  
sur les appareils à voilure tournante :  
Technologies et entraînement)

This Report documents the findings of Task Group HFM-162 (2008 – 2011) that investigated the training and technologies employed by member NATO Nations to mitigate the impact of brownout on rotary-winged operations.

# The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- 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.

The content of this publication has been reproduced directly from material supplied by RTO or the authors.

Published January 2012

Copyright © RTO/NATO 2012  
All Rights Reserved

ISBN 978-92-837-0149-1

Single copies of this publication or of a part of it may be made for individual use only. The approval of the RTA Information Management Systems Branch is required for more than one copy to be made or an extract included in another publication. Requests to do so should be sent to the address on the back cover.

# Table of Contents

	<b>Page</b>
<b>List of Figures</b>	<b>viii</b>
<b>List of Tables</b>	<b>xi</b>
<b>List of Acronyms</b>	<b>xii</b>
<b>Acknowledgements</b>	<b>xv</b>
<b>Programme Committee</b>	<b>xvi</b>
 <b>Executive Summary and Synthèse</b>	<b>ES-1</b>
 <b>Chapter 1 – Introduction</b>	<b>1-1</b>
1.1 The Rotary-Wing Brownout Problem	1-1
 <b>Chapter 2 – Physiological and Perceptual Limitations: Current Approach in Brownout</b>	<b>2-1</b>
2.1 Introduction	2-1
2.2 Background on Spatial Orientation in Flight	2-1
2.3 The “Brownout” Phenomenon	2-1
2.4 Pertinent Orientation Information for Helicopter Take-Offs and Landings	2-2
2.5 Physiological Limitations During Brownout	2-2
2.6 Other Aggravating Factors that May Predispose SD	2-4
2.7 Inadequacies of Current Landing Approach During Brownout	2-4
2.8 Conclusion	2-8
2.9 References	2-8
 <b>Chapter 3 – Countermeasures: Human Machine Interfaces</b>	<b>3-1</b>
3.1 Introduction	3-1
3.2 Visual Display	3-1
3.2.1 2-D Low Speed Symbology – Brownout Symbology System (BOSS)	3-1
3.2.2 3-D Conformal Symbology Display System – FTL 3-D Conformal Symbology	3-4
3.2.2.1 Synthetic Vision	3-6
3.3 Alternative Displays	3-7
3.3.1 3-D Audio Displays Overview	3-7
3.3.2 Tactile Displays	3-9
3.3.3 Haptic Controls	3-10
3.3.4 Conclusion	3-10
3.4 References	3-10

<b>Chapter 4 – Technology: Sensors and Data Processing</b>	<b>4-1</b>
4.1    Introduction	4-1
4.2    Technology Assumptions	4-1
4.2.1    The Helicopter	4-1
4.2.2    Mission Scenario	4-1
4.2.3    Minimal Information Required for Safe Landing	4-2
4.2.4    Types of Brownout Accident	4-2
4.3    Technologies	4-3
4.3.1    Onboard Systems	4-3
4.4    Analysis of Sensor Sub-Systems	4-4
4.4.1    Radar	4-4
4.4.1.1    Active MMW Radar Altimeter Sensor	4-4
4.4.1.2    MMW Electronic Bumper Sensor	4-5
4.4.1.3    Scanning Active Millimetre Wave (MMW) Radar Sensor	4-7
4.4.2    Laser	4-9
4.4.2.1    LADAR Sensor System	4-9
4.4.3    Passive Electro-Optical	4-11
4.4.3.1    Visible Waveband or Low Light Level TV Cameras	4-11
4.4.3.2    Passive MMW Imaging Sensor	4-12
4.4.3.3    Thermal Imaging Sensor	4-14
4.5    Human Machine Interface/Display Sub-Systems	4-15
4.5.1    Head-Mounted Display	4-15
4.5.1.1    Capability	4-15
4.5.1.2    Strengths	4-15
4.5.1.3    Limitations	4-16
4.5.1.4    System Maturity	4-16
4.5.1.5    System Integration Issues	4-16
4.5.1.6    Required Sub-Systems	4-17
4.5.1.7    Human Factors	4-17
4.5.2    Symbology	4-17
4.5.2.1    Two-Dimensional Symbology	4-18
4.5.2.2    Conformal Landing Symbology	4-20
4.5.2.3    Synthetic Vision	4-21
4.5.3    Tactile	4-24
4.5.3.1    Capability	4-24
4.5.3.2    Strengths	4-24
4.5.3.3    Limitations	4-24
4.5.3.4    System Maturity	4-24
4.5.3.5    System Integration Issues	4-25
4.5.3.6    Required Sub-Systems	4-25
4.5.3.7    Human Factors	4-25
4.6    Flight Control	4-25
4.6.1    Automatic Flight Control Systems (AFCS) with Advanced Flight Control Laws	4-25

4.6.1.1	Capability	4-25
4.6.1.2	Strengths	4-25
4.6.1.3	Limitations	4-26
4.6.1.4	System Maturity	4-26
4.6.1.5	System Integration Issues	4-26
4.6.1.6	Required Sub-Systems	4-26
4.6.1.7	Human Factors	4-26
4.6.2	Haptic Cueing with Active Sidesticks for Helicopter Operation	4-26
4.6.2.1	Capability	4-27
4.6.2.2	Strengths	4-28
4.6.2.3	Limitations	4-28
4.6.2.4	System Maturity	4-28
4.6.2.5	System Integration Issues	4-28
4.6.2.6	Required Sub-Systems	4-28
4.6.2.7	Human Factors	4-28
4.6.3	Dimensional Audio	4-28
4.6.3.1	Capability	4-28
4.6.3.2	Strengths	4-29
4.6.3.3	Limitations	4-29
4.6.3.4	System Maturity	4-29
4.6.3.5	System Integration Issues	4-29
4.6.3.6	Required Sub-Systems	4-29
4.6.3.7	Human Factors	4-29
4.6.4	Head-Up Displays	4-29
4.6.4.1	Capability	4-29
4.6.4.2	Strengths	4-30
4.6.4.3	Limitations	4-30
4.6.4.4	System Maturity	4-30
4.6.4.5	System Integration Issues	4-30
4.6.4.6	Required Sub-Systems	4-30
4.6.4.7	Human Factors	4-31
4.6.5	Helmet-Mounted Sight and Display (HMSD)	4-31
4.6.5.1	Capability	4-31
4.6.5.2	Strengths	4-31
4.6.5.3	Limitations	4-31
4.6.5.4	System Maturity	4-31
4.6.5.5	System Integration Issues	4-31
4.6.5.6	Required Sub-Systems	4-31
4.6.5.7	Human Factors	4-32
4.6.6	Summary on Capabilities and Limitations	4-32
4.7	Discussion	4-37
4.7.1	Technology Availability and Maturity	4-37
4.7.2	Short-Term Brownout Solutions	4-39
4.7.3	Promising Long-Term Solutions	4-39

---

4.7.4	Abandoned Potential Solutions	4-39
4.7.5	Example Brownout Solutions	4-40
4.7.5.1	Day Scenario	4-40
4.7.5.2	Night Scenario	4-41
4.7.5.3	Worst Case Scenario	4-41
4.8	Conclusions	4-43
4.9	References	4-43

## **Chapter 5 – Risk Management Strategies to Counter Brownout**

**5-1**

5.1	Introduction	5-1
5.2	Principles of Risk Management	5-1
5.3	Contributory Factors	5-1
5.4	Landing Techniques	5-2
5.4.1	Zero Speed Landing	5-3
5.4.2	Short Running Landing	5-4
5.4.3	Low Hover and Land	5-5
5.4.4	High Hover and Vertical Descent	5-6
5.5	Comparison of Landing Techniques	5-7
5.6	Crew Coordination	5-8
5.6.1	Overshoot	5-10
5.7	Tactical Constraints/Variations	5-10
5.8	Take-Off Techniques	5-11
5.9	Ground and Hover Taxi Maneuvers	5-11
5.10	Night Operations	5-11
5.11	Snow Operations	5-12
5.12	Approach to Land	5-12
5.13	Take Off	5-13
5.14	Under Slung Loads	5-13
5.14.1	USL Techniques	5-13
5.15	Formation Procedures	5-13
5.16	Platform Specifics	5-14
5.16.1	Tilt Rotor	5-14
5.16.2	Tandem Rotor	5-14
5.16.3	Single Main Rotor	5-14
5.16.4	Undercarriage Factors	5-15
5.17	Training for Transitions in Degraded Visual Environment	5-15
5.17.1	Development of the Procedure	5-15
5.17.2	Theoretical Training	5-16
5.17.3	Synthetic Training	5-16
5.17.3.1	Vision	5-16
5.17.3.2	Motion	5-16
5.17.3.3	Crew Concept	5-16
5.17.3.4	Synthetic Training Conclusions	5-16

5.17.4	Actual Flying	5-17
5.17.5	Continuation Training	5-17
5.17.6	Training Conclusions	5-17
5.18	Conclusions	5-17
<b>Chapter 6 – Conclusion</b>		<b>6-1</b>
6.1	Sensor Development	6-2
6.2	High-Resolution LADAR	6-3
<b>Chapter 7 – Supplemental Material</b>		<b>7-1</b>
<b>Annex A – TTPC-AER-TP2-2011 Task Outcome Report for Enhanced/Synthetic Vision Pilotage Systems</b>		<b>A-1</b>
A.1	Task Description	A-1
A.2	Achievement of Task Objectives	A-1
A.3	Conclusions	A-23
A.4	Recommendations	A-23
A.5	References	A-23
A.6	Annex A – Personnel and Organizations Involved	A-24
<b>Annex B – In-Flight Studies with Tactile Displays</b>		<b>B-1</b>
B.1	Flight Tests Using TSAS	B-1
B.2	TSAS Lite	B-2
B.3	Flight Test with TNO Tactile Torso Display	B-3
B.4	Concluding Remarks	B-8
B.4.1	Open Issues	B-9
B.5	References	B-9
<b>Annex C – Combination of Visual Display System with Sensor Technologies</b>		<b>C-1</b>
C.1	3D-LZ LADAR System	C-1
C.1.1	Integration of Symbology and Sensor-Based Imagery	C-3
C.1.2	3D-LZ Yuma Flight Test	C-8
C.1.2.1	Objective Results	C-13
C.1.2.2	Subjective Results	C-20
C.1.2.3	Conclusions	C-23
C.1.2.4	Future Suggested Improvements	C-24
C.2	References	C-24

# List of Figures

<b>Figure</b>		<b>Page</b>
Figure 2-1	The Vestibular System	2-3
Figure 2-2	Helicopter Entering a Brownout Condition	2-5
Figure 2-3	Helicopter Entering a Snow-Induced Whiteout Condition	2-6
Figure 2-4	An Example of a Take-Off in Brownout Conditions	2-6
Figure 3-1a	Enroute Page of BOSS Symbology	3-2
Figure 3-1b	Hover-Approach-Take-Off (HAT) Page of BOSS Symbology	3-3
Figure 3-2	A Comparison between 2-D and 3-D Symbology Displays	3-4
Figure 3-3	2-D Flight Data are Combined with the 3-D Symbols	3-5
Figure 3-4	Line of Sight Principle	3-6
Figure 3-5	3-D Audio	3-8
Figure 3-6	Examples of Tactile Cueing Devices; Vest; Seat	3-9
Figure 5-1	Zero Speed Landing	5-4
Figure 5-2	Short Running Landing	5-5
Figure 5-3	Low Hover and Land	5-6
Figure 5-4	High Hover and Vertical Descent	5-7
Figure A-1a	Hover Symbology for Hawkowl	A-2
Figure A-1b	Low Level Flight and Approach for Hawkowl	A-2
Figure A-2	Imaging Sensors and Pilot's Panel-Mounted Display	A-2
Figure A-3	New Flight Path Marker Symbol (ATP-FPM) Used with Synthetic Terrain Imagery as Flown on the US Army Fly-by-Wire RASCAL UH-60	A-3
Figure A-4	Flight Test Result – Maximum Low Altitude Error	A-3
Figure A-5	Flight Test Result – Max. Ground Track Error	A-4
Figure A-6	Pilot's Display for the Integrated Multi-Sensor Synthetic Imaging System (IMSIS) Used in Simulation by the US Army AFDD	A-4
Figure A-7	Sandblaster Display Includes Radar Data (Close) and Pre-Stored Terrain Elevation Data (Far) and Symbology	A-6
Figure A-8	Low Visibility Landing (LVL) Symbology	A-7
Figure A-9a	Start Approach	A-8
Figure A-9b	Nearing LZ	A-8
Figure A-9c	At LZ	A-8
Figure A-10	University of Iowa Simulator for Brownout Landing	A-9
Figure A-11a	CAAS Display Modified with an Integrated Altimeter and Vertical Speed Indicator	A-10
Figure A-11b	Synthetic Vision Display	A-10

Figure A-12	NASA-Ames Vertical Motion Simulator with Panel-Mounted Displays and NVG-HUD	A-11
Figure A-13	BOSS Display as Flown on the NASA-Ames Vertical Motion Simulator	A-11
Figure A-14	Test Matrix for NASA-Ames Simulation	A-12
Figure A-15	Vertical Speed at Touchdown, BOSS Study in the NASA-Ames Simulator	A-12
Figure A-16	Distance from Landing Point, NASA-Ames Simulator	A-13
Figure A-17	BAE Terrain Elevation Data Morphed with Simulated Radar Data	A-14
Figure A-18	BAE LVL Symbology	A-14
Figure A-19	HALS Enroute Page with BOSS Symbology	A-15
Figure A-20a	National Research Council Canada Bell 412 Research Helicopter	A-16
Figure A-20b	Pilot Flying Approach Using BOSS Display with Hood to Obscure the Out-the-Window View	A-16
Figure A-21	CAE Corporation Augmented Visionics System (AVS) with BOSS Symbology Superimposed	A-16
Figure A-22	Lateral Speed at Touchdown for BOSS Symbology	A-17
Figure A-23	3D-LZ Display Screen Captures during Actual Brownout Landings in an EH-60L Aircraft	A-18
Figure A-24	Vertical Speed Recorded During All Brownout Landings	A-19
Figure A-25	Lateral Speed Recorded During All Brownout Landings	A-19
Figure A-26	HQR Rating for 3D-LZ	A-19
Figure A-27	Display Preference for 3D-LZ	A-19
Figure A-28a	Final Configuration BOSS Enroute Page	A-20
Figure A-28b	Final Configuration BOSS Hover-Approach-Take-Off Page	A-20
Figure A-29	ANVIS HUD Symbology Set	A-21
Figure A-30	Seahawk Operating to Frigate at Night	A-21
Figure A-31	AS Simulation of Seahawk Operating to FFG Frigate with NVGs and HUD	A-22
Figure A-32	HUD Effectiveness Ratings – Ship Recovery	A-22
Figure B-1	TSAS-Lite Belt	B-2
Figure B-2	Ground Track During Hover Performance	B-3
Figure B-3	TNO Tactile Torso Display and Inside View of a Tactor	B-4
Figure B-4	Cartoon Showing the Horizontal Tactor Array for Indication of Groundspeed, and the Vertical Array for Indication of Height-Above-Terrain	B-5
Figure B-5	Recorded Height-Above Terrain, Forward Speed, and Lateral Speed Recorded During the Last Landing Maneuver in Three Conditions (Bearing and Altitude Information Presented on Tactile Display, Clear Vision, and No Tactile Support)	B-7
Figure B-6	Handling Qualities Rating Scale	B-8
Figure C-1	Gimballed LADAR, Fixed FLIR, and Fixed Color Camera Mounted on Aircraft Nose	C-2
Figure C-2	LADAR Display Modes	C-3
Figure C-3	AFDD Synthetic Vision Cab	C-4
Figure C-4	AFRL SIRE Helicopter Simulator	C-4

Figure C-5	Average Handling Quality Rating	C-5
Figure C-6	Average Horizontal Translation Rate Rating	C-6
Figure C-7	Average Vertical Translation Rate Rating	C-6
Figure C-8	Average Preference Ranking	C-7
Figure C-9	Scales for the Horizontal Velocity, Target Velocity, and Target Position Symbols	C-8
Figure C-10	Combined Altimeter and Vertical Speed Indicator with Target Altitude Symbol Used for the Approach to High Hover Maneuver	C-9
Figure C-11	Combined Altimeter and Vertical Speed Indicator with Target Vertical Speed Symbol Used for the Landing Maneuver	C-9
Figure C-12	Vertical Profile for the Vertical Speed Guidance Algorithm	C-10
Figure C-13	Dual Display with VSD and HSD	C-11
Figure C-14	Right: Switched Display on Low-Speed Page; Left: Display Stays as an HSD	C-11
Figure C-15	Landings were Conducted Primarily in Lane 7 at the Yuma Proving Ground Dust Course	C-12
Figure C-16	Lanes were Plowed to Increase Quantity of Dust (EH-60L shown)	C-12
Figure C-17	Vertical Speed	C-14
Figure C-18	Lateral Speed	C-15
Figure C-19	Forward Speed	C-16
Figure C-20	Aft Speed	C-17
Figure C-21	Landing Position (at -1 ft Radar Altitude) Relative to Target Landing Point as Measured by EGI and Displayed to the Pilot	C-18
Figure C-22	Lateral Position Error	C-19
Figure C-23	Longitudinal Position Error	C-20
Figure C-24	Display Preference for the Four Evaluation Pilots	C-20
Figure C-25	Average HQR	C-21
Figure C-26	Average Scores for the TLX Dimensions	C-22

## List of Tables

<b>Table</b>		<b>Page</b>
Table 4-1	Technology Readiness Levels	4-6
Table 4-2	System Maturity Level Key	4-32
Table 4-3	Sensor Technologies, Limitations, and System Maturity Levels	4-33
Table 4-4	HMI / Display Hardware Technologies, Limitations, and System Maturity Levels	4-34
Table 4-5	HMI / Display Symbology Technologies, Limitations, and System Maturity Levels	4-35
Table 4-6	HMI / Display Technologies, Limitations, and System Maturity Levels	4-36
Table 4-7	Flight Control Technologies, Limitations, and System Maturity Levels	4-37
Table 5-1	Comparison of Landing Techniques	5-8

## List of Acronyms

2-D	Two Dimensional
3-D	Third Dimensional
AAFD	Army Aeroflightdynamics Directorate
AATD	Aviation Applied Technology Directorate
ACAH	Attitude Command Attitude Hold
AFCS	Automated Flight Control System
AFDD	Aeroflightdynamics Directorate
AFRL	Air Force Research Laboratory
AGL	Above Ground Level
ALARP	As Low As Reasonably Practical
AMRDEC	Aviation and Missile Research Development and Evaluation Centre
AUM	All Up Mass
AVS	Advanced Vision System
BOSS	Brownout Symbology System
BRU	Boresight Reticule Unit
BSAU	Brownout Situational Awareness Upgrade
CAAS	Common Avionics Architecture System
CG	Center of Gravity
CMOTS	Commercial Military Off-The-Shelf
CNS	Central Nervous System
CONOPS	Concept of Operations
CRM	Crew Resource Management
CRT	Cathode-Ray Tube
CSAR	Combat Search And Rescue
DAFCS	Digital Advanced Flight Control Systems
DARPA	Defence Advanced Research Projects Agency
DAS	Distributed Aperture System
DNVG	Display Night Vision Goggle
DoD	Department of Defense
DSTL	Defence Science and Technology Laboratory
DTED	Digital Terrain and Elevation Database
DVE	Degraded Visual Environments
EGI	Embedded GPS/Inertial system
FARP	Forward Arming and Refuel Point
FLIR	Forward-Looking Infrared
FM	Frequency Modulation
FOR	Field Of Regard
FOV	Field Of View
GHz	Gigahertz
GPS	Global Positioning System
GVE	Good Visual Environment

HALS	Helicopter Autonomous Landing System
HAT	Height Above Terrain
HDD	Head-Down Display
HFM	Human Factors and Medicine
HMD	Helmet-Mounted Display
HMI	Human Machine Interface
HMSD	Helmet-Mounted Sight and Display
HOCAS	Hands On Collective And Stick
HOGE	Hover Out of Ground Effect
HP	Handling Pilot
HRM	Hover Reference Markers
HRTF	Head-Related Transfer Function
HSD	Horizontal Situation Display
HUD	Head-Up Display
Hz	Hertz
ICR	International Collaborative Research
IED	Improvised Explosive Device
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IR	Infrared
IRBA	Institut de Recherche Biomédicale des Armées
IRT	Immediate Response Team
KIAS	Knots Indicated Airspeed
LADAR	Laser Detection And Ranging
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
LIDAR	Light Detection And Ranging
LLLTV	Low-Light-Level Television
LLTV	Low-Light Television
LOS	Line Of Sight
LP	Landing Point
LS	Landing Site
LVL	Low-Visibility Landing
LWIR	Long-Wave Infrared
LZ	Landing Zone
MFD	Multi-Function Display
MHz	Megahertz
MMW	Millimeter Wave
MW	Medium Wave
MWIR	Mid-Wave Infrared
NATO	North Atlantic Treaty Organisation
NHP	Non-Handling Pilot
NM	Nautical Miles
NVD	Night Vision Device
NVG	Night Vision Goggle

---

OSW	Outside World
PFP	Partners for Peace
PhLASH	Photographic Landing Augmentation System for Helicopters
PMMW	Passive Millimeter Wave
PNVS	Panoramic Night Vision System
QRF	Quick-Reaction Force
RADAR	Radio Detection And Ranging
RNLAF	Royal Netherlands Air Force
ROD	Rate Of Decent
RTO	Research and Technology Organisation
RW	Rotary Wing
RWB	Rotary-Wing Brownout
SA	Situational Awareness
SD	Spatial Disorientation
SERE	Survive Evade Resist and Extract
SOP	Standard Operating Procedure
SV	Synthetic Vision
TA	Terrain Avoidance
TF	Terrain Following
TG	Task Group
TI	Thermal Imagery
TNO	Netherlands Organization for Applied Scientific Research
TRL	Technology Readiness Level
TTCP	The Technical Cooperation Program
UAV	Unmanned Aerial Vehicle
UH	Utility Helicopter
UK	United Kingdom
US	United States
USAARL	United States Army Aeromedical Research Laboratory
USL	Under Slung Load
VMC	Visual Meteorological Conditions

## Acknowledgements

The Task Group acknowledges the gracious hosts and hostesses for our six, semi-annual working meetings and the generous use of meeting facilities in the Canada, France, Germany, United Kingdom and United States, for RTO-HFM-162 from October 2007 through June 2010.

- 1<sup>st</sup> meeting: Moffett Field, CA, USA, US Army AFDD, October 2007 – Host: Mr. Zoltan Szoboszlay
- 2<sup>nd</sup> meeting: Paris FRA, IRBA, April 2008 – Hostess: Dr. Anne-Emmanuelle Priot
- 3<sup>rd</sup> meeting: Munich DEU, ESG Corp., September 2008 – Host: Capt. Detlef Kolletzki (retired)
- 4<sup>th</sup> meeting: Ft. Rucker, AL, USA, USAARL, March 2009 – Host: Dr. Art Estrada
- 5<sup>th</sup> meeting: Toronto CAN, DRDC, September 2009 – Host: Dr. Bob Cheung
- 6<sup>th</sup> meeting: London GBR, USAF EOARD, June 2010 – Hostess: LtCol. Tammy Savoie

# Programme Committee

## CHAIRMAN

Dr. William ALBERY  
Booz Allen Hamilton  
1465 E. Social Row Rd.  
Centerville, OH 45458  
USA

E-mail: [walbery@gmail.com](mailto:walbery@gmail.com)

## CANADA

Dr. Bob CHEUNG  
DRDC Toronto  
1133 Sheppard Avenue West  
P.O. Box 2000  
Toronto, Ontario M3M 3B9  
E-mail: [bob.cheung@drdc-rddc.gc.ca](mailto:bob.cheung@drdc-rddc.gc.ca)

## FRANCE

Dr. Anne-Emmanuelle PRIOT  
IRBA  
BP 73  
91223 Brétigny-sur-Orge Cedex  
E-mail: [aepriot@imassa.fr](mailto:aepriot@imassa.fr)

## GERMANY

LtCol. Thorsten EGER  
DEU Army Aviation School  
Achumer Straße 1  
D-31675 Bückeburg  
E-mail: [thorstenwernereger@bundeswehr.org](mailto:thorstenwernereger@bundeswehr.org)

Mr. Peter KIELHORN  
EADS Deutschland GmbH  
P.O. Box 88039  
Friedrichshafen  
E-mail: [peter.kielhorn@cassidian.com](mailto:peter.kielhorn@cassidian.com)

Capt. Detlef KOLLETZKI (Retired)  
Senior Consultant  
29336 Nienhagen  
Waldweg 39  
E-mail: [dkolletzki@online.de](mailto:dkolletzki@online.de)

Dr. Thomas MÜNSTERER  
EADS Deutschland GmbH  
P.O. Box 88039  
Friedrichshafen  
E-mail: [thomas.muensterer@cassidian.com](mailto:thomas.muensterer@cassidian.com)

## ISRAEL

Mr. Ofer KLEIN  
Elbit Systems  
Aerospace Adv. Tech. Center  
P.O. Box 539  
Haifa 31053  
E-mail: [ofeklein@elbitsystems.com](mailto:ofeklein@elbitsystems.com)

Mr. Erez NUR  
Senior Consultant  
E-mail: [erez@flare.co.il](mailto:erez@flare.co.il)

## NETHERLANDS

Maj. Marjon de GRAAFF  
Royal Netherlands Airforce  
Center for Man in Aviation  
Kampweg 3  
3769 DE Soesterberg  
E-mail: [m.d.graaff.02@mindef.nl](mailto:m.d.graaff.02@mindef.nl)

Dr. Eric GROEN  
TNO  
Kampweg 5  
P.O. Box 23  
3769 ZG Soesterberg  
E-mail: [eric.groen@tno.nl](mailto:eric.groen@tno.nl)

## NORWAY

Capt. Vidar NORDSETH  
720 SQ/137 Air Wing  
Flyplassveien 300  
N-1590 Rygge  
E-mail: [vidar.nordseth@gmail.com](mailto:vidar.nordseth@gmail.com)

Dr. Jan OWE  
Norwegian Armed Forces Medical Services  
P.O. Box 14 Blindern  
0313 Oslo  
E-mail: [j.o.owe@flymed.uio.no](mailto:j.o.owe@flymed.uio.no)

## SWEDEN

Mr. Patrik LIF  
FOI – Swedish Defence Research Agency  
SE-581  
11 Linköping  
E-mail: [patrik.lif@foi.se](mailto:patrik.lif@foi.se)

Dr. Staffan NÄHLINDER  
FOI – Swedish Defence Research Agency  
SE-581  
11 Linköping  
E-mail: [staffan.nahlinder@foi.se](mailto:staffan.nahlinder@foi.se)

## UNITED KINGDOM

Mr. Adrian BALL  
Air and Weapons Systems  
D-111, Grenville Bldg. E.  
Portsmouth Hill  
Fareham, PO17 6AD  
E-mail: [anball@mail.dstl.gov.uk](mailto:anball@mail.dstl.gov.uk)

LtCol. Alastair BUSHBY  
Dept. Aviation Medicine  
SA Aviation  
Middle Wallop, Stockbridge  
E-mail: [aphcssmid-sam@mod.uk](mailto:aphcssmid-sam@mod.uk)

## UNITED STATES

Dr. Bill ERCOLINE  
Wyle Laboratories  
Bldg. 170 Gillingham Drive  
Brooks City-Base, TX 78235  
E-mail: [bill.ercoline.ctr@brooks.af.mil](mailto:bill.ercoline.ctr@brooks.af.mil)

Dr. Art ESTRADA  
U.S. Army Aeromedical Research Laboratory  
P.O. Box 620577  
Fort Rucker, AL 36362  
E-mail: [arthur.estrada@us.army.mil](mailto:arthur.estrada@us.army.mil)

Dr. R. Andy MCKINLEY  
711<sup>th</sup> Human Performance Wing  
2215 1<sup>st</sup> Street  
Wright-Patterson AFB, OH 45433  
E-mail: [andy.mckinley@wpafb.af.mil](mailto:andy.mckinley@wpafb.af.mil)

Mr. Bob PEARSON  
Air Force Research Laboratory  
1864 4<sup>th</sup> Street  
Wright-Patterson AFB, OH 45433  
E-mail: [robert.pearson2@wpafb.af.mil](mailto:robert.pearson2@wpafb.af.mil)

Dr. Alan PINKUS (Editor)  
711<sup>th</sup> Human Performance Wing  
2255 H Street  
Wright-Patterson AFB, OH 45433  
E-mail: [alan.pinkus@wpafb.af.mil](mailto:alan.pinkus@wpafb.af.mil)

Dr. Angus RUPERT  
U.S. Army Aeromedical Research Laboratory  
P.O. Box 620577  
Fort Rucker, AL 36362  
E-mail: [angus.rupert@us.army.mil](mailto:angus.rupert@us.army.mil)

Mr. Zoltan SZOBOSZLAY  
U.S. Army Aeroflightdynamics Directorate  
Ames Research Center  
Moffett Field, CA 94035  
E-mail: [zsoboszlay@us.army.mil](mailto:zsoboszlay@us.army.mil)

Ms. Catherine WEBB  
U.S. Army Aeromedical Research Laboratory  
P.O. Box 620577  
Fort Rucker, AL 36362  
E-mail: [catherine.webb@us.army.mil](mailto:catherine.webb@us.army.mil)



<b>REPORT DOCUMENTATION PAGE</b>			
<b>1. Recipient's Reference</b>	<b>2. Originator's References</b>	<b>3. Further Reference</b>	<b>4. Security Classification of Document</b>
	RTO-TR-HFM-162 AC/323(HFM-162)TP/400	ISBN 978-92-837-0149-1	UNCLASSIFIED/ UNLIMITED
<b>5. Originator</b>	Research and Technology Organisation North Atlantic Treaty Organisation BP 25, F-92201 Neuilly-sur-Seine Cedex, France		
<b>6. Title</b>	Rotary-Wing Brownout Mitigation: Technologies and Training		
<b>7. Presented at/Sponsored by</b>	This Report documents the findings of Task Group HFM-162 (2008 – 2011) that investigated the training and technologies employed by member NATO Nations to mitigate the impact of brownout on rotary-winged operations.		
<b>8. Author(s)/Editor(s)</b>	<b>9. Date</b> Multiple January 2012		
<b>10. Author's/Editor's Address</b>	<b>11. Pages</b> Multiple 182		
<b>12. Distribution Statement</b>	There are no restrictions on the distribution of this document. Information about the availability of this and other RTO unclassified publications is given on the back cover.		
<b>13. Keywords/Descriptors</b>	3-D audio display 3-D conformal display Brownout landing Brownout mitigation Brownout symbology	Degraded visual environment Haptic control Helicopter flight training Rotary-wing aircraft	Spatial disorientation Synthetic display Tactile display White-out
<b>14. Abstract</b>	The RTO HFM-162 Rotary-Wing Brownout Mitigation Task Group was formed to examine the effects of Rotary-Wing Brownout (RWB) and whiteout on pilots during operations. Brownout is the condition developed by recirculating rotor downwash as a helicopter lands or takes off in an arid or a snowy (whiteout) environment. The dust, dirt, or snow that is developed by the downwash renders out-the-cockpit visibility severely degraded or non-existent. The resultant mishaps due to the Degraded Visual Environment (DVE) are a serious problem and partner nations report losses of aircraft and personnel. This study was undertaken to investigate the incidence and severity of the problem in partner nations, to examine and document current and planned technology developments, and to evaluate and document the brownout training procedures within NATO. To provide a true, multi-purpose helicopter sensor, the TG members envision laser radar technology integrated with a navigation forward looking infrared radar. Intuitive hovering and landing cockpit display symbology, such as that described in this report, must also be an integral part of an effective system for DVE landings.		





BP 25  
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE  
Télécopie 0(1)55.61.22.99 • E-mail [mailbox@ita.nato.int](mailto:mailbox@ita.nato.int)



## DIFFUSION DES PUBLICATIONS RTO NON CLASSIFIEES

Les publications de l'AGARD et de la RTO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous. Si vous souhaitez recevoir toutes les publications de la RTO, ou simplement celles qui concernent certains Panels, vous pouvez demander d'être inclus soit à titre personnel, soit au nom de votre organisation, sur la liste d'envoi.

Les publications de la RTO et de l'AGARD sont également en vente auprès des agences de vente indiquées ci-dessous.

Les demandes de documents RTO ou AGARD doivent comporter la dénomination « RTO » ou « AGARD » selon le cas, suivi du numéro de série. Des informations analogues, telles que le titre et la date de publication sont souhaitables.

Si vous souhaitez recevoir une notification électronique de la disponibilité des rapports de la RTO au fur et à mesure de leur publication, vous pouvez consulter notre site Web ([www.rto.nato.int](http://www.rto.nato.int)) et vous abonner à ce service.

### CENTRES DE DIFFUSION NATIONAUX

#### **ALLEMAGNE**

Streitkräfteamt / Abteilung III  
Fachinformationszentrum der Bundeswehr (FIZBw)  
Gorch-Fock-Straße 7, D-53229 Bonn

#### **BELGIQUE**

Royal High Institute for Defence – KHID/IRSD/RHID  
Management of Scientific & Technological Research  
for Defence, National RTO Coordinator  
Royal Military Academy – Campus Renaissance  
Renaissancelaan 30, 1000 Bruxelles

#### **CANADA**

DSIGRD2 – Bibliothécaire des ressources du savoir  
R et D pour la défense Canada  
Ministère de la Défense nationale  
305, rue Rideau, 9<sup>e</sup> étage  
Ottawa, Ontario K1A 0K2

#### **DANEMARK**

Danish Acquisition and Logistics Organization (DALO)  
Lautrupbjerg 1-5, 2750 Ballerup

#### **ESPAGNE**

SDG TECIN / DGAM  
C/ Arturo Soria 289  
Madrid 28033

#### **ESTONIE**

Estonian Ministry of Defence  
Estonian National Coordinator for NATO RTO  
Sakala 1, Tallinn 15094

#### **ETATS-UNIS**

NASA Center for AeroSpace Information (CASI)  
7115 Standard Drive  
Hanover, MD 21076-1320

#### **FRANCE**

O.N.E.R.A. (ISP)  
29, Avenue de la Division Leclerc  
BP 72, 92322 Châtillon Cedex

#### **GRECE (Correspondant)**

Defence Industry & Research General  
Directorate, Research Directorate  
Fakinos Base Camp, S.T.G. 1020  
Holargos, Athens

#### **REPUBLIQUE TCHEQUE**

LOM PRAHA s. p.  
o. z. VTÚLaPVO  
Mladoboleslavská 944  
PO Box 18  
197 21 Praha 9

#### **HONGRIE**

Hungarian Ministry of Defence  
Development and Logistics Agency  
P.O.B. 25, H-1885 Budapest

#### **ITALIE**

General Secretariat of Defence and  
National Armaments Directorate  
5<sup>th</sup> Department – Technological  
Research  
Via XX Settembre 123, 00187 Roma

#### **LUXEMBOURG**

Voir Belgique

#### **NORVEGE**

Norwegian Defence Research  
Establishment, Attn: Biblioteket  
P.O. Box 25  
NO-2007 Kjeller

#### **PAYS-BAS**

Royal Netherlands Military  
Academy Library  
P.O. Box 90.002  
4800 PA Breda

#### **POLOGNE**

Centralna Biblioteka Wojskowa  
ul. Ostrobramska 109  
04-041 Warszawa

#### **PORTUGAL**

Estado Maior da Força Aérea  
SDFA – Centro de Documentação  
Alfragide, P-2720 Amadora

#### **SLOVENIE**

Ministry of Defence  
Central Registry for EU and

NATO

Vojkova 55

1000 Ljubljana

#### **TURQUIE**

Milli Savunma Bakanlığı (MSB)  
ARGE ve Teknoloji Dairesi  
Başkanlığı  
06650 Bakanlıklar  
Ankara

### AGENCES DE VENTE

#### **NASA Center for AeroSpace Information (CASI)**

7115 Standard Drive  
Hanover, MD 21076-1320

#### **The British Library Document Supply Centre**

Boston Spa, Wetherby  
West Yorkshire LS23 7BQ  
ROYAUME-UNI

#### **Canada Institute for Scientific and Technical Information (CISTI)**

National Research Council Acquisitions  
Montreal Road, Building M-55  
Ottawa K1A 0S2, CANADA

Les demandes de documents RTO ou AGARD doivent comporter la dénomination « RTO » ou « AGARD » selon le cas, suivie du numéro de série (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Des références bibliographiques complètes ainsi que des résumés des publications RTO et AGARD figurent dans les journaux suivants :

#### **Scientific and Technical Aerospace Reports (STAR)**

STAR peut être consulté en ligne au localisateur de ressources uniformes (URL) suivant: <http://ntrs.nasa.gov/search.jsp>  
STAR est édité par CASI dans le cadre du programme NASA d'information scientifique et technique (STI)  
NASA Langley Research Center, STI Program Office, MS 157A  
Hampton, Virginia 23681-0001

ETATS-UNIS

#### **Government Reports Announcements & Index (GRA&I)**

publié par le National Technical Information Service  
Springfield  
Virginia 2216  
ETATS-UNIS  
(accessible également en mode interactif dans la base de données bibliographiques en ligne du NTIS, et sur CD-ROM)



BP 25

F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE  
Télécopie 0(1)55.61.22.99 • E-mail [mailbox@rtt.nato.int](mailto:mailbox@rtt.nato.int)



## DISTRIBUTION OF UNCLASSIFIED RTO PUBLICATIONS

AGARD & RTO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all RTO reports, or just those relating to one or more specific RTO Panels, they may be willing to include you (or your Organisation) in their distribution.

RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for RTO or AGARD documents should include the word 'RTO' or 'AGARD', as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable.

If you wish to receive electronic notification of RTO reports as they are published, please visit our website ([www.rto.nato.int](http://www.rto.nato.int)) from where you can register for this service.

### NATIONAL DISTRIBUTION CENTRES

#### BELGIUM

Royal High Institute for Defence – KHID/IRSD/RHID  
Management of Scientific & Technological Research  
for Defence, National RTO Coordinator  
Royal Military Academy – Campus Renaissance  
Renaissanceelaan 30  
1000 Brussels

#### CANADA

DRDKIM2 – Knowledge Resources Librarian  
Defence R&D Canada  
Department of National Defence  
305 Rideau Street, 9<sup>th</sup> Floor  
Ottawa, Ontario K1A 0K2

#### CZECH REPUBLIC

LOM PRAHA s. p.  
o. z. VTÚLaPVO  
Mladoboleslavská 944  
PO Box 18  
197 21 Praha 9

#### DENMARK

Danish Acquisition and Logistics Organization  
(DALO)  
Lautrupbjerg 1-5  
2750 Ballerup

#### ESTONIA

Estonian Ministry of Defence  
Estonian National Coordinator for NATO RTO  
Sakala 1, Tallinn 15094

#### FRANCE

O.N.E.R.A. (ISP)  
29, Avenue de la Division Leclerc  
BP 72, 92322 Châtilion Cedex

#### GERMANY

Streitkräfteamt / Abteilung III  
Fachinformationszentrum der Bundeswehr (FIZBw)  
Gorch-Fock-Straße 7  
D-53229 Bonn

#### GREECE (Point of Contact)

Defence Industry & Research General  
Directorate, Research Directorate  
Fakinos Base Camp, S.T.G. 1020  
Holargos, Athens

#### HUNGARY

Hungarian Ministry of Defence  
Development and Logistics Agency  
P.O.B. 25, H-1885 Budapest

#### ITALY

General Secretariat of Defence and  
National Armaments Directorate  
5<sup>th</sup> Department – Technological  
Research  
Via XX Settembre 123, 00187 Roma

#### LUXEMBOURG

*See Belgium*

#### NETHERLANDS

Royal Netherlands Military  
Academy Library  
P.O. Box 90.002  
4800 PA Breda

#### NORWAY

Norwegian Defence Research  
Establishment, Attn: Biblioteket  
P.O. Box 25  
NO-2007 Kjeller

#### POLAND

Centralna Biblioteka Wojskowa  
ul. Ostrobramska 109  
04-041 Warszawa

#### PORUGAL

Estado Maior da Força Aérea  
SDFA – Centro de Documentação  
Alfragide, P-2720 Amadora

### SALES AGENCIES

#### NASA Center for AeroSpace Information (CASI)

7115 Standard Drive  
Hanover, MD 21076-1320  
UNITED STATES

#### The British Library Document Supply Centre

Boston Spa, Wetherby  
West Yorkshire LS23 7BQ  
UNITED KINGDOM

#### Canada Institute for Scientific and Technical Information (CISTI)

National Research Council Acquisitions  
Montreal Road, Building M-55  
Ottawa K1A 0S2, CANADA

Requests for RTO or AGARD documents should include the word 'RTO' or 'AGARD', as appropriate, followed by the serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of RTO and AGARD publications are given in the following journals:

#### Scientific and Technical Aerospace Reports (STAR)

STAR is available on-line at the following uniform resource locator: <http://ntrs.nasa.gov/search.jsp>

STAR is published by CASI for the NASA Scientific and Technical Information (STI) Program

NASA Langley Research Center, STI Program Office, MS 157A  
Hampton, Virginia 23681-0001

UNITED STATES

#### Government Reports Announcements & Index (GRA&I)

published by the National Technical Information Service  
Springfield  
Virginia 2216  
UNITED STATES  
(also available online in the NTIS Bibliographic Database  
or on CD-ROM)