RTO-MP-25
AC/323(AVT)TP/13

RTO-MP-25

NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 25

New Metallic Materials for the Structure of Aging Aircraft

(les Nouveaux Matériaux métalliques pour les structures des aéronefs d'ancienne génération)

Papers presented at the Applied Vehicle Technology Panel (AVT) Workshop, held in Corfu, Greece, 19-20 April 1999.

Published April 2000

Distribution and Availability on Back Cover

RTO-MP-25
AC/323(AVT)TP/13

NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION
BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 25

New Metallic Materials for the Structure of Aging Aircraft

(les Nouveaux Matériaux métalliques pour les structures des aéronefs d'ancienne génération)

Papers presented at the Applied Vehicle Technology Panel (AVT) Workshop, held in Corfu, Greece, 19-20 April 1999.

The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative 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 coordination 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 coordinates RTO's cooperation 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 initial cooperation.

The total spectrum of R&T activities is covered by 7 Panels, dealing with:

- SAS Studies, Analysis and Simulation
- SCI Systems Concepts and Integration
- SET Sensors and Electronics Technology
- IST Information Systems Technology
- AVT Applied Vehicle Technology
- HFM Human Factors and Medicine
- MSG Modelling and Simulation

These Panels are made up of national representatives as well as generally recognised 'world class' scientists. The Panels 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 cooperation 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.

Printed on recycled paper

Published April 2000

ISBN 92-837-1029-0

Printed by Canada Communication Group Inc.
(A St. Joseph Corporation Company)
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

New Metallic Materials for the Structure of Aging Aircraft

(RTO MP-25)

Executive Summary

Military hardware is very demanding on structural performance. Advanced materials and processing methods are providing new options for materials selection and component design. The papers presented showed how new metallic alloys and composite materials can improve the performance and life of airframe structures. Larger units can be manufactured by improved processes such as investment casting, welding, creep-age forming and high-speed machining. This reduces the parts count and reduces assembly costs. Life can be extended by new corrosion resistant coatings, but these must be environmentally friendly.

The round table discussion closing the meeting focussed on three main issues requiring further work: integrating sub-structures into larger structures, cost-benefit issues of applying new materials and cost reduction through "Qualification by Analysis".

Larger structures were discussed under the aspects of inspectability and damage tolerance. They may be easier to inspect since they have less fasteners, less holes etc. However, large unit constructions do not contain the crack stoppers inherent in smaller riveted components. This must be considered carefully in design. Also the load path during failure will be different in these new units so substitution needs careful stress analysis and full understanding of the failure modes.

However, these large parts will undoubtedly require coatings to protect them from corrosion and care should be taken to ensure that this does not impair inspectability. Discussion raised the point that civil aircraft experience more corrosion damage, although they are usually manufactured from similar materials. For example, Dassault Aviation see more corrosion problems in business jets than in the Mirage, but business jets fly about twice as many hours per year. British and Canadian experience has shown a high incidence of corrosion in transports and maritime patrol aircraft, although this is often linked to poor design and coating technology which reflects the age of the systems.

The balance of cost against benefit is an important issue. With the small fleet sizes of European airforces it is difficult to introduce new materials to overcome ageing problems. The cost of re-certification testing is too high for the potential benefit. Substitution only becomes an option when there is a serious problem which would require part replacement several times through the life cycle of the aircraft. Since this represents a significant barrier to the application of new materials, the options for removing this barrier were discussed.

A change to a system of "Qualification by Analysis" would provide the step change necessary for materials substitution. This topic has already been raised as a potential AVT Technical Team activity under ageing systems. Certifying authorities insist on full structural tests for new flight-critical components. However there is already some shift away from testing since new versions of aircraft can be approved if they are extrapolations of existing designs and have appropriate laboratory and analytical data to support the new design. Numerical stress analysis of designs is now relatively easy and accurate. However there is still poor quantitative understanding of the effects of ageing and the definition of failure. Qualification by analysis will need a full identification of all the possible failure modes and a risk assessment which quantifies the most important areas of concern. These may change with time as the aircraft role is changed and if damage, such as corrosion or inelastic strains start to affect the load paths in the structure. These are issues which should be addressed in the life cycle management of the system.

les Nouveaux Matériaux métalliques pour les structures des aéronefs d'ancienne génération

(RTO MP-25)

Synthèse

Les performances structurales du matériel militaire doivent être exceptionnelles. Or, les nouvelles méthodes de traitement et les matériaux avancés offrent de nouvelles opportunités pour le choix des matériaux et la conception des composants. Les communications présentées ont montré les possibilités des nouveaux alliages métalliques et des matériaux composites pour l'amélioration des performances et du cycle de vie des cellules. Des éléments plus grands peuvent désormais être fabriqués par le biais de procédés avancés tels que le moulage de précision, le soudage, le formage qui anticipe les effets du fluage et du vieillissement, et l'usinage ultra-rapide. Ces procédés permettent de réduire le nombre de pièces et de diminuer les coûts de montage. Les nouveaux revêtements résistant à la corrosion permettent de prolonger la durée de vie, mais doivent être sans danger pour l'environnement.

La table ronde qui a clôturé la réunion a porté essentiellement sur trois grands domaines pour lesquels il y a lieu d'entreprendre des travaux supplémentaires, à savoir : l'intégration des sous-structures dans des structures plus grandes, la comparaison coûts-avantages de la mise en oeuvre de nouveaux matériaux et la réduction des coûts par « la qualification par l'analyse ».

Les éléments de grande dimension ont été examinés du point de vue de leur contrôlabilité et leur tolérance à l'endommagement. S'ils sont plus faciles à contrôler (absence de fixations, moins d'ouvertures etc...), les grands éléments n'ont pas les arrêts de crique habituellement intégrés aux composants rivés plus petits. Il faut en tenir compte lors de la conception. De même, les voies de contrainte en cas de défaillance seront différentes pour les nouveaux ensembles ; par conséquent tout remplacement doit être précédé d'une analyse poussée des contraintes et les modes de défaillance doivent être bien appréciées.

Cependant, ces grands ensembles devront certainement être revêtus d'une protection afin de les protéger contre la corrosion, et cela ne doit pas compromettre leur contrôlabilité. Il est ressorti des discussions que les aéronefs civils subissent plus d'endommagements dûs à la corrosion que les avions militaires, bien qu'en général, ils soient fabriqués à partir de matériaux analogues. A titre d'exemple, la compagnie Dassault Aviation a relevé plus de cas de corrosion sur les avions d'affaires à réaction que sur les Mirages, même si les avions d'affaires effectuent deux fois plus d'heures de vol par an que les Mirages. L'expérience des britanniques et des canadiens montre que la corrosion se produit fréquemment sur les aéronefs de transport et de patrouille maritime, même si ce phénomène est souvent lié à des défauts de conception et à des technologies de revêtement qui témoignent de l'âge des systèmes.

Le compromis entre coûts et avantages demeure une question importante. Etant donné les flottes relativement réduites des armées de l'air européennes, il est difficile, pour résoudre les problèmes de vieillissement, de mettre en place des nouveaux matériaux. En effet, les coûts des essais en vue d'une nouvelle certification sont trop élevés par rapport aux avantages possibles. Le remplacement ne peut être proposé qu'en cas de problèmes importants, nécessitant le remplacement de pièces plusieurs fois pendant le cycle de vie d'un aéronef. Etant donné que celà représente un obstacle sérieux à la mise en oeuvre des nouveaux matériaux, les différentes possibilités d'élimination de cet obstacle ont été abordées.

L'adoption d'un système de « Qualification par l'analyse » serait un premier pas vers le nécessaire remplacement des matériaux. Ce sujet a déjà été proposé pour une éventuelle activité d'une équipe technique AVT dans le cadre des systèmes vieillissants. Les autorités de certification imposent des essais structuraux complets pour tout nouveau composant indispensable à la sécurité. Cependant, les fabricants font de moins en moins appel aux essais, puisque de nouvelles configurations peuvent être approuvées dans la mesure où il s'agit d'extrapolations d'études déjà réalisées et que la nouvelle conception soit étayée par des données analytiques et des résultats d'essais en laboratoire. L'analyse numérique des contraintes est aujourd'hui précise et simple à réaliser. Cependant, il n'existe que peu de données quantitatives sur les effets du vieillissement et la définition de la défaillance. La mise en oeuvre généralisée de la qualification par analyse passe par l'identification détaillée de toutes les modes de défaillance possibles et une évaluation des risques qui quantifie les domaines les plus préoccupants. Ces domaines risquent de changer avec le temps, au fur et à mesure que le rôle de l'aéronef évolue, et en particulier si l'endommagement, par la corrosion ou les contraintes inélastiques, commence à modifier les voies de contrainte dans la structure. Toutes ces questions sont à aborder dans le cadre de l'examen de la gestion du cycle de vie d'un système.

Click inside the blue boxes or on the titles to view the corresponding section

Contents

* Paper was prepared in time for the meeting but was not presented.

* Paper was available at the time of the meeting but not presented.

Theme

Structural components of aging aircraft can be replaced with components manufactured from materials with specifications of a higher qualification, thus enhancing various parameters including overall life cycle cost (LCC). Recent research has led to development of several new materials, heat treatments and processing technology which can be used for the replacement of components prone to corrosion, stress corrosion and fatigue. Specific examples include: a new T77 heat treatment for 7150 alloy; a new alloy 7055, and new processing to control composition and microstructure, e.g. 2524. New alloys have been developed, e.g.: high strength aluminium lithium alloy 2195; fatigue resistant aluminium lithium alloy 2097; laminated hybrids of aluminium and titanium alloys; Timetal 1100 for up to 1100-F; Ti62222 alloy; lower oxygen versions of Ti-6Al-4V; new beta titanium alloys; improved metal matrix composites; high strength, high corrosion resistant steels; improved Ni-Co alloys and low carbon steels.

These new materials and processes may add significant life to aging aircraft that form the backbone of the NATO operational force structure: the KC-135, introduced more than 40 years ago; e.g. the F-15 air superiority fighter, operational 20 to 25 years ago; the F-16 KC-10 became operational at least 15 years ago. Many are expected to remain in service an additional 25 years or more. Maintaining them is based on economic and safety considerations. Retrofitting damaged components with new advanced materials can considerably reduce life cycle cost. NATO must consider the use of these new materials and the proposed workshop provides a unique forum to discuss and further promote common approaches necessary for keeping international fleets.

Thème

Les composants structuraux des aéronefs en service depuis longtemps peuvent être remplacés par des composants fabriqués à partir de matériaux avec de meilleures spécifications, en vue d'améliorer certains paramètres tels que les coûts globaux de possession (LCC). Les travaux de recherche récents ont conduit au développement de matériaux, de traitements thermiques et de technologies de transformation, dont la mise en oeuvre permettrait de remplacer les composants sujets à la corrosion, à la corrosion sous contrainte, et à la fatigue. Parmi d'autres exemples il faut citer : un nouveau traitement thermique pour l'alliage 7150, un nouvel alliage 7055, et de nouveaux traitements pour le contrôle de la composition et de la microstructure, par exemple le 2524. Des nouveaux alliages ont été développés, par exemple l'alliage aluminium-lithium à haute résistance 2195 ; l'alliage aluminium-lithium 2097 résistant à la fatigue ; des hybrides stratifiés d'alliages d'aluminium et de titane ; le Timetal 1100 pour des températures allant jusqu'à 1100 °F ; l'alliage Ti62222 ; des versions de Ti-6Al-4V à teneur en oxygène réduite ; de nouveaux alliages bêta titane ; des matériaux composites à matrice métallique améliorés ; des aciers anticorrosion à haute résistance ; des alliages Ni-Co améliorés et des aciers à bas carbone.

Ces nouveaux matériaux et traitements devraient permettre de prolonger de façon appréciable la durée de vie des aéronefs en service depuis longtemps qui composent l'essentiel des forces opérationnelles de l'OTAN. Le KC-135, dont l'entrée en service date de plus de 40 ans, le F-15, avion de supériorité aérienne, opérationnel depuis 20 à 25 ans ; et le F-16, et le KC-10 entré en service il y a au moins 15 ans. Bon nombre de ces appareils devront rester en service pendant encore 25 ans au moins. Leur maintenance est tributaire de considérations de sécurité et d'ordre économique. Le remplacement de composants endommagés par des matériaux avancés permettrait de diminuer les coûts globaux de possession de façon considérable. L'OTAN doit réfléchir à l'utilisation de ces nouveaux matériaux et l'atelier proposé représente un forum unique pour la discussion et la promotion continue d'approches communes du problème de la conservation des flottes aériennes internationales.

Publications of the RTO
Applied Vehicle Technology Panel

MEETING PROCEEDINGS (MP)

Design for Low Cost Operation and Support
MP-37, Spring 2000

Structural Aspects of Flexible Aircraft Control
MP-36, Spring 2000

Aerodynamic Design and Optimization of Flight Vehicles in a Concurrent Multi-Disciplinary Environment
MP-35, Spring 2000

Gas Turbine Operation and Technology for Land, Sea and Air Propulsion and Power Systems (Unclassified)
MP-34, Spring 2000

New Metallic Materials for the Structure of Aging Aircraft
MP-25, April 2000

Small Rocket Motors and Gas Generators for Land, Sea and Air Launched Weapons Systems
MP-23, April 2000

Application of Damage Tolerance Principles for Improved Airworthiness of Rotorcraft
MP-24, January 2000

Gas Turbine Engine Combustion, Emissions and Alternative Fuels
MP-14, June 1999

Fatigue in the Presence of Corrosion
MP-18, March 1999

Qualification of Life Extension Schemes for Engine Components
MP-17, March 1999

Fluid Dynamics Problems of Vehicles Operation Near or in the Air-Sea Interface
MP-15, February 1999

Design Principles and Methods for Aircraft Gas Turbine Engines
MP-8, February 1999

Airframe Inspection Reliability under Field/Depot Conditions
MP-10, November 1998

Intelligent Processing of High Performance Materials
MP-9, November 1998

Exploitation of Structural Loads/Health Data for Reduced Cycle Costs
MP-7, November 1998

Missile Aerodynamics
MP-5, November 1998

EDUCATIONAL NOTES

Measurement Techniques for High Enthalpy and Plasma Flows
EN-8, April 2000

Development and Operation of UAVs for Military and Civil Applications
EN-9, April 2000

Planar Optical Measurements Methods for Gas Turbine Engine Life
EN-6, September 1999

High Order Methods for Computational Physics (published jointly with Springer-Verlag, Germany)
EN-5, March 1999

Fluid Dynamics Research on Supersonic Aircraft
EN-4, November 1998

Integrated Multidisciplinary Design of High Pressure Multistage Compressor Systems
EN-1, September 1998

TECHNICAL REPORTS

Recommended Practices for Monitoring Gas Turbine Engine Life Consumption
TR-28, April 2000

Verification and Validation Data for Computational Unsteady Aerodynamics
TR-26, Spring 2000

A Feasibility Study of Collaborative Multi-facility Windtunnel Testing for CFD Validation
TR-27, December 1999

Workshop Programme Committee

Programme Committee
Chairman
Dr. E. Starke Jr
Materials Science
UVA Light Metals Center
Thornton Hall, Room B102
VA 22903-2442, USA

CANADA
Dr. J-P. Immarigeon
Chief, Materials
Institute for Aerospace Research
National Research Council of Canada
Montreal Road
Ottawa, Ontario K1A 0R6

FRANCE
I.P.A. P. Armando
Adj. Chef Dept. Etudes Générales
et Matériaux, DCAe/STPA
4, Av. Porte d'Issy
00460 ARMEES

Mr. Y. Barbaux
Chef Service Matériaux Métalliques
Aérospatiale
Centre de Recherches Louis Blériot
12, rue Pasteur, B.P. 76
92152 Suresnes Cedex

Mr. D. Chaumette
Chef Etudes Générales
Direction Technique Aéronef
Dassault Aviation
78, Quai Marcel Dassault
92214 Saint-Cloud

Dr. A. Lasalmonie
Département YKO - SNECMA
Etablissements de Villaroche
77550 Moissy Cramayel

GERMANY
Dipl.-Ing. G. Günther
Daimler-Benz Aerospace LMT 22
Postfach 80 11 60
81663 Munich

ITALY
Prof. M. Marchetti
Universita "La Sapienza"
Dipartimento Aerospaziale
Via Edossiana, 16
00184 Roma

Lt. Colonel G. Zennaro
c/o D.G.C.A.A.A.S.-13, DIV.
Viale dell'Universita, 4
00185 Roma

Programme Committee
Co-Chairman
Dr. J. Waldman
Dept. of Materials Engineering
Drexel University
32nd and Chestnut Streets
Charlottesville, Philadelphia
PA 19104, USA

PORTUGAL
Enga. Helena de Melo Carvalho
INETI - Department of Materials
Azinhaga dos Lameiros
A Estrada do Paco do Lumiar
1699 Lisbon Codex

SPAIN
Dr. E. Sanchiz
Jefe Aerea de Programas
Subdireccion de Programas y
Sistemas Aeronautico – INTA
Carretera Torrejon-Ajalvir, Km 4
28850 Torrejon de Ardoz (Madrid)

Mr. R. Servent
Div. de Estructuras y Materiales
Laboratorio de Diseno y Analisis
Estructural – INTA
Carretera Torrejon Ajalvir, Km.4
28850 Torrejon de Ardoz (Madrid)

UNITED KINGDOM
Prof. R. Potter
Technical Directorate
A1 Bldg, Room G030, CODY RLDC
DERA Farnborough
Hampshire GU14 0LX

Dr. M. Winstone
Technical Manager, SM2
Structure Materials Centre
Room 2008, Griffith Building (A7)
DERA, Ively Road
Farnborough, Hampshire, GU14 0LX

Dr. T. Ronald
Deputy Director
Hypersonic Technology
Programme Office
WL/POP(HyTech)
Wright-Patterson AFB, OH 45433-75433

Dr. D. Viechnicki
Chief Materials Div. US Army Re.Lab
Weapons & Materials Research
Directorate Attn: AMSRL-WM-M
Aberdeen Proving Ground
MD 21005-5069

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	RTO-MP-25 AC/323(AVT)TP/13	ISBN 92-837-1029-0	UNCLASSIFIED/ UNLIMITED

5. Originator Research and Technology Organization
North Atlantic Treaty Organization
BP 25, 7 rue Ancelle, F-92201 Neuilly-sur-Seine Cedex, France

6. Title
New Metallic Materials for the Structure of Aging Aircraft

7. Presented at/sponsored by
the Applied Vehicle Technology Panel (AVT) Workshop, held in Corfu, Greece, 19-20 April 1999.

8. Author(s)/Editor(s)	9. Date
Multiple	April 2000

10. Author's/Editor's Address	11. Pages
Multiple	108

12. Distribution Statement 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.

13. Keywords/Descriptors

Metals	Tolerances (mechanics)
Alloys	Failure
Composite materials	Structural integrity
Airframes	Fracture mechanics
Service life	Fatigue (materials)
Life cycle costs	Corrosion
Military aircraft	Benefit cost analysis
Commercial aircraft	Stress analysis
Aluminum alloys	Protective coatings
Aging (metallurgy)	Durability
Damage	Aging aircraft

14. Abstract

This workshop dealt with the replacement of Structural components of aging aircraft with components manufactured from materials with specifications of a high qualification, thus enhancing various parameters including overall life cycle cost technology (LCC).

The following topics were treated:

- An Overview
- Aluminium Alloys and Composites
- Processing, Fatigue and Durability

NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25 • 7 RUE ANCELLE
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@rta.nato.int

DIFFUSION DES PUBLICATIONS
RTO NON CLASSIFIEES

L'Organisation pour la recherche et la technologie de l'OTAN (RTO), détient un stock limité de certaines de ses publications récentes, ainsi que de celles de l'ancien AGARD (Groupe consultatif pour la recherche et les réalisations aérospatiales de l'OTAN). Celles-ci pourront éventuellement être obtenues sous forme de copie papier. Pour de plus amples renseignements concernant l'achat de ces ouvrages, adressez-vous par lettre ou par télécopie à l'adresse indiquée ci-dessus. Veuillez ne pas téléphoner.

Des exemplaires supplémentaires peuvent parfois être obtenus 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 sur la liste d'envoi de l'un de ces centres.

Les publications de la RTO et de l'AGARD sont en vente auprès des agences de vente indiquées ci-dessous, sous forme de photocopie ou de microfiche. Certains originaux peuvent également être obtenus auprès de CASI.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr, (FIZBw)
Friedrich-Ebert-Allee 34
D-53113 Bonn

BELGIQUE
Coordinateur RTO - VSL/RTO
Etat-Major de la Force Aérienne
Quartier Reine Elisabeth
Rue d'Evère, B-1140 Bruxelles

CANADA
Directeur - Recherche et développement - Communications et gestion de l'information - DRDCGI 3
Ministère de la Défense nationale
Ottawa, Ontario K1A 0K2

DANEMARK
Danish Defence Research Establishment
Ryvangs Allé 1, P.O. Box 2715
DK-2100 Copenhagen Ø

ESPAGNE
INTA (RTO/AGARD Publications)
Carretera de Torrejón a Ajalvir, Pk.4
28850 Torrejón de Ardoz - Madrid

ETATS-UNIS
NASA Center for AeroSpace Information (CASI)
Parkway Center
7121 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)
Hellenic Ministry of National Defence
Defence Industry Research & Technology General Directorate
Technological R&D Directorate
D.Soutsou 40, GR-11521, Athens

HONGRIE
Department for Scientific Analysis
Institute of Military Technology
Ministry of Defence
H-1525 Budapest P O Box 26

ISLANDE
Director of Aviation
c/o Flugrad
Reykjavik

ITALIE
Centro documentazione tecnico-scientifica della Difesa
Via Marsala 104
00185 Roma

LUXEMBOURG
Voir Belgique

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

PAYS-BAS
NDRCC
DGM/DWOO
P.O. Box 20701
2500 ES Den Haag

POLOGNE
Chief of International Cooperation Division
Research & Development Department
218 Niepodleglosci Av.
00-911 Warsaw

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

REPUBLIQUE TCHEQUE
VTÚL a PVO Praha / Air Force Research Institute Prague
Národní informační středisko obranného výzkumu (NISČR)
Mladoboleslavská ul., 197 06 Praha 9

ROYAUME-UNI
Defence Research Information Centre
Kentigern House
65 Brown Street
Glasgow G2 8EX

TURQUIE
Millî Savunma Başkanliği (MSB)
ARGE Dairesi Başkanliği (MSB)
06650 Bakanliklar - Ankara

AGENCES DE VENTE

NASA Center for AeroSpace Information (CASI)
Parkway Center
7121 Standard Drive
Hanover, MD 21076-1320
Etats-Unis

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
Document Delivery
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://www.sti.nasa.gov/Pubs/star/Star.html
STAR est édité par CASI dans le cadre du programme NASA d'information scientifique et technique (STI)
STI Program Office, MS 157A
NASA Langley Research Center
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)

Imprimé par le Groupe Communication Canada Inc.
(membre de la Corporation St-Joseph)
45, boul. Sacré-Cœur, Hull (Québec), Canada K1A 0S7

NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25 • 7 RUE ANCELLE

F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE

Telefax 0(1)55.61.22.99 • E-mail mailbox@rta.nato.int

DISTRIBUTION OF UNCLASSIFIED RTO PUBLICATIONS

NATO's Research and Technology Organization (RTO) holds limited quantities of some of its recent publications and those of the former AGARD (Advisory Group for Aerospace Research & Development of NATO), and these may be available for purchase in hard copy form. For more information, write or send a telefax to the address given above. **Please do not telephone**.

Further copies are sometimes available from the National Distribution Centres listed below. If you wish to receive all RTO publications, 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 publications may be purchased from the Sales Agencies listed below, in photocopy or microfiche form. Original copies of some publications may be available from CASI.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordinateur RTO - VSL/RTO
Etat-Major de la Force Aérienne
Quartier Reine Elisabeth
Rue d'Evère, B-1140 Bruxelles

CANADA
Director Research & Development Communications & Information Management - DRDCIM 3
Dept of National Defence
Ottawa, Ontario K1A 0K2

CZECH REPUBLIC
VTÚL a PVO Praha / Air Force Research Institute Prague
Národní informační středisko obranného výzkumu (NISČR)
Mladoboleslavská ul., 197 06 Praha 9

DENMARK
Danish Defence Research Establishment
Ryvangs Allé 1, P.O. Box 2715
DK-2100 Copenhagen Ø

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

GERMANY
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr, (FIZBw)
Friedrich-Ebert-Allee 34
D-53113 Bonn

GREECE (Point of Contact)
Hellenic Ministry of National Defence
Defence Industry Research & Technology General Directorate
Technological R&D Directorate
D.Soutsou 40, GR-11521, Athens

HUNGARY
Department for Scientific Analysis
Institute of Military Technology
Ministry of Defence
H-1525 Budapest P O Box 26

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Centro documentazione tecnico-scientifica della Difesa
Via Marsala 104
00185 Roma

LUXEMBOURG
See Belgium

NETHERLANDS
NDRCC
DGM/DWOO
P.O. Box 20701
2500 ES Den Haag

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

POLAND
Chief of International Cooperation Division
Research & Development Department
218 Niepodleglosci Av.
00-911 Warsaw

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

SPAIN
INTA (RTO/AGARD Publications)
Carretera de Torrejón a Ajalvir, Pk.4
28850 Torrejón de Ardoz - Madrid

TURKEY
Millî Savunma Başkanliği (MSB)
ARGE Dairesi Başkanliği (MSB)
06650 Bakanliklar - Ankara

UNITED KINGDOM
Defence Research Information Centre
Kentigern House
65 Brown Street
Glasgow G2 8EX

UNITED STATES
NASA Center for AeroSpace Information (CASI)
Parkway Center
7121 Standard Drive
Hanover, MD 21076-1320

SALES AGENCIES

NASA Center for AeroSpace Information (CASI)
Parkway Center
7121 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
Document Delivery
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://www.sti.nasa.gov/Pubs/star/Star.html
STAR is published by CASI for the NASA Scientific and Technical Information (STI) Program
STI Program Office, MS 157A
NASA Langley Research Center
Hampton, Virginia 23681-0001
United States

Government Reports Announcements & Index (GRA&I)
published by the National Technical Information Service
Springfield
Virginia 22161
United States
(also available online in the NTIS Bibliographic Database or on CD-ROM)

Printed by Canada Communication Group Inc.
(A St. Joseph Corporation Company)
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

ISBN 92-837-1029-0