AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD ADVISORY REPORT 360

Aerospace 2020

(Aéronautique et espace à l'horizon 2020)

Volume I — Summary

This document should be announced and supplied only to NATO, Government Agencies of NATO nations and their bona fide contractors, and to other recipients approved by the AGARD National Coordinators.

Ce document ne doit être notifié et distribué qu'à l'OTAN, qu'aux instances gouvernementales des pays de l'OTAN et à leurs organismes dépendants, ainsi qu'à leurs contractants dûment habilités et aux autres demandeurs agréés par les Coordonnateurs Nationaux pour l'AGARD.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

The Mission of AGARD

According to its Charter, the mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

— Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

— Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

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

Published April 1997

Printed by Canada Communication Group
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

AGARD

NATO - OTAN

7 RUE ANCELLE • 92200 NEUILLY-SUR-SEINE

FRANCE

Telefax 0(1)55.61.22.99 • Telex 610 176

DISTRIBUTION OF UNCLASSIFIED

AGARD PUBLICATIONS

AGARD holds limited quantities of the publications that accompanied Lecture Series and Special Courses held in 1993 or later, and of AGARDographs and Working Group reports published from 1993 onward. For details, write or send a telefax to the address given above. *Please do not telephone.*

AGARD does not hold stocks of publications that accompanied earlier Lecture Series or Courses or of any other publications. Initial distribution of all AGARD publications is made to NATO nations through the National Distribution Centres listed below. Further copies are sometimes available from these centres (except in the United States). If you have a need to receive all AGARD publications, or just those relating to one or more specific AGARD Panels, they may be willing to include you (or your organisation) on their distribution list. AGARD publications may be purchased from the Sales Agencies listed below, in photocopy or microfiche form.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD — VSL
Etat-major de la Force aérienne
Quartier Reine Elisabeth
Rue d'Evere, 1140 Bruxelles

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

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

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92322 Châtillon Cedex

GERMANY
Fachinformationszentrum Karlsruhe
D-76344 Eggenstein-Leopoldshafen 2

GREECE
Hellenic Air Force
Air War College
Scientific and Technical Library
Dekelia Air Force Base
Dekelia, Athens TGA 1010

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
Aeroporto Pratica di Mare
00040 Pomezia (Roma)

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 90502
1006 BM Amsterdam

NORWAY
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
N-2007 Kjeller

PORTUGAL
Estado Maior da Força Aérea
SDFA - Centro de Documentação
Alfragide
2700 Amadora

SPAIN
INTA (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 Goddard Space Flight Center
Code 230
Greenbelt, Maryland 20771

The United States National Distribution Centre does NOT hold stocks of AGARD publications.
Applications for copies should be made direct to the NASA Center for AeroSpace Information (CASI) at the address below.
Change of address requests should also go to CASI.

SALES AGENCIES

NASA Center for AeroSpace Information
(CASI)
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
United States

The British Library
Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
United Kingdom

Requests for microfiches or photocopies of AGARD documents (including requests to CASI) should include the word 'AGARD' and the AGARD serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Note that AGARD Reports and Advisory Reports should be specified as AGARD-R-nnn and AGARD-AR-nnn, respectively. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR)
published by NASA Scientific and Technical
Information Division
NASA Langley Research Center
Hampton, Virginia 23681-0001
United States

Government Reports Announcements and 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
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

AGARD

NATO - OTAN

7 RUE ANCELLE • 92200 NEUILLY-SUR-SEINE

FRANCE

Télécopie 0(1)55.61.22.99 • Télex 610 176

DIFFUSION DES PUBLICATIONS

AGARD NON CLASSIFIEES

Aucun stock de publications n'a existé à AGARD. A partir de 1993, AGARD détiendra un stock limité des publications associées aux cycles de conférences et cours spéciaux ainsi que les AGARDographies et les rapports des groupes de travail, organisés et publiés à partir de 1993 inclus. Les demandes de renseignements doivent être adressées à AGARD par lettre ou par fax à l'adresse indiquée ci-dessus. *Veuillez ne pas téléphoner.* La diffusion initiale de toutes les publications de l'AGARD est effectuée auprès des pays membres de l'OTAN par l'intermédiaire des centres de distribution nationaux indiqués ci-dessous. Des exemplaires supplémentaires peuvent parfois être obtenus auprès de ces centres (à l'exception des Etats-Unis). Si vous souhaitez recevoir toutes les publications de l'AGARD, ou simplement celles qui concernent certains Panels, vous pouvez demander à être inclu sur la liste d'envoi de l'un de ces centres. Les publications de l'AGARD sont en vente auprès des agences indiquées ci-dessous, sous forme de photocopie ou de microfiche.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Fachinformationszentrum Karlsruhe
D-76344 Eggenstein-Leopoldshafen 2

BELGIQUE
Coordonnateur AGARD-VSL
Etat-major de la Force aérienne
Quartier Reine Elisabeth
Rue d'Evere, 1140 Bruxelles

CANADA
Directeur - Gestion de l'information
(Recherche et développement) - DRDGI 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 (AGARD Publications)
Carretera de Torrejón a Ajalvir, Pk.4
28850 Torrejón de Ardoz - Madrid

ETATS-UNIS
NASA Goddard Space Flight Center
Code 230
Greenbelt, Maryland 20771

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

GRECE
Hellenic Air Force
Air War College
Scientific and Technical Library
Dekelia Air Force Base
Dekelia, Athens TGA 1010

ISLANDE
Director of Aviation
c/o Flugrad
Reykjavik

ITALIE
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
Aeroporto Pratica di Mare
00040 Pomezia (Roma)

LUXEMBOURG
Voir Belgique

NORVEGE
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
N-2007 Kjeller

PAYS-BAS
Netherlands Delegation to AGARD
National Aerospace Laboratory NLR
P.O. Box 90502
1006 BM Amsterdam

PORTUGAL
Estado Maior da Força Aérea
SDFA - Centro de Documentação
Alfragide
2700 Amadora

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

Le centre de distribution national des Etats-Unis ne détient PAS de stocks des publications de l'AGARD.

D'éventuelles demandes de photocopies doivent être formulées directement auprès du NASA Center for AeroSpace Information (CASI) à l'adresse ci-dessous. Toute notification de changement d'adresse doit être fait également auprès de CASI.

AGENCES DE VENTE

NASA Center for AeroSpace Information
(CASI)
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
Etats-Unis

The British Library
Document Supply Division
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
Royaume-Uni

Les demandes de microfiches ou de photocopies de documents AGARD (y compris les demandes faites auprès du CASI) doivent comporter la dénomination AGARD, ainsi que le numéro de série d'AGARD (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Veuiller noter qu'il y a lieu de spécifier AGARD-R-nnn et AGARD-AR-nnn lors de la commande des rapports AGARD et des rapports consultatifs AGARD respectivement. Des références bibliographiques complètes ainsi que des résumés des publications AGARD figurent dans les journaux suivants:

Scientific and Technical Aerospace Reports (STAR)
publié par la NASA Scientific and Technical
Information Division
NASA Langley Research Center
Hampton, Virginia 23681-0001
Etats-Unis

Government Reports Announcements and Index (GRA&I)
publié par le National Technical Information Service
Springfield
Virginia 22161
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
45, boul. Sacré-Cœur, Hull (Québec), Canada K1A 0S7

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-360 Vol. I		NATO UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly-sur-Seine, France

6. Title
Aerospace 2020

7. Presented at/sponsored by

8. Author(s)/Editor(s)	9. Date
Multiple	April 1997

10. Author's/Editor's Address	11. Pages
Multiple	44

12. Distribution Statement Limited Distribution — See Front Cover.

13. Keywords/Descriptors

Aerospace engineering
Forecasting
Arms proliferation
Nuclear proliferation
Synthetic environments
Miniaturization
Man machine systems
Human factors engineering
Man computer interface
Situational awareness
Data fusion
Communications networks
Decision making
Information systems
Weapon systems
Directed energy weapons
Remotely piloted vehicles
UAV (Unmanned Aerial Vehicle)
Tactical aircraft
Tactical warfare
Hypersonic vehicles
Air-breathing missiles
Launchers
Fighter aircraft
Threat evaluation
Laser weapons
Defense economics

14. Abstract

Volume 1, the summary volume, of the report of the NATO Advisory Group for Aerospace Research and Development (AGARD) study: 'Aerospace 2020'. This study explores the most advanced technologies, relevant to aerospace, being researched and developed in laboratories today. The study focuses on the most promising current technologies and the organisational and tactical consequences they will have at the field and system levels, over the course of the next 25 years.

Topics include: a discussion of the impact of proliferation, human-machine interaction, synthetic environments, directed-energy weapons, information technologies, unmanned tactical aircraft, suborbital launchers, hypersonic missiles, and a discussion of affordability issues.

Technologies are assessed from the viewpoints of both potential capabilities and threats. Observations and recommendations are presented.

Foreword

Change is affecting every aspect of our lives, and the pace of change is accelerating. In an effort to forecast where the forces of change will lead NATO and its member Nations over the next quarter century, the NATO Advisory Group for Aerospace Research and Development (AGARD) commissioned the *Aerospace 2020* study.

The study attempts to strike a balance between possibility and promise. Some discussions are undoubtedly too conservative while others too optimistic. In any case, *Aerospace 2020* attempts to identify methods and processess that will help the Alliance and the Nations benefit from the opportunities, and prepare for the possible dangers, which change inevitably creates.

The study involved virtually all of the AGARD organisation, capatalising, in particular, on the strengths of its seven Technical Panels composed of experts in fields ranging from aerospace medicine to fluid dynamics. The study also tapped the military expertise of representatives from AGARD's Aerospace Applications Studies Committee and the information management skills of the Technical Information Committee. Consistent with the nature and philosophy of AGARD, each of these participants expanded the network of professionals to include views and opinions of civilian and military experts from industry, government and academia.

We wish to take this opportunity to thank all of the people who contributed to the *Aerospace 2020* study and assisted in its preparation and production. Special thanks are extended to Dr. Hywel Davies, rapporteur; to Lt. Col. John Wheatley, study executive; and to Jürgen Wild, Director of AGARD, and his staff.

As AGARD evolves into NATO's new Research and Technology Organisation, it will retain its spirit of service to the Alliance, of international cooperation and of dedicated professionalism. It is in keeping with this spirit that *Aerospace 2020* is presented, and we hope the study will prove valuable to NATO and its members as plans, preparations, and decisions are made for our entry into the 21st century.

Michael I. Yarymovych
Chairman of AGARD

Nils Holme
Study Director
Aerospace 2020

La version française de ce volume paraîtra ultérieurement

Table of Contents

1. Introduction

The challenge of change which NATO is facing has many dimensions, one of which is the rapid advance of technology. The changes are such that their combined effects have the potential to significantly affect the quality of military strength in the future.

The NATO Advisory Group on Aerospace Research and Development (AGARD) recognised that these changes and their ramifications are of such importance that they should be examined more thoroughly. In March 1995 AGARD's National Delegate Board commissioned a study with the following objectives:

- To assess how emerging technologies may influence changes in aerospace systems and concepts of operation.
- To alert decision makers to the advantages the emerging technologies may have for NATO and NATO Nations, and to make them aware of the possible threats that new and readily available technologies may pose when acquired by potential adversaries.
- To recommend to the Nations active pursuit, both individually and cooperatively, of the most promising aerospace technologies and to offer advice, where appropriate, on collective action.

To achieve these objectives, *Aerospace 2020* explores the most advanced technologies being researched and developed in laboratories today. Rather than speculate on science and technology theories for the future, the study focuses on the most promising current technologies and the organisational and tactical consequences they will have at the field and system levels over the course of the next 25 years.

The scope of the study - from 1995 to the year 2020 - supports the view, held by many, that all major systems which will be deployed in 10 years exist today. After ten years, however, new systems may lead to radically new concepts in the way military force, or the threat of its use, is employed to influence the wills and actions of others.

It has been noted that "20/20" vision is the medical designation for unimpaired eyesight, and it is often said that "hindsight is always 20/20". It is AGARD's hope that this study of aerospace technology, and the effects it will have as we approach the year 2020, will prove to have been a clear vision with 20/20 foresight.

Basic Assumptions

The primary purpose of the Alliance is to provide military security for its member Nations. This and the following assumptions form the foundation upon which discussions presented in this volume are based:

- NATO must remain prepared to act in direct defence of its member states.
- NATO must remain prepared to take action against threats to vital interests of the Alliance outside the NATO area. Such operations may range from large-scale war to low-intensity conflicts to counter-terrorist activity.

- Ethical constraints that exist within NATO regarding the conduct of violent conflict and warfare will not diminish and, in fact, are likely to increase. Potential opponents, however, may not respect or practice the same constraints.
- NATO membership will expand in the coming decades. This expansion will require the integration of new national forces and infrastructures.

In addition to remaining a strong and independent alliance, NATO will continue to work closely with the United Nations in its efforts to resolve international conflicts by diplomatic and/or military means. The UN will continue to support military forces involved in a number of operations around the world. As today, NATO may serve as the primary contractor with operations conducted under full NATO command or as a contributor to forces under UN command.

To meet its obligations, UN forces must be capable of rapid, flexible deployment. NATO is the only organisation with the ability to efficiently run a multinational operation. It is essential to world peace and stability that this ability be maintained and improved. For NATO, however, conducting non-traditional missions, possibly with non-NATO nations which do not necessarily share the same approach to technology, organisation, or command and control methods, will pose a continuing challenge in the years to come.

Approach

Aerospace 2020 is the result of joint efforts by the AGARD Technical Panels and the Aerospace Applications Studies Committee (AASC). Beginning in 1995 and ending in early 1997, a study group consisting of representatives from the AGARD Panels and the AASC, a study director, a rapporteur, and a study executive coordinated the work, selected the main topics of the study, and reviewed the results. This collaborative approach permitted the study group to draw on the insights of the large number of internationally established experts who form the membership of these bodies. However, this approach also limited the scope of the study to the areas of expertise covered by the AGARD bodies.

The first step of the study was a “bottom-up” survey conducted by the AGARD Technical Panels to determine what their experts thought would be the most significant changes in aerospace technology over the next 25 years. Following a review from the military point of view by the AASC, a list of topics was defined. Two non-technical discussions - “The Future of Defence Environments” and “Enduring Military Needs” - were coordinated by the AASC. Discussions of other topics selected for inclusion were coordinated by the appropriate AGARD Technical Panel, as shown in table 1-1.

AGARD Technical Panel:	Topic:
Aerospace Medical Panel (AMP):	Human and machine interaction Human implications of sustained operations
Flight Vehicle Integration Panel (FVP):	Aircraft design integration Synthetic environments
Fluid Dynamics Panel (FDP):	Extreme long-range vehicles Versatile access to space
Mission Systems Panel (MSP):	Mission management Unmanned tactical aircraft
Propulsion and Energetics Panel (PEP):	Hypersonic air-breathing missiles
Sensor and Propagation Panel (SPP):	Communications electronic warfare Progress in stealth versus anti-stealth Real-time reconnaissance, surveillance, and target acquisition (RSTA)
Structures and Materials Panel (SMP):	Affordability

Table 1-1: Panel contributions by topic.

Aerospace 2020 consists of three parts:

Volume One - a brief summary of the main results of the study, with recommendations.

Volume Two - a detailed discussion reflecting the topics selected for study, organised in a way that enables review of their interrelationships and impact.

Volume Three - a series of short technical papers, selected for their specialist interest and carrying the signatures of their authors or the contributing AGARD Technical Panel.

A list of study group members is provided in appendix A of this volume. A detailed list of study participants and contributors is provided in *Aerospace 2020, Volume 2,* appendix A.

From Technology to Operational Capabilities

As mentioned above, one of the aims of the *Aerospace 2020* study is to assess the way in which emerging technologies may influence changes in aerospace systems and concepts of operation. Projections of technological capabilities are somewhat uncertain, but most of these uncertainties are well understood. This is not always the case when making projections of operational capabilities that result from advances in technology, especially when such projections involve totally new systems and operational concepts. New concepts sometimes encounter secondary limitations, for example in methods or basic principles, which significantly affect their implementation. These factors are discussed in some cases in the study, but limitations may also be recognised in the future that are not understood today.

It is also important to acknowledge that assessments of concepts of operation are limited and, to a great extent, are based on qualitative analysis. The AGARD Technical Panels are primarily technology oriented, dealing at the systems level only in the fields of aircraft and aircraft missions. Systems considerations are more typically examined by AGARD in ad hoc studies initiated by the AASC, generally two per year for selected topics.

Relationship to Other Studies

Several surveys of emerging military technologies and assessments of their consequences have been published in recent years; most notably *New World Vistas*, produced by the U.S. Air Force Scientific Advisory Board in 1995. This study is of great value, particularly with respect to its completeness and depth of coverage. Of course, specialist judgements will sometimes differ in matters of the more distant future, and there are a few such differences in *Aerospace 2020.*

More significantly, the studies differ in their basic points of reference. NATO's perspective regarding military threats, opportunities and recommendations is determined by the purposes and functions defined in the North Atlantic Charter. This focus is different from that of the U.S. Air Force.

Thus, *Aerospace 2020* discusses topics relevant to the Alliance or to individual Nations as members of the Alliance. This means, for example, that the study makes no attempt to examine topics from a global perspective. By its very nature, NATO provides a framework for the establishment of common infrastructure systems and common development projects. The *Aerospace 2020* study examines activities which can be undertaken by the Alliance or by member Nations working cooperatively through the Alliance.

2. A View of the World

Earlier in the 20th century, military actions focused on declared wars or countering insurrections. Acceptance of defeat by the opponent was the ultimate goal. Today, other motives may lead countries or groups to challenge the West. Rather than seeking a well-defined victory, some adversaries may seek to inflict politically intolerable damage in order to promote a social agenda or achieve political objectives. It is a widely held view that the threat of large-scale global or nuclear war in coming decades appears to have lessened, while less predictable types of conflict, more limited in scope, may occur more frequently and may be prolonged.

While this change in perspective and the impact it will have in planning and conducting military operations in the next 25 years is commonly accepted, other elements of change relevant to this study are less well known, and some are controversial. All are significant, however, and the study will show that even though NATO and NATO Nations have a strong advantage with respect to technological, organisational and financial resources, it will be challenging to gain superiority against opponents who do not necessarily play by our rules.

Proliferation of Technology

Today, a great deal of sophisticated technology that would once have been available only to the most powerful military establishments, is available commercially and, quite literally, "off-the-shelf". The easy accessibility of such advanced technology dramatically reduces the comparative advantage to developers. This is especially significant in view of the trend that the cost of inflicting damage by precision weapons is decreasing, while the cost and difficulty of protecting against the threat they pose is increasing.

Typically, for example, in low-level conflicts the aim may be to inflict damage by high-precision action against valuable targets and to avoid collateral damage, especially to civilian populations. Though several varieties of "smart" weapons have been developed to meet this requirement, their availability is currently limited by their high cost. However, within the 25-year time frame of this study, these weapon technologies will become widely available as the cost of purchasing such weapons declines. The cost of protecting against them is expected to remain high.

Furthermore, the cost of causing arbitrary damage for political effect (for example by technically advanced terror actions) is decreasing at an even greater rate. Adversaries who contemplate achieving their aims by generating arbitrary damage will have an increasing number of options, and such actions will be difficult to prevent.

Thus, if not countered, the harm caused by an enemy with second-rate capabilities could negate the advantages offered to the West by its first-rate technologies. These challenges to the West could manifest themselves in ways quite different from head-on military assault. In direct battles, the West would continue to have an advantage and continue to exercise significant strength. The outcome in less traditional confrontations will be less certain.

Asymmetries of Conscience

Differences in culturally embedded values and attitudes have always been an important factor in warfare. While NATO policies are continuously adjusted to reflect more restrictive definitions of tolerable risk-of-loss and unintended harm, it is becoming increasingly apparent that such restraint is not universally supported or practised. In fact, it is now reasonable to assume that future adversaries may try to maximise the advantages they can gain through "asymmetries of conscience"; that is, the willingness to pursue means which NATO Nations find unacceptable.

Some asymmetries of conscience are based on ethical standards; some include practical considerations. For example, despite the great costs involved, NATO has strict requirements for the safe storage and handling of the systems it develops and accepts. Some opponents, however, may be more interested in less expensive systems that can be used immediately, rather than in quality systems which are safe.

Other examples of constraints which the West finds necessary and imposes upon itself range from environmental considerations to the use of chemical and biological weapons. Although, in many cases, international treaties have been signed acknowledging agreements to restraining principles, many countries have not joined in these treaties, and even some that have signed do not appear to take them seriously.

Thus, NATO is faced with defending itself against tactics and weapons which it finds unacceptable to use. To prevent such asymmetries of conscience from providing a decisive military advantage against the Alliance, it becomes even more important to fully exploit the advantages NATO has with respect to its financial resources, technology, and its ability to organise effectively.

Engines of Change

In reviewing the potential impact of emerging technologies, *Aerospace 2020* suggests that the greatest advances will not be in "classic" areas of aerospace technology such as material development or aircraft design. These areas will continue to evolve, but the most significant innovations will be driven by the power of several other trends.

The Civilian Push

Historically, in most areas of technological research and development, the military has led the way in finding solutions that eventually become the basis for civilian applications. Although some of the most fundamental changes in military capabilities will continue to be the result of military-specific research (especially in the areas of electronics and electro-optics), an increasing number of military applications will be based on existing civilian technology. Civilian "dual use" technologies are already having an impact in areas such as information and communication technology, and "virtual reality" concepts. In short, civilian market forces, not military needs, will drive some of the technology needed by the military in the future.

Synthetic Environments

Advances in information technology will profoundly change how simulation is used in all aspects of commercial development, testing and production, and in military training and operational decision making. Future users will have ready access to global, constantly available "synthetic environments" of linked simulations, massive databases, and models. Such an environment will be constantly and automatically updated with real-world data and be capable of immediate response to the user's input. If fully realised, the synthetic environment concept will make powerful, highly credible analytical capabilities accessible throughout the information networks of the future.

Space Access

In the next 25 years, the number of satellites in orbit will continue to increase, perhaps by tens of thousands. While access to space will still be expensive (launch costs ranging from USD 10 000 to 20 000 per kilogram for expendable launchers), the value provided to both the military and civilian sectors will justify the expense. Many civilian communications networks are totally reliant on space-based assets. Competition is increasing in the race to reduce the cost of space operations to meet this growing market.

The European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA), as well as Russia and Japan, are currently developing the next generation of reusable space launchers. The primary objective is to reduce launch costs. Estimates for possible reductions in launch cost per kilogram of payload vary in the range of factors from three to ten, depending on differing assumptions with respect to launch operations.

Other benefits should include launch-almost-on-demand and the capability to retrieve or service-in-orbit failed or aging satellites. The military can become customers of these agencies, without incurring military development costs. The military may also take advantage of technology "demonstrators" by converting them to military use after their "proof of concept" role has been fulfilled. In either case, to achieve the maximum benefit of this civilian technology, the requirements specifying military needs must be defined in the early phases of development.

Miniaturisation

The need to increase mechanical and/or computational capability while reducing system weight and volume will continue. Microtechnology will enable lightweight, compact, adaptable modules based on micro-electromechanics and electronics, and evolving nano-technologies. Applications under study include: inertial sensors, electronic eyes, micro-radar, and guided bullets. In the medium- to long-term perspective, biotechnological materials and processes such as protein-based computers, and sensors using natural materials are expected to find practical applications.

Human and Machine Partnership

By the year 2020, an operator will interact with an electronic workspace as a cooperative partner. Dialogue between the system and the operator will be based not only on operator inputs, but also on the machine's ability to accurately assess the physical and mental state of the operator. Operator inputs may be communicated by deliberate voice commands, gestures, or even subtle muscle movements. The machine will sense the operator's state with signals from the brain measured by electroencephalography (EEG) in conjunction with other biological readings. Assessment will be based on artificial intelligence technologies and an improved understanding of the relationships between electrical brain activity and the performance of cognitive and motor tasks.

This human-machine partnership will reduce the number and intensity of tasks which require uniquely human contributions. It will adapt itself to human biorhythms, and it will make possible extended operations beyond today's limitations. The operator remains fully conscious of the environment and maintains authority over system functions.

The partnership will be made possible by advances in information assessment, artificial intelligence, psychophysiological processing, and advanced models of human performance and behaviour.

3. Information Dominance

Achieving the ability to provide a more complete overview of a theatre of operations to all command and control levels, whether in a high-intensity war or a low-level conflict, is a primary goal for technology and force development.

Today's revolution in information management will continue. The nature of the fields of information management and computer science is such that the changes which occur today will accelerate the pace of tomorrow's changes. It appears that the maximum rate of change will not be limited by technology, but by organisational limitations affecting the rate with which new technology can be applied. Nevertheless, we can predict that by the year 2020 an "information sphere" will surround military operations and our daily lives, much as the atmosphere surrounds the planet.

The driving force of this accelerating rate of change will not be military research, but rather the growth of the civilian market. International markets such as media and entertainment, banking and investment, and travel and transportation will support the development of cost-effective tools and procedures for managing worldwide networks of communications and information.

Such tools and procedures will be available to NATO as a basis for specialised military applications. They will also become available to future opponents. The notable exception to this pattern might come from NATO's access to space, but only if the Nations follow a policy of achieving and maintaining technological superiority in space-based military applications.

The expected improvements in allied reconnaissance and intelligence capabilities will make it more difficult for opponents to avoid our detection and monitoring of their military systems and activities. In response, many countries are already moving critical facilities underground. Furthermore, it is conceivable that some opponents might systematically seek protection against detection by hiding military activity in population centres, creating "urban armies", not just guerrillas. Should such tactics become reality, they would change the nature of warfare in unpredictable ways.

The revolution in information management will have a significant impact on the command and control process - from the command and control centre functions down to the platform level - particularly in the following areas:

- Situation awareness
- Communication and information networks
- Decision making
- Plans and orders

Situation Awareness

Future systems will permit automated situation-monitoring (and information fusing) of thousands of events in tens of minutes; they will be capable of monitoring and/or managing the activities of more than a thousand targets and assets per hour. This will result in a high level of confidence in our *knowledge of our own operations, the enemy situation, the situation of third-party forces, and the environment (weather, terrain, vegetation, etc.) of any future battle space.*

By the year 2020, NATO forces will near the state where they can precisely detect many types of targets which are presently undetectable; for example, stealthy platforms and well-camouflaged ground vehicles. These targets may be moving or stationary. Using Moving Target Indication (MTI) and Automated Target Recognition (ATR) technologies, targets will be accurately identified and located, even in adverse terrain.

Systems will be established to track friendly forces. We can expect to have an automated ability to locate and evaluate status down to the level of individual fighting systems (aircraft, tanks, etc.). As an automated task, this will drastically reduce the burden of requesting and transmitting myriad "situation reports" from every level of command. The inherent accuracy of such systems will prove valuable in the prevention of fratricide.

This vision of situation awareness will be realised through a combination of evolutionary improvements in battlefield communications (discussed later in this chapter) and revolutionary advances in the fields of sensors and data fusion.

Sensor Systems

Future sensor systems will combine improvements in sensing technology, signal processing, and positioning to improve coverage, resolution, target discrimination and location accuracy. Some examples include:

- **Synthetic Aperture Radar (SAR)** for airborne and space-borne platforms that allows day or night observation basically independent of weather. SAR systems are presently limited by the need to transmit large amounts of data by line-of-sight communication to ground stations for processing that is not real-time. Real-time, onboard processing of photo-quality pictures will be operational by the year 2000, and onboard processing for feature extraction is expected to be available by 2015. This will reduce communication requirements and make SAR information from satellites and aircraft directly available, also to lower-level units.

  Miniaturisation techniques are expected to reduce the mass and volume of SAR systems by a factor of 100 by the year 2020. SAR will then be mounted on small unmanned aerial vehicles (UAVs) and, possibly, individual munitions. There will be trade-offs between coverage and resolution. Scenes taken from satellites of areas 100x100 km may be processed in real-time to one metre resolution. Smaller scenes from lower flying platforms will provide resolution in the centimetre range, enabling classification of targets such as ground vehicles. SAR techniques will also be applied at UHF frequencies to permit limited penetration in dry soil and shallow water, although with reduced resolution.

- **Microwave radiometry sensors** used from aircraft or missiles will provide passive, near-range imaging of metal surfaced objects, nearly independent of the time of day and the weather. These sensors use low data-rates, so they will be easily supported by future communications networks. Using the techniques of aperture synthesis, they will provide near optical quality serial images ("microwave movies").

- Sensors employing **hyperspectral sensing** will use a large number of bands from below to beyond the visible spectrum (in the range 0.3 to 15μm) to scan a scene or object, collect bits of information from each band, and fuse the information to develop accurate target profiles. The coverage and other aspects of performance will be comparable to present optical or infrared sensor systems.
- By the year 2020, a much larger array of sensors is expected to be available. These sensors will cover a larger portion of the electromagnetic spectrum than today. Miniaturisation and the integration of such technological advances as the combination of digital beam-forming to boost antenna performance with the use of conformal phased-array design will make it possible to accommodate very high-resolution antennas on extremely small platforms.

Since only a small amount of information may be available in any band of the electromagnetic spectrum, the process of fusing the information and comparing it to other intelligence and information sources becomes crucial.

Data Fusion

The new domain of data fusion will expand our present ability to integrate and analyse data, and convert it into useful combat information for commanders. Data gathered from multiple passes by multiple sensor systems, which today requires a full staff to analyse, will, by 2020, be automatically analysed in seconds so the data can be communicated, as appropriate, directly to the supported combatants.

Data fusion is the processing and combining of data and information from multiple sources to the level of accuracy and completeness required for a given task. In principle, data fusion is not a novel concept. Innovation lies in combining new types of sensors with greatly improved methods of processing the data received from them. When used together, the new sensors provide a much more complete and detailed registration of the physical characteristics of a scene under survey than can be provided by any single sensor. High-speed and high-capacity computers make it possible to apply the advanced processing methods required to combine - or fuse - the data. When needed, computers of adequate capacity can be made small enough to fit into compact sensor systems, such as the target seekers of small missiles.

Data fusion makes use of a variety of mathematical methods but, in general, the more similar the data, the simpler the methods of fusion. Data considered "similar" includes such information as pictures taken of the same scene at the same time but in different frequency bands (different "colors") by the same sensor system. More complex methods, requiring associative or "artificial intelligence"-type processes, are used to fuse data of different types; for example, data from radars, electronic intelligence, and inconsistent eyewitness reports.

New sensory-system concepts will be developed that, for example, combine data from multi-wavelength sensors at separate and diverse locations as an approach to counter stealth. Sensor data may also be fused with archived data, such as earlier observations, as a means of automatically detecting changes, as in damage assessment.

In many applications data fusion would be used to extract all useful information at the sensor, and thus reduce communication requirements. For example, if only the object identification and location need to be transmitted - not the sensor images themselves -

the volume of data to be communicated is greatly reduced. Similar techniques will be used to fuse data beyond the sensor.

For distribution to users, the information will be combined to form "packets" of information tailored to meet the needs of the recipient. For instance, multiple sensor inputs of missile launchers and hostile radars might be reported to individual aircraft as threats and include automatic overlays of their danger areas. The information would be displayed to the theatre commander as an anti-aircraft missile battery, and to the force artillery commander as a request for immediate suppressive fires as part of his "joint suppression of enemy air-defence" mission. All of this communication would be done concurrently in near real-time.

In addition to increasing our situation awareness, data fusion will reduce false alarm rates and provide some protection against jamming and spoofing. However, real-time data fusion from non-collocated sensors will require robust, high data-rate inter-sensor communications.

All methods of data fusion are verified by checking against *known* objects and phenomena. Machines, like humans, are sometimes misled when faced with situations beyond their knowledge and experience. This fundamental limitation must be kept in mind when using information that is processed and combined automatically. Stratagems will remain an important part of warfare.

Communication and Information Networks

Information networks will consist of terrestrial, space, and airborne links. They will connect command and control centres remote from the battlefield with tactical (surface and airborne) centres physically on the battlefield. NATO will be able to put such networks in place rapidly and flexibly to meet the needs of a variety of major or minor regional conflicts, or of peacekeeping operations.

Commercial development of fibre optic technology provides gigabytes-per-second terrestrial and undersea connections. Concepts such as global Theatre Broadcast Services (TBSs) will provide both high-capacity multichannel (similar to 100-plus TV channels) and two-way connectivity for selective "user pull" and "smart push" of information.

TBS concepts using long-endurance UAVs will provide options for improving the robustness of connections (for example resistance to electronic countermeasures). Further enhancements should be enabled by developments in laser links, optical switching, and modulation.

Although voice communications are practical, robust, and relatively easy, they are slow and inefficient. They are also more vulnerable to active electronic warfare. It is doubtful, however, that any system which totally eliminated voice would suffice. Voice will remain a primary means of immediate communication between commanders and their subordinates. It will be nearly impossible to protect all stations from jamming; voice traffic, even more than digital links, will rely on system redundancy to ensure communications. Although large-scale commercial development of satellite communications is underway, these systems do not provide high levels of security or survivability. Complete reliance on such commercial systems would increase NATO's vulnerability.

The availability of reliable communications networks with high capacity will facilitate the development of an "information infrastructure" for NATO command and control. This infrastructure will consist of general information databases (containing, for example, geographical, meteorological and mapping data), data fusion centres, intelligence centres (including "artificial intelligence" systems to assist interpretation of information), and support systems for the command and control functions described above.

Decision Making

Automation in the decision cycle will make it possible for NATO commanders to operate inside their opponent's decision and action cycles.

The time spent gathering information will be minimised by the improvements in intelligence collection and situation analysis described in the section "Situation Awareness". In addition, the time required to develop and analyse courses of action will also be reduced. This will be made possible by improved decision aids and improved access to information provided by the application of synthetic environment technology.

As synthetic environment technology matures, commanders will be provided the means to test alternative courses of action by using simulations which integrate the real-time situation of the current battlefield with stored data. The resulting simulation will include details about the capabilities of own and enemy systems and units, as well as dynamic models of the adversary's assets and the possible strategies and tactics.

Other improvements in support of the command function will be found in areas of more traditional staff work. Computer systems, functioning as "automated staff assistants", will apply personalised screening and extraction criteria to automatically sort out information most relevant to the receiver (similar to pilot's associates under development today). Based on the commander's defined intent, this automated assistant will be capable of:

- Assessing information about the mission and the mission environment.
- Searching for and extracting critical items of information.
- Alerting the commander to priority information and possible errors.
- Monitoring the commander's fitness and warning of "overload" conditions.
- Adjusting data input to avoid overtaxing the commander.

Using these tools, NATO commanders will stay one step ahead of adversaries not so equipped. Better information yields better decisions. Better decisions must then be translated into combat plans and orders.

Plans and Orders

The process of developing plans and producing orders - cycles currently measured in days - will be measured in hours, and possibly minutes, by the year 2020.

The speed of developing combat orders and plans, as well as the level of confidence in their details, will be increased by the interaction of the following:

- Systems capable of tasking tens of sensors and directing thousands of actions per hour in peak periods.
- Automated development of plans and orders. For example, the ability to plan for hundreds of targets per hour, and for tens of targets per minute in peak periods.
- New software for monitoring missions, including battle damage assessment, identification of assets, etc.
- Future developments to permit increasing on-line collaboration and assessment by intelligence and operations personnel using potential enhancements such as dynamic holographic display interfaces and environmental modelling prediction.

The successful integration of these elements will significantly decrease the time needed to develop and disseminate combat plans and orders.

Conclusions and Recommendations

Technologies for new sensor systems will make it possible to conduct surveillance and reconnaissance at any level of detail or temporal precision required for military purposes. High-resolution coverage of regions ranging from one to ten metres will be performed on a routine basis by satellite-borne systems using primarily high-performance synthetic aperture radar (SAR), hyperspectral passive detection, and signal intelligence. The same sensor principles adapted for use from tactical and small unmanned aircraft will provide coverage of tactical areas to an accuracy of decimetres, nearly independent of weather and light conditions. Enemy forces and activities hidden in population centres will remain the most difficult challenge for reconnaissance and surveillance.

Improvements in performance will be achieved by improvements in the various sensor and processing systems and by the fusion of data from geographically separate sensors that may or may not be of the same type. Realising these improvements will require considerable effort technically, operationally and, not least, organisationally. Highly accurate position fixing, essential for the fusion of high-resolution data from geographically separate sensors, is a critical requirement.

Communications will be improved as a result of:

- Increased use of civilian services for high-capacity connectivity between fixed installations.
- Improved technology to meet military requirements, such as security and authentication in civilian networks.
- New concepts for tactical communications.

It is expected that communications between fixed installations can be provided quite economically to meet the foreseeable military demand. Though technology will be available to meet requirements for greatly increased transmission capacities, the cost and operational considerations for tactical field communications may limit service at the lower unit levels.

The command function may be supported by powerful simulation models working from real-time situation data on own and enemy forces, background information on terrain, infrastructure, weather, and battle models to examine alternative plans of action and enemy options. Staff work required for the preparation of situation reports, plans and orders may be highly automated to facilitate prompt distribution and reduce staffing levels. Realisation of these benefits will require long-term programs for step-by-step development and implementation, taking advantage of civilian developments in areas such as simulation techniques and virtual reality technology.

An increase in capacity and other improvements in communication offer great flexibility with regard to the geographic location of various command functions and resource centres of an integrated C^3I structure. This flexibility will, in turn, facilitate the rapid implementation of modifications or additions to NATO's command structure.

NATO should:

- Support research for sensor technology and systems; in particular, advanced synthetic aperture radar (SAR), hyperspectral sensing, and signal intelligence.
- Support research for sensor fusion methods and experimental verification, including concepts and interoperability aspects of the fusion of data from geographically separate sensors of the same kind or of different kinds.
- Support the development and implementation of high-precision global positioning systems (GPSs) to decimetre accuracy as an aid to the fusion of high-resolution data and to the accurate determination of target positions (position fixing).
- Consider implementing common resources for data fusion in support of NATO level commands.
- Support research and experimental verification of advanced applications for planning and decision making, including simulation and virtual-reality based technologies in support of NATO level commands.
- Support research and technology in advanced communication networking, making maximum use of civilian concepts and services while implementing necessary military requirements in areas such as reliability of connectivity, cryptographic security and authentication.
- Study how geographically distributed resources for C^3I support - fusion centres, simulation facilities and novel communication networking, etc. - can be used to implement a more flexible command infrastructure for NATO. Such flexibility should simplify the integration of new member Nations and facilitate, as necessary, the customising (on short notice, if required) of command structures for combined joint task force operations or other types of operations.

4. Weapon Systems

By the year 2020, directed-energy weapons will become operational. Other weapon systems will be characterised by improvements in:

- *Remote operation - the ability to sense and strike without exposing friendly forces to the risks of direct confrontation.*
- *Precision - the ability to strike with precision with circular error probabilities measured in decimetres.*
- *Miniaturisation - to improve transportability while reducing signature.*
- *Increased speed - to shorten reaction times.*

The *Aerospace 2020* study highlights five weapon systems that will play crucial roles in military aerospace during the next 25 years.

- Directed-energy weapons
- Unmanned tactical aircraft
- Extreme long-range and long-endurance vehicles
- Hypersonic air-breathing missiles
- Manned combat aircraft

Directed-energy Weapons

The use of directed-energy weapons will become common within the next 25 years. They will be used for attacking sensors, materials, and, despite the best intentions of international treaties, may be used by adversaries against human beings.

There are many categories of directed-energy weapons but for this review we will focus on two:

- Laser weapons (ranging from low to high power systems)
- Electromagnetic weapons

Laser Directed-energy Weapons

The potential effectiveness of lasers as weapons is based on a very short "time of flight" coupled with a high intensity, highly directional beam. Low and medium power lasers exist today in many varieties. Most military development programs involve high-power lasers suitable for military applications and "agile" lasers operating at several wavelengths or changeable wavelengths to defeat protective filters.

Low power laser radiation can cause dazzling, or reversible or irreversible blinding of personnel, windows, or sensors. The United Nations, including NATO member Nations, is seeking to enact an International Ban on Blinding Lasers (Vienna, 1995-1996). If an agreement is reached, it will still be necessary to ensure the availability of protective measures and tactics to counter this threat, since it cannot be assumed that all potential enemies will accept and/or respect the ban.

The expected development of laser weapons over the next 25 years is summarised in Table 4-1.

Type	Primary effect	Forecast
Low power	Dazzle	Readily achievable.
Low and medium power	Damage to sensors	Presently in reach of many countries; basic technologies exist.
High power	Damage to vulnerable structures	Will be achieved.
	Attack of theatre ballistic missiles (TBMs) in the boost phase	Will be achieved.
	Active self-defence for aircraft	Will be achieved.
	Attack of space-based assets from aircraft or ground	Technically achievable in 25 years.
	Air-to-air combat	Probably achievable from large aircraft in 25 years.
	Air attack on ground-based military targets	Not probable within 25 years.

Table 4-1: Laser-weapon development prospects over the next 25 years.

The development of laser weapons will have profound implications for NATO. Indeed, it is likely to change the entire concept of aerospace combat. This is an area which must continue to receive priority in applied technology research and in studies of uses, threats and countermeasures.

Electromagnetic Weapons

Evolving technologies will permit the attack and destruction of electronic components through the use of high-power microwaves or related systems.

For long-range applications, a critical technology will be large phased-arrays with high peak-power handling capability. It is likely that this technology will be limited to a few countries and will be limited to large, relatively immobile weapon systems. Defensive applications appear more realistic, but attack of low-earth-orbit satellites may be possible.

For shorter ranges, simpler radio frequency (RF) munitions will be available. The ability to replace the warhead of a missile or artillery shell by a high peak-power radio frequency radiating device will be commonplace by the year 2020. These munitions will be effective against high concentrations of critical electronic equipment, such as command and control centres. Such munitions could be particularly devastating when used against commercial off-the-shelf systems with no built in protection against RF attack.

Unmanned Tactical Aircraft

The unmanned tactical aircraft (UTA) of the future are envisioned to be a class of air combat systems with performance characteristics tailored to enhance mission effectiveness, rather than to meet the physiological needs of the air crew. The new systems will expand tactical aircraft mission options by eliminating the risk of air crew casualties or capture and by performing many *missions more efficiently than conventional piloted aircraft. During the next 25 years, UTAs will become an integral part of the air forces of many countries.*

The UTA concept encompasses a broad class of controlled, recoverable vehicles designed to conduct the full range of tactical missions using ordinary aircraft weapons, onboard sensors, and tactics. A UTA can be designed with varying degrees of autonomy and could be controlled from a ground, air, or sea-based station. The operator will be able to use information from on-board sensors, off-board sensors, and theatre databases.

UTAs will have the benefits inherent in both manned and unmanned operations. As an unmanned system, a UTA can be utterly fearless, perform missions which are too hazardous for pilots, and be expended as required by the situation and the value of the tactical objectives involved. At the same time, the operator retains the latitude to make decisions that may be required by the tactical situation. Depending on the mission, the control exercised over UTA systems could range from total human control to total machine autonomy.

The class of UTA vehicles extends from more flexible and capable versions of currently deployed unmanned aerial vehicles (UAVs) to a full spectrum of future unmanned tactical combat aircraft. In order of increasing complexity, UTAs can be developed for the types of missions shown in table 4-2:

Mission	**Comments**
Reconnaissance, surveillance and target acquisition (RSTA), including battle damage assessment and target designation Electronic warfare	Extensions of missions currently being performed by the UAV and RPV family of platforms.
Suppression of enemy air defence Strike against fixed targets Interdiction; strike against mobile targets	High performance results from eliminating pilot safety concerns. Requires advanced mission control.
Air defence (against aircraft and cruise missiles)	Enhanced capability to provide long-endurance combat air patrol (CAP).
Close air support	High performance results from eliminating pilot safety concerns. Increases the requirement for precision and reliability of mission control. Most demanding mission.

Table 4-2: UTA mission characteristics.

Perhaps most importantly, a UTA can offer a reduced cost option to supplement or complement piloted aircraft. The greatest savings will be realised in peace time support costs; operators will train at their stations using simulations. Actual flight will be required only for verification of operability of the flight vehicle and the associated systems. This could easily reduce the lifetime flying hours of the system by two-thirds, as compared with a manned aircraft.

The successful construction of the UTA itself appears possible on the basis of presently available technology. However, a number of issues must be resolved in cost-effective ways before UTAs can be used in military operations. These issues include normal air safety, reliable communications with capacities provided only by line-of-sight systems, and challenging data processing and human operator interfaces at the control centre.

The cost and complexity of these control centres could be the most significant disadvantage of the UTA when compared with manned tactical aircraft. For example, weapons carrying UTAs operating on long-range missions out of airfields may require quite complex communications and control procedures. For NATO, a common infrastructure and standardised procedures for UTA operations would undoubtedly enhance the viability of the UTA concept.

Extreme Long-range and Long-endurance Vehicles

Aircraft with considerably increased operating range and cargo capacity will reduce the logistics burden of military air transport by reducing the need for air refuelling and refuelling at destination. Advanced cargo handling systems will make it possible to reduce the amount of handling equipment required at the point of delivery. Design trade-offs will enable very long endurance for aircraft with smaller payloads; for example airborne surveillance and control centres and "mother ships" for unmanned aerial vehicles (UAVs) and remotely piloted vehicles (RPVs).

The report *New World Vistas*[1], by the U.S. Air Force Scientific Advisory Board, considers design trade-offs for transport aircraft and concludes that a design for a payload of 150 000 pounds delivered at 12 000 nautical miles with return without refuelling would be a realistic goal. The gross take-off weight would be one million pounds. Realisation of this design, however, will require advances in all major fields of aircraft technology including propulsion, materials, aerodynamics, and design and manufacturing.

In the next few years, experimental systems with laser and microwave weapons will be fitted onto existing transport aircraft. Within 25 years, the introduction of aircraft with considerably extended range and endurance, together with the reduced weight of directed-energy weapons, will lead to operationally flexible airborne systems. Such aircraft will also be suitable for reconnaissance and/or surveillance. The new aircraft could serve as a replacement for the current Airborne Warning and Control System (AWACS) aircraft, as a future platform for Electronic Intelligence (ELINT) operations and/or as a future carrier of Joint Surveillance and Target Attack Radar Systems (JSTARS).

---

[1] *New World Vistas* - Air and Space Power for the 21st Century, Mobility Volume

This aircraft could also be used as an aircraft or missile carrier. It could function as an AWACS with its own offensive capability. Remotely piloted vehicles that are launched and recovered from a large transport aircraft in friendly airspace could be used to demonstrate Alliance presence and resolve.

The carrier concept could also be used to perform the air-to-air role, particularly in no-fly zones and low intensity areas. This could be a cost-effective way to provide a protected airspace when the frequency of intercepts is low. It could also be useful in the initial conflict build-up stage to provide air cover for expeditionary forces.

Long-endurance aircraft performing multiple sorties before refuelling or servicing will increase the effectiveness of airlifts and reduce the need for forward basing. Use of precision air-drop systems will multiply that effectiveness.

While such large aircraft will offer a wide range of possibilities for the Alliance, they must be developed with a strong emphasis on self-protection. It must be accepted that many, if not most, of our future adversaries will wish to inflict the maximum psychological damage to the Alliance without triggering an overwhelming military response. Such a large, high-value asset, representative of the Alliance's technological superiority, would provide a perfect target for such an attack.

Long-range and Long-endurance UAVs and RPVs

This class of air vehicles could act in any role ranging from reconnaissance, surveillance and target acquisition to a "micro-fighter". Operating from a carrier aircraft, such vehicles could fill several missions, including escort cover for the carrier aircraft. It is well within reason to expect that these vehicles could carry weapons, could designate the target for weapons, or could, themselves, be the weapon. More advanced versions could be controlled entirely by personnel in the carrier aircraft. The main benefit of this combination of air vehicles will be the ability to continuously monitor an area without having personnel exposed to hostile actions, while retaining the ability to react instantaneously, if required.

Hypersonic Air-breathing Missiles

> *By the year 2020 a hypersonic air-breathing missile which can fly at Mach 8 (2.4 km/sec.) will be available. Such a missile will be capable of being on target within 10 to 15 minutes, at its maximum range of 1200 to 1500 kilometres. It will have adequate payload capacity to carry a multispectral reconnaissance sensor and information relay package, or a warhead and fusing package suitable for attack on well-protected targets. It will be small enough to be launched by an F-15 or F-16 size aircraft. The cost will be comparable to that of a current cruise missile (between USD 1 and 1.5 million per unit).*

The key to a future high speed (Mach 6 to 8) air-breathing propulsion missile using storable hydrocarbon fuels is the SCRAMJET engine. A hypersonic missile would fly too fast to be shot down by existing methods, and it would take the development of extremely high-performance antimissile systems to threaten it.

Such a hypersonic missile could fulfill several mission requirements including:

- **Extended air defence:** A hypersonic air-breathing missile could be an effective weapon against extremely high payoff aerial targets. Such a target set in the future might include JSTARS, the airborne laser, AWACS, or any of the family of carrier aircraft described earlier.
- **Strike against hardened or buried targets:** The kinetic energy of a Mach 6 to 8 level strike system makes it uniquely suited for this mission. Deep or hard point targets will require terminal seekers, given the low circular error probable (CEP) needed to defeat these targets. The targeting data must be precise enough to allow a transition from Global Positioning System (GPS) or inertial navigation system (INS) navigation to terminal guidance.
- **Strike against time-critical targets:** Targets that may require rapid response include tactical ballistic missiles (TBMs), aircraft, ground maneuver units, artillery, and ships. Some of these targets, in particular TBMs that can be relocated, may be situated hundreds of miles inside hostile territory and may evade detection by mobility and countermeasures. Therefore, the targeting data must be timely enough so that weapon launch can occur within seconds-to-minutes of target detection. The data must be accurate enough to allow weapons equipped with GPS receivers and INSs to achieve high probabilities of kill. Additionally, moving targets will require either in-flight targeting updates, or a seeker using Automated Target Recognition (ATR) for target detection and terminal guidance.

Although the initial development of such a system may be beyond the means of most countries, the cost of purchasing such systems, once they exist, will be well within the means of most future adversaries.

Reusable Suborbital Launchers

By the year 2020 it will be possible to observe any point on earth from the outer edge of the atmosphere, with very short notice (approximately one hour), using a reusable suborbital observation vehicle. This operational flexibility will allow observations at the time and place needed, independent of the orbital limitations and predictability associated with satellite observation.

A reusable suborbital vehicle could be launched from the ground or from a large aircraft, such as a Boeing 747, and could be recovered after landing at a friendly runway. The primary technologies required to realise this capability are lightweight, high-temperature materials and structures, and advanced rocket (or combined air-breathing and rocket) propulsion. These technologies are expected to be available by 2010, with the possible exception of air-breathing propulsion. This may take another ten years to be applied to fully reusable suborbital vehicles. The technologies may become available as the result of civilian efforts towards commercial reusable launchers.

Observations at altitudes as low as 150 kilometres could be made without entering an opponents airspace. A reusable suborbital vehicle would follow a ballistic exo-atmospheric trajectory for most of its flight. (Exo-atmospheric overflight is not considered an aggressive act.) The trajectory of the vehicle would not positively identify the vehicle's target area, or even the nature of the vehicle.

It will also be difficult to discriminate its radar echo from satellites and other space objects. Even if it were positively identified, the survivability of a suborbital vehicle would be excellent. The vehicle's near orbit velocity, and the very short time (a few minutes) available to accurately determine its trajectory would make interception outside of the atmosphere extremely difficult.

Future Manned Combat Aircraft

Combat aircraft will remain central to aerospace power in the next 25 years. The manned combat aircraft will remain the primary platform for most missions (strike, interception, reconnaissance, etc.).

No single power or combination of powers outside of NATO can match the Alliance's technological ability to produce a new generation of manned combat aircraft. We must maintain this qualitative edge, but the challenges are considerable. The main challenge will probably not be limitations of technology, but finding necessary compromises between military requirements, national priorities, industrial interests, and economic issues, to arrive at a combat aircraft fleet which is effective in a worldwide scenario and affordable to NATO Nations.

A critical issue of mission effectiveness will be survivability. Even a superior aircraft will face new threats. Long-range air-to-air missiles, hypersonic missiles and, ultimately, laser weapons will pose serious challenges. Situation awareness will enhance survivability. Future aircraft must take full advantage of information and control technologies, allowing for total flexibility - even within multi-aircraft formations - to deal with changes in the mission environment.

In addition, the following areas will need emphasis: active self-defence, miniature weapons, modular aircraft, high-volume stealth airframes, low-cost avionics, and advanced electronic warfare systems. The development of agile and long-range air-to-air missiles, high-speed long-range air-to-surface missiles, and advanced surface-to-air missiles with high- and low-altitude intercept capability, will also be required.

To maximise effectiveness and survivability, the investment in weapons and aircraft must be balanced. For NATO to retain the advantage in survivability will require continuous development and improvement. The greatest difficulty will be in controlling costs. Strategies for cost control are discussed in chapter 6.

Conclusions and Recommendations

The realisation of directed-energy weapons, in particular laser weapons, is expected to be the most important development in military aerospace in the next 25 years. Laser weapons will reach such levels of maturity during this period that they will change warfare in fundamental ways. Laser-based self-protection systems for aircraft, and offensive airborne weapons will offer decisive advantages to those who possess them over those who do not.

Directed energy at radio and radar frequencies will be used at the tactical level to damage electronic equipment. Protection or reduction of vulnerability is possible for most types of equipment and installations, but cost-effective solutions require careful implementation in the basic design.

Unmanned tactical aircraft (UTAs) are expected to become competitive for some missions presently performed by manned tactical aircraft. The basic technologies required for design of the air vehicle exist. The limiting factors are found in the areas of mission control; that is, communications, sensor fusion, operator-machine environment, and control procedures. For NATO, a common infrastructure and standardised procedures for UTA operations would enhance the UTA concepts.

The range x payload of transport aircraft will be increased, perhaps by a factor of 15. This increase will lead to more economical and flexible air transport and airborne surveillance and control centres, and to new concepts such as airborne laser and microwave weapons. The increase may also lead to "mother ships" for UAVs and RPVs which could be performing close-range reconnaissance and, possibly, attack missions.

Hypersonic (Mach 8) air-breathing missiles will be available at unit costs comparable to present cruise missiles. These hypersonic missiles could become effective weapons against high-value aircraft, tactical ballistic missiles and hardened ground targets.

NATO should:

- Evaluate directed-energy technologies and their potential applications on a broad basis, and consider programs supporting the development of the more promising applications. The aim should be to maintain long-term superiority in this evolving weapons area.
- Conduct system studies to establish how directed-energy weapons may effect tactics and force structures in the long term. Since the changes can be expected to be profound, an early understanding is essential for timely action.
- Develop improved and standardised solutions to achieve more cost-effective protection of electronic equipment against the effects of electromagnetic pulse (EMP) and radio frequency (RF) weapons. In particular, consideration should be given to the protection of civilian off-the-shelf (COTS) units when used as parts of military equipment or in military installations.
- Evaluate concepts for unmanned tactical aircraft, including mission definition and associated infrastructure, and procedures for mission control. If found promising, concepts should be developed through a cooperative program for feasibility demonstration.
- Evaluate concepts for "mother ship" operation of unmanned aerial vehicles (UAVs) and remotely piloted vehicles (RPVs). If found promising, concepts should be developed through a cooperative program for feasibility demonstration.
- Evaluate concepts for the use of hypersonic, air-breathing propulsion weapons.
- Evaluate the possible application of civilian reusable launcher technology for the development of suborbital observation vehicles.
- Encourage programs for the development of affordable manned tactical aircraft, with emphasis on the critical aspects of maintaining aircraft survivability in combat and coordinating national resources.

5. Vulnerabilities and Threats

> *NATO and its member Nations will not be the only beneficiaries of future high-technology development. The global availability of both the technologies and the expertise of those who create them will pose new threats to our military effectiveness and new challenges in the way we protect civilians as well as the military.*

In a large-scale war, maintaining the essential functions of the government, public services, and the economic sector is a primary concern. This is necessary to ensure the supply of the goods and services essential for the military effort and for the survival of civilian populations. The vulnerability of the Alliance in this regard is beyond the scope of the study. Instead, *Aerospace 2020* explores the nature of evolving threats and vulnerabilities that may result from new technologies and inflict unacceptable damage even in lower-level conflicts.

Information Systems

It is widely assumed that information systems and, in particular, large distributed systems, are vulnerable to intended and unintended interference. Such information systems are now indispensable in nearly all functions of society, including the military. Although we are very dependent on these systems, the local calamities that have been experienced as a result of breakdowns have not yet resulted in total failure of the integrated functions of government, public service or industry. There are several well-known cases of large-scale failures of electric power grids, but these have been the result of past electrical engineering practices, not the failure of an information system.

Considering the large number of extensive information systems in use, this experience suggests that there is an inherent reliability and fault tolerance in the designs of the systems. It also suggests that functionality is no longer necessarily dependent on individual pieces of equipment. As a result, any assessment of vulnerability must consider the risks posed to the functions a system performs, rather than the risks to system components.

Survivability of functions in a large, distributed information system can be secured by architecture that enables the system to reorganise and redistribute its functions. Systems are already designed to be redundant and self-organising, so that failure of one part leads to adjustments that make the best use of the resources still available. Designed redundancies build in the capacity to allow the system to immediately compensate for damage or faults. This ability to self-organise also enables “graceful degradation”; that is, the ability to automatically divert resources from lower priority tasks in order to maintain essential functions. Incorporating these and other creative methods of distributing functionality will become even more important in system designs of the future.

To reduce the vulnerability of military information systems, priority must be given to the development of new technologies that provide three basic elements of protection:

- **Protection of individual pieces of the system against the physical destruction of electronics by high-power microwave (HPM) weapons.**

  As discussed in chapter 4, a variety of weapons that can damage or destroy unprotected electronic equipment by strong electromagnetic radiation at radio frequencies will be widely available. All radio receivers, whether in handsets or satellites, are vulnerable to such weapons. Protective measures include careful design, but redundancies at the system level are also essential. Other types of electronic and electrical equipment can be protected more easily. But effective, low-cost protection of systems and individual components must, in most cases, be implemented at the design stage.

- **Protection of the integrity of information.**

  Information systems can be vulnerable to many forms of "attack" including the disruption of operating systems to cause system malfunctions, theft of information, destruction or false modification of information, and the introduction of false information. Most forms of such data attacks require unauthorised access. Protective measures include encryption techniques, authorisation techniques to verify the identity of the user, and multilevel security that isolates internal information based on levels of security and authorisation of access. The technological challenge is to find solutions that are also acceptable from a practical point of view. It is expected that such solutions are achievable - with the probable exception of those that would provide adequate protection against "unfaithful servants" and enemy use of captured equipment and personnel.

- **Protection of capabilities essential to the performance of the entire system.**

  Although protective measures will be applied to individual installations and equipment, efforts to preserve the integrity and performance of integrated information systems are expected to be handled in designs at the systems level. Among other things, these designs will include: communications by self-organising networks of different transmission and switching systems, distribution and multiplication of databases, and barriers against viruses and other fault conditions.

Laser Weapons

Both the human eye and electro-optic sensors are sensitive to visible laser energy and can be permanently damaged even by low intensity lasers. Low and medium power lasers are commercially available for a number of applications. Despite current efforts to achieve an international ban on weapons intended for blinding, the threat from these lasers if used as weapons cannot be ignored. The loss of eyesight is, of course, a very serious threat for any individual, but the effect of lasers used against aircraft, especially low-flying (landing) aircraft or helicopters, could prove disastrous.

Protective measures against lasers used for blinding include optical filters against the most common laser wavelengths, complete protection of one eye, or a spare optical sensor. Although important, these measures are not considered to be adequate against repeated attacks, or against the multifrequency and variable frequency lasers which will be common in the future.

Low-cost Missiles

Perhaps more than any other weapon system, the cost of defending against low-cost missiles is far greater than the cost to the attacker. Ballistic missiles and cruise missiles with ranges of several hundred kilometres and warheads of as much as 100 kilograms are expected to be available at prices within the reach of most potential enemies. NATO requirements for quality and precision will not be met by such low-cost missiles based on commercially available technology. However, they may be used by adversaries to inflict intolerable damage on population centres, industrial resources, communication centres, or other high-value targets.

The threat is increased if low-cost missiles are used to carry weapons of mass destruction. Earlier NATO studies have shown that countering these threats will be technically feasible but will demand considerable resources, especially if long-duration early warning systems against surprise attack become a requirement. Vigilant surveillance and intelligence for detecting and monitoring situations, and for determining the need for pre-emptive measures, military or otherwise, will be essential.

Unmanned Aerial Vehicles

When requirements for accuracy are not high (for example terrorist activities or low-level conflicts), a low-cost version of an unmanned aerial vehicle (UAV) will be suitable for the delivery of weapons of a few tens of kilograms over distances of, at least, tens of kilometres. Defence against such systems has not been studied extensively but, as with low-cost missiles, pre-emptive actions based on surveillance and intelligence are expected to be the best means of countering this threat.

Hypersonic Missiles

While the cost of developing a hypersonic missile will be beyond the means of most countries, the purchase price will not. The simplest version of a Mach 6 to 8 missile could present a significant threat as a surface-to-air or surface-to-surface missile against high-value targets. There is no existing effective countermeasure to such a weapon once it is launched.

Recommendations

NATO should:

- Support the development and evaluation of principles and methods to minimise the foreseeable threats to integrated military information systems. Develop system-level design rules that can be applied to NATO's information systems.
- Evaluate the threat posed by low and medium power lasers to aircraft and helicopter pilots. Study protective measures such as concepts for "closed cockpit" operation (non-visual flight).
- Continue evaluation of concepts of extended air defence against ballistic missiles and cruise missiles. Expand the scope to include hypersonic missiles. Evaluate threats from weapons-carrying, unmanned aerial vehicles and remotely piloted vehicles.

6. Affordability

Military production and procurement is gradually adopting the philosophy that dominates civilian production - improvements must be made at nearly a constant cost. The obvious approach to this new challenge is to apply civilian industrial practices in the development and production of military systems. This will happen, but some factors remain unique to the military.

Since the end of World War II, advances in technology that have been applied for military purposes have focused primarily on improving performance. Improvements in military systems have been made to ensure superiority over potential adversaries and to counter potential threats, with little regard to cost. However, the cost-per-unit of these improvements has increased dramatically. In contrast, in civilian production, new technologies have been implemented only when they simultaneously improve performance and maintain or reduce costs. This is possible (and occasionally quite necessary) because the cost of civilian products is dependent upon the prosperity and preferences of the consuming public.

The cost of military systems has not been matched by increases in military budgets, and the number of units of major systems has been reduced. Until now, this has not been a major problem. The more advanced systems, although fewer in number, have contributed more, often much more, to the total force strength than the larger number of systems they have replaced.

The algebra of cost versus performance versus number may still work to the advantage of maximum performance at the unit level, but two factors intervene to change the overview of costs at the total force level. First, the number of units is becoming so small that units are not necessarily available when and where they are needed. Second, combat losses could cause a rapid decline in overall strength and combat effectiveness. These effects are considered potentially critical, and reductions in military budgets make the problem worse.

This means that new systems cannot cost much more to acquire, own and operate than the systems they replace. It also means that new systems designed to combat new threats will be compared in value to systems handling already existing priorities.

In order to afford the minimum level of essential military capabilities, future advances in technology will be achieved by applying new philosophies of design and manufacturing. In particular, these philosophies will focus on reducing life-cycle costs. The following approaches merit consideration.

Define cost as the primary design parameter. Total life-cycle cost, specifically development, procurement and operating cost, must be taken fully into account at the design stage. Performance goals must be clearly defined at a high level with regard to the function of the system, rather than at the level of detailed technical performance. Success in meeting cost specifications and reaching performance goals will invariably be the result of a large number of decisions affecting the entire design. Thus, it is essential that the design effort be organised to allow trade-offs across the complete system.

Introduce new technologies only when they "buy" their way in. The tangible benefits - improved performance and/or reliability - must not be accepted at additional cost. Mission requirements should be restricted to what is actually needed, and no elaboration of the requirement should be accepted without thorough trade-off studies of the costs and the benefits. In addition, the portfolio of mission requirements should be negotiable and changeable as the costs of meeting the various requirements become better known.

Facilitate system integration and later modification by using "open" architectures. The implementation of integrated modular avionics as "open systems" (based, for example, on generally recognised interface standards), will not only reduce acquisition costs, but also life-cycle costs since system upgrades will be less expensive. Additional cost benefits can be expected from the development of exchangeable hardware and software for automatic processing. This will also facilitate system upgrades over the life of the system. The implementation of modular, object-oriented software techniques will further reduce costs. The greatest savings will come from standardising the development of software; for example formally structured codes produced with high-level architectural tools.

Exploit commonalities with the civilian market. Many of tomorrow's technologies will evolve for the civilian market. Economies of scale and competition for market share will help limit costs. This trend should produce new, affordable capabilities which the military must be prepared to exploit.

Using civilian technology and, in many cases, civilian off-the-shelf (COTS) systems in ways specialised to meet military needs offers great potential for cost reduction, but it is often not as straightforward as it seems. There are several ramifications for NATO and the Nations that should not be underestimated or overlooked.

First, it is often assumed that military development costs will decrease significantly as more civilian technology is available. However, applying and adapting this technology for military purposes can be a demanding task, requiring as much, if not more, time and effort that is not without cost.

Second, in the civilian market the economic life of an off-the-shelf system, such as a portable computer, is dictated by competition. While for many consumers today this life is considered to be three to six years, for many manufacturers it is only three to six months. For the military, however, the economic life of equipment and systems is much longer - perhaps 30 years - because costs are organisational and related to such things as logistics and training.

Extend modular design to families of related systems. A strategic approach to cost reduction is to review the composition of fleets of related systems. A fleet of tactical aircraft, for example, composed primarily of one family of multi-role aircraft would be less expensive to own and operate due to the commonality in manufacturing, logistical support, and training. This family of aircraft would perform a wide range of tactical missions. The aircraft would require a modular airframe, able to incorporate several options and variations:

- A single-seat design, or a two-seat design, with the second crew member taking the space of internal fuel.
- A single-seat short take-off, vertical landing (STOVL) version with the lift package in place of a second crew member.
- A carrier-borne fighter with a larger wing span (obtained by replacing outer wing panels only).
- Replaceable wing panels to improve payload range and allow long-range interdiction missions.

- Conformal packs to augment internal weapons, to provide extra fuel, and to carry additional avionics and antennas for electronic support measures (ESM) and suppression of enemy air defence (SEAD) missions.

The basic airframe, together with all possible combinations of conformal packs, could be designed for stealth.

Use concurrent engineering methods. Concurrent engineering (the integrated production team) and virtual manufacturing have made the "paperless airplane" process achievable and applicable to any aerospace system. Access to the same digital description and databases has integrated design tools with advanced simulations of both the product and the manufacturing process. Physical models can be replaced with digital pre-assembly models, eliminating most post-design changes and reducing time-to-market by 50%. These pre-assembly, or "virtual", prototypes, simulate both the performance and the topology of the structure, controls, systems, and so forth. This provides credible analysis for determining non-interference, accessibility for service and repair, cost, and other factors. Partially replacing physical testing, such as structural and wind-tunnel testing of air vehicles, by analysis allied to virtual manufacturing and virtual processing (the simulation of manufacturing processes for metal, polymers, and other materials) will result in further cost savings.

Conclusions and Recommendations

Radically new systems will result from combining the military and civilian technologies that evolve in the next 25 years. Systems related, for example, to laser weapons, unmanned tactical aircraft and highly integrated support of command and control will be developed. Affordability of these systems will depend on the implementation of new approaches for controlling costs.

NATO should:

- Support cooperation in developing and promulgating "best practices" in the control of life-cycle costs.
- Develop analytical standards and simulation tools to measure intended upgrades and new systems against needs on the basis of performance and cost.
- Concentrate technology support in areas which are most promising for cost reduction on a total system basis and which are not supported by the civilian market.

7. NATO Research and Technology

The recommendations presented in *Aerospace 2020* regarding research and technology priorities for NATO invite reflection on NATO's policy to support these recommendations.

In the early days of NATO and AGARD, technology was in a phase of such explosive growth that virtually all successful developments could be usefully applied. As a result, the policy supporting research and technology focused more on securing a stimulating research environment than on the selection of the areas of research.

This policy was consistent with the nature of science. A "genuine" innovation, a creative idea breaking new ground, cannot be planned or predicted. The foresight of such innovation is the territory of a few selected visionaries, who are often not widely believed. Such research is still vital, however, and it continues to be unwise to attempt to make such innovative basic technology prove its usefulness in advance to justify expenditures. It takes time before the impact of a genuine innovation, or the scope of its potential, can be fully understood. The laser is just one of many examples supporting this fact.

While only a small fraction of research and development efforts can be classified as genuinely innovative, there are many decisions which must be made with regard to the bulk of research and development efforts devoted to advanced technology and its applications. The range of these technologies and the cost of high-quality research has grown, and will continue to grow, so significantly that establishing priorities for NATO support is both critical and urgent.

While it is beyond the scope of this study to make recommendations regarding the organisation of NATO research and technology, some observations have emerged as a result of the study that might warrant consideration.

Observation 1: The rate of technical development and the consequences of the developments vary considerably from one technology area to another. NATO research and technology support should be adjusted accordingly, emphasising those areas of development which simultaneously have the greatest potential for strong growth and have the most important military consequences.

At one time, aircraft design met these criteria. Twenty-five years ago, in the period from 1968 to 1977, many of the aircraft still in use today made their first flights, including such well-known models as the Anglo-French Concorde, Boeing's 747, the F-14, F-15, and F-16 fighter aircraft by Grumman, McDonnell Douglas, and General Dynamics respectively, and the NASA Space Shuttle. Current versions of these aircraft have been improved and updated, but conceptually, at the applications level, they have not changed. Expectations are that some of these aircraft will still be flying, and perhaps even produced, in the year 2020.

Today, several new technologies have emerged which better meet the criterion of a strong development growth-rate in combination with great practical importance to warrant research support. Stealth technology, for example, is a major innovation which can be expected to influence all future combat aircraft designs, despite the fact that it has not yet been widely applied. Similarly, the development of detection or "counter-stealth" technologies to defeat it also meets the criterion. Other examples include electro-optics, laser technology, and specialised military information technology.

Observation 2: In view of the shift from military to civilian leadership in some areas of technology, NATO should maintain a policy that provides research support in areas where progress is to NATO's benefit, but seems unlikely to be served by civilian initiatives.

Observation 3: NATO should make systematic efforts to examine new *system concepts* at an early stage in order to acquire a better understanding of their potential operational and economic benefits and limitations.

Such analysis would help generate guidelines for development and facilitate, as well as motivate, cooperative efforts between Nations and between industries. In addition, NATO should increase its use of systems-oriented analysis, simulation, and feasibility demonstrations when determining the areas and level of support it will provide.

Observation 4: NATO should support a recurring, informal military and scientific forum on innovative approaches to future defence.

The *Aerospace 2020* study has revealed a spectrum of research and technology areas which deserve careful consideration when determining the future focus of NATO support. Whether considered individually or collectively, they offer possibilities that will help strengthen NATO's ability to ensure the security of its member Nations in an unpredictable future.

In order to realise these possibilities, or even some of them, we must negotiate technological and economic challenges beyond the means of most Nations. The research and technology framework of the Alliance offers opportunities to meet these challenges with a common effort.

Appendix A: Study Group Members

Study Director:	Mr. Nils Holme Director General Norwegian Defence Research Establishment Norway
Rapporteur:	Dr. Hywel Davies Ministry of Defence (Ret.) United Kingdom
Aerospace Applications Study Committee (AASC):	Brig. Gen. Giuseppe Marani Chief of Staff Commando 5 Forza Aerea Tattica Alleata Italy
	Col. Thomas L. Allen AFSAA/CC, The Pentagon United States
	Col. Achille Gielis Policy Requirement Division, SHAPE Belgium
Aerospace Medical Panel (AMP):	Dr. Paul Vandebosch Col. BAF (Ret.) Belgium
	Lt. Col. Egil Alnaes, MD PhD Oslo Military Clinic Norway
Flight Vehicle Integration Panel (FVP):	Dipl. Ing. Horst Wünnenberg Manager of Flight Physics and Predesign Fairchild Dornier Germany
	Mr. Barry Tomlinson Flight Dynamics and Simulation Department Defence Evaluation and Research Agency United Kingdom
	Prof. Luis M. B. da Costa Campos Instituto Superior Tecnico Portugal

Fluid Dynamics Panel (FDP):	Prof. Dr. Cahit Çiray Aeronautical Engineering Department Middle East Technical University Turkey
	Mr. Christian Dujarric Future Launchers Office European Space Agency France
	Mr. David R. Selegan Wright Laboratory United States
Mission Systems Panel (MSP):	Prof. Dr. Heinz Winter Director Institut für Flugführung, DLR Germany
	Mr. James K. Ramage Chief Flight Control Systems Branch Wright Laboratory United States
Propulsion and Energetics Panel (PEP):	Mr. Robert E. Henderson Senior Program Manager Engineering Division Universal Technology Corporation United States
	Mr. Don M. Rudnitski Head, Engine Laboratory Institute for Aerospace Research National Research Council of Canada Canada
	Prof. Dr. Dietmar K. Hennecke Fachgebiet Gasturbinen und Flugantriebe Technische Hochschule Darmstadt Germany
Sensor and Propagation Panel (SPP):	Mr. F. Christophe Dept. Micro-Ondes, ONERA-CERT France
	Prof. D. H. Höhn Director, FGAN-FfO Research Institute for Optics Germany

Structures and Materials Panel (SMP):	Prof. Richard T. Potter Business Manager Structural Materials Centre DERA Farnborough United Kingdom
	Prof. Dr. Otto Sensburg Chief Engineer Daimler-Benz Aerospace (DASA) Militärflugzeuge Germany
Technical Information Committee (TIC):	Mr. R. Paul Ryan Deputy Administrator Defense Technical Information Center United States
	Dr. Heinz Häge Streitkräefteamt/Abt.III, FIZBw Germany
AGARD Executives:	AASC: Col. M. Shoemaker, USAF AMP: Maj. R. Poisson, CAF FVP: Lt. Col. J. Wheatley, USA FDP: Dr. J. Molloy, NASA MSP: Lt. Col. P. Fortabat, FAF PEP: Dr. P. Tonn, Germany SPP: Lt. Col. G. Del Duca, IAF SMP: Dr. J. Carballal, Spain TIC: Mr. G. Hart, NATO