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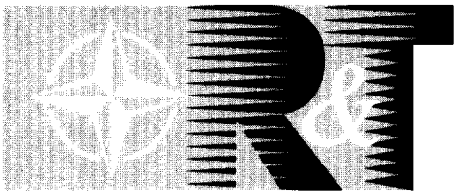

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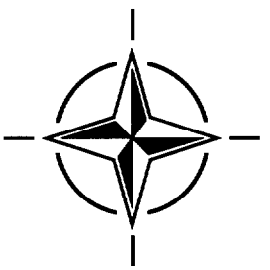
Design Principles and Methods for Aircraft Gas Turbine Engines

(les Principes et méthodes de conception des turbomoteurs)

Papers presented at the RTO Applied Vehicle Technology Panel (AVT) Symposium - organized by the former AGARD Propulsion and Energetics Panel (PEP) - held in Toulouse, France, 11-15 May 1998.



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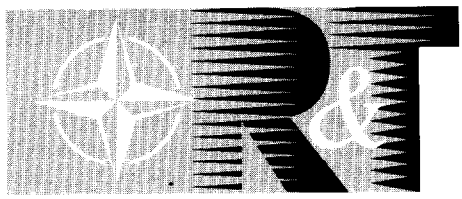

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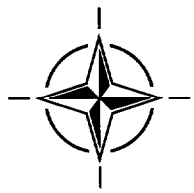

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Design Principles and Methods for Aircraft Gas Turbine Engines

(RTO MP-8)

Executive Summary

After more than half a century of operational use of gas turbine engines to power military aircraft, this symposium sets the focus on highlights of today's achievements in research and development of aircraft engine technology.

Future military aircraft will require significant performance gains from the propulsion system to provide enhanced operational flexibility, longer range, better fuel efficiency and improved affordability.

Gas turbine engines combine disciplines from all major engineering sciences in a most interdependent way. The energy concentration in engine components is permanently increasing. Aerodynamic loads, materials, cooling techniques, structural components, mechanical systems, combustors, augmentors and nozzles are equally designed to the limit of know-how. Sophisticated methods and design tools are used, relying on electronic control and monitoring systems, which safely operate engines close to their boundaries of flow stability and their mechanical integrity, at the same time pushing further the useable life span and reducing life cycle cost (LCC). The symposium addressed gas turbine design aspects for all classes of engines, including turbofan/turbojet, turboprops/turboshaft and turboramjet engines for tactical, transport, helicopter and expendable aircraft applications. The results will permit the military user to better understand the limit and options of any gas turbine engine in performance and use. They will also allow the industries of the NATO countries to better meet the design goals and other requirements set by the military customer thus improving NATO's defense and peace keeping capability while respecting today's budget constraints.

Les principes et méthodes de conception des turbomoteurs

(RTO MP-8)

Synthèse

Après plus d'un demi-siècle d'exploitation opérationnelle des turbomoteurs pour la propulsion d'avions militaires, ce symposium met en lumière les principales avancées réalisées dans le domaine de la recherche et du développement des technologies des moteurs d'avion.

Les propulseurs des avions militaires du futur devront assurer des gains de performances sensibles afin de permettre une plus grande souplesse opérationnelle, une autonomie plus grande, un meilleur rendement du carburant et un coût d'acquisition plus acceptable.

La technologie des turbomoteurs couvre des disciplines représentatives de l'ensemble des sciences de l'ingénieur, qui sont fortement imbriquées. La concentration des efforts sur les organes moteur ne cesse de s'accroître. Aussi, le calcul des charges aérodynamiques, des matériaux, des techniques de refroidissement, des éléments structuraux, des systèmes mécaniques, des chambres de combustion, des augmenteurs de poussée et des tuyères touche, aujourd'hui, aux limites des connaissances techniques. Il est fait appel à des méthodes et des outils de conception sophistiqués, qui sont tributaires de systèmes électroniques de contrôle et de surveillance. Ces systèmes permettent d'exploiter les moteurs dans des conditions proches des limites de stabilité de la veine et de l'intégrité mécanique, en toute sécurité, tout en prolongeant leur durée de vie et en diminuant leur coût global de possession (LCC). Le symposium a examiné les différents aspects de la conception des turbomoteurs pour toutes catégories de propulseur, y compris les réacteurs à double flux/turboréacteurs, les turbopropulseurs/turbomoteurs et les turbo-statoréacteurs pour des applications tactiques, de transport, hélicoptère et avions non-réutilisables. Les conclusions du symposium permettront à l'utilisateur militaire de mieux comprendre les limites de performance et les options offertes par tout turbomoteur. Elles permettront également aux industriels des pays membres de l'OTAN de mieux répondre aux objectifs de conception et aux autres exigences annoncées par le client militaire, afin d'améliorer les capacités de défense et de maintien de la paix de l'OTAN, tout en respectant les contraintes budgétaires actuelles.

Contents

SESSION II: MECHANICAL SYSTEMS

SESSION III: CONTROLS

SESSION IV: COMBUSTORS/AUGMENTORS

SESSION V: COMPRESSION SYSTEMS PART I

SESSION IX: ENGINE DESIGN AND ANALYSIS PART II

Theme

Future aircraft will require significant performance gains from the propulsion system to provide enhanced operational flexibility, longer range, better fuel efficiency and improved affordability. Gas turbine engines will be required to provide excellent performance and durability with minimum weight over a wide range of operating conditions. Improvements in aerodynamics, cooling technology, materials, structures and mechanical systems will offer the prospect of significantly improved performance and mechanical integrity within affordability constraints. Full progress can only be realized by the incorporation of advanced systems and component design methods utilising sophisticated mathematical models of flows, thermal behaviour, stresses, vibration, etc. This symposium will address gas turbine design aspects for all classes of engines, including turbofan/turbojet, turboprops/turboshaft and turboramjet engines for tactical, transport, helicopter and expendable aircraft applications.

Thème

Les propulseurs des avions futurs devront réaliser des gains en performances considérables afin de permettre une meilleure souplesse opérationnelle, une plus grande autonomie, une diminution de la consommation spécifique et un coût d'acquisition plus acceptable. Les turbomoteurs devront fournir d'excellentes performances et faire preuve de durabilité pour une masse minimale dans un large éventail de conditions opérationnelles. Des améliorations dans le domaine de l'aérodynamique, des technologies de refroidissement, des matériaux, des structures et des systèmes mécaniques, offrent des perspectives d'amélioration considérables au niveau des performances et des caractéristiques d'intégrité mécanique, tout en permettant de respecter les contraintes budgétaires imposées. Cependant, aucun progrès véritable ne pourra être réalisé sans l'incorporation de systèmes avancés et de méthodes de conception de composants faisant appel à des modèles mathématiques sophistiqués d'écoulements, de comportements thermiques, de contraintes, de vibrations etc. Ce symposium examinera les différents aspects de la conception des turbomoteurs pour toutes les catégories de moteurs, y compris les turboréacteurs/réacteurs à double flux, les turbopropulseurs/turbomoteurs et les turbo-statoréacteurs, pour applications tactiques, ainsi que pour les avions de transport, hélicoptères et aéronefs non réutilisables.

Recent Publications of the Former AGARD Propulsion and Energetics Panel

CONFERENCE PROCEEDINGS (CP)

Engine Response to Distorted Inflow Conditions
AGARD CP 400, March 1987

Transonic and Supersonic Phenomena in Turbomachines
AGARD CP 401, March 1987

Advanced Technology for Aero Engine Components
AGARD CP 421, September 1987

Combustion and Fuels in Gas Turbine Engines
AGARD CP 422, June 1988

Engine Condition Monitoring — Technology and Experience
AGARD CP 448, October 1988

Application of Advanced Material for Turbomachinery and Rocket Propulsion
AGARD CP 449, March 1989

Combustion Instabilities in Liquid-Fuelled Propulsion Systems
AGARD CP 450, April 1989

Aircraft Fire Safety
AGARD CP 467, October 1989

Unsteady Aerodynamic Phenomena in Turbomachines
AGARD CP 468, February 1990

Secondary Flows in Turbomachines
AGARD CP 469, February 1990

Hypersonic Combined Cycle Propulsion
AGARD CP 479, December 1990

Low Temperature Environment Operations of Turboengines (Design and User's Problems)
AGARD CP 480, May 1991

CFD Techniques for Propulsion Applications
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Insensitive Munitions
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Combat Aircraft Noise
AGARD CP 512, April 1992

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Heat Transfer and Cooling in Gas Turbines
AGARD CP 527, February 1993

Fuels and Combustion Technology for Advanced Aircraft Engines
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Technology Requirements for Small Gas Turbines
AGARD CP 537, March 1994

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AGARD CP 558, February 1995

Environmental Aspects of Rocket and Gun Propulsion
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Advanced Aero-Engine Concepts and Controls
AGARD CP 572, June 1996

Service Life of Solid Rocket Propellants
AGARD CP 586, May 1997

Aircraft Fire Safety
AGARD CP 587, September 1997

Future Aerospace Technology in the Service of the Alliance — Sustained Hypersonic Flight
AGARD CP 600, Volume 3, December 1997

Advanced Non-Intrusive Instrumentation for Propulsion Engines
AGARD CP 598, May 1998

ADVISORY REPORTS (AR)

The Uniform Engine Test Programme *(Results of Working Group 15)*
AGARD AR 248, February 1990

Test Cases for Computation of Internal Flows in Aero Engine Components *(Results of Working Group 18)*
AGARD AR 275, July 1990

Test Cases for Engine Life Assessment Technology *(Results of Working Group 20)*
AGARD AR 308, September 1992

Terminology and Assessment Methods of Solid Propellant Rocket Exhaust Signatures *(Results of Working Group 21)*
AGARD AR 287, February 1993

Guide to the Measurement of the Transient Performance of Aircraft Turbine Engines and Components *(Results of Working Group 23)*
AGARD AR 320, March 1994

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AGARD AR 323, July 1994

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AGARD AR 332, September 1995

Structural Assessment of Solid Propellant Grains *(Results of Working Group 25)*
AGARD AR 350, December 1997

CFD Validation for Propulsion System Components *(Results of Working Group 26)*
AGARD AR 355, May 1998

LECTURE SERIES (LS)

Blading Design for Axial Turbomachines
AGARD LS 167, June 1989

Comparative Engine Performance Measurements
AGARD LS 169, May 1990

Combustion of Solid Propellants
AGARD LS 180, July 1991

Steady and Transient Performance Prediction of Gas Turbine Engines
AGARD LS 183, May 1992

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AGARD LS 188, June 1993

Research and Development of Ram/Scramjets and Turboramjets in Russia
AGARD LS 194, December 1993

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AGARD LS 195, May 1994

Mathematical Models of Gas Turbine Engines and their Components
AGARD LS 198, December 1994

Integrated Multidisciplinary Design of High Pressure Multistage Compressor Systems (LS-211)
published as RTO EN 1, September 1998

AGARDOGRAPHS (AG)

Measurement Uncertainty within the Uniform Engine Test Programme
AGARD AG 307, May 1989

Hazard Studies for Solid Propellant Rocket Motors
AGARD AG 316, September 1990

Advanced Methods for Cascade Testing
AGARD AG 328, August 1993

REPORTS (R)

Application of Modified Loss and Deviation Correlations to Transonik Axial Compressors
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AGARD R 810, January 1997 *(NATO Unclassified)*

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Reliability	Materials	Transport aircraft
Compressors	Vibration	Helicopters
Mathematical models	Turbofan engines	

14. Abstract

The symposium dealt with design approaches for military aircraft propulsion systems to provide enhanced operational flexibility, longer range, better fuel efficiency and improved affordability. All classes of gas turbines were addressed in nine sessions as follows:

- Engine Design and Analysis (Part I) (5 papers)
- Mechanical Systems (6 papers)
- Controls (4 papers)
- Combustors/Augmentors (4 papers)
- Compressor Systems (Part I) (5 papers)
- Compressor Systems (Part II) (3 papers)
- Turbines (Part I) (5 papers)
- Turbines (Part II) (4 papers)
- Engine Design and Analysis (Part II) (4 papers)

These proceedings also include a Technical Evaluation Report and a Keynote address published in French and English.

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