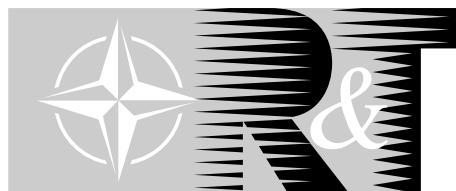


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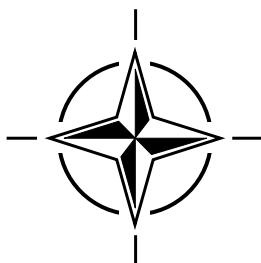
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RTO MEETING PROCEEDINGS 36

Structural Aspects of Flexible Aircraft Control

(les Aspects structuraux du contrôle actif et flexible des aéronefs)

Papers presented at the Specialists' Meeting of the RTO Applied Vehicle Technology Panel (AVT) held in Ottawa, Canada, 18-20 October 1999.



Published May 2000

Distribution and Availability on Back Cover

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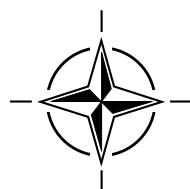
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The Research and Technology Organization (RTO) of NATO

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

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- SCI Systems Concepts and Integration
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- IST Information Systems Technology
- AVT Applied Vehicle Technology
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Published May 2000

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ISBN 92-837-0014-7



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

Structural Aspects of Flexible Aircraft Control

(RTO MP-36)

Executive Summary

The papers presented at this meeting dealt with the state-of-the-art, underlying theory of the influencing factors and characteristics, and existing capabilities of Nations to integrate various factors during the design stage while observing the effects on aircraft layout and behaviour.

Aircraft are inherently flexible and flexibility can be used to advantage as a design feature for improved performance. Flexible aircraft are subject to interaction between flight mechanics, structural dynamics, and flight control system dynamics. Aeroviscoelastic instability can lead to disastrous failures in aircraft as was recently the case for several fighter aircraft. These problems are very similar to flutter accidents which occurred two decades ago. Limit cycle oscillations could restrict fighter aircraft performance particularly those with various store configurations. This problem is most relevant to air-to-ground attack and fighter aircraft.

Flight control systems increasing the stability, or the active control of low damped or unstable aircraft with rigid or flexible modes, have additional coupling effects on flight mechanics and structural responses. These interactions must be considered when designing the airframe structure, flight control systems, and elastic alleviation systems in order to avoid bad handling qualities and bad ride comfort.

An integral analysis of flight mechanics, flight control, static and dynamic loads, flutter and aeroviscoelasticity has to be carried out. Therefore, a compatible mathematical model of the coupled dynamics of flight mechanics, flight control, and structural dynamics must be established. Such models (using the time and frequency domain descriptions) are available in the military aircraft industry to assist in the design and clearance of flight control systems. However, the design of flight control systems and structures is usually performed separately. As such, an integrated interdisciplinary design of flight control systems is generally not feasible due to its complexity. At present, it is only used to improve the control system and the structural capability of components in critical areas.

How to improve the design methods used in the development of military fighter aircraft, and its use in transport aircraft design applications was an outcome of this meeting.

les Aspects structuraux du contrôle actif et flexible des aéronefs

(RTO MP-36)

Synthèse

Les communications présentées lors de cette réunion ont examiné l'état actuel des connaissances dans ce domaine, les théories régissant les facteurs déterminants et les caractéristiques et les capacités actuelles des pays membres de l'OTAN à incorporer ces différents facteurs dans le processus de conception, ainsi que les effets sur la configuration et le comportement des aéronefs.

Les aéronefs sont intrinsèquement flexibles et cette flexibilité peut être mise à profit au stade de la conception pour améliorer leurs performances. Les aéronefs flexibles sont sujets à des interactions entre la mécanique du vol, la dynamique structurale et la dynamique des systèmes de pilotage. L'instabilité aéroservoélastique peut conduire à une défaillance catastrophique de l'avion, comme il a été démontré récemment pour plusieurs avions de combat. Ces problèmes ressemblent aux accidents dûs au flottement, survenus il y a deux décennies. Il se peut que le rayon d'action des avions de combat soit limité par les oscillations limites, et surtout dans le cas de certaines configurations d'emports. Ce problème affecte particulièrement les avions de combat d'attaque au sol.

Les systèmes de pilotage privilégiant l'augmentation de la stabilité, ou le contrôle actif d'aéronefs instables ou aux oscillations faiblement amorties ayant des modes rigides ou flexibles peuvent créer des effets de couplage supplémentaires affectant la mécanique du vol et les réponses structurales. Ces interactions doivent être prises en compte lors de la conception de la cellule, des systèmes de commande de vol et des systèmes d'allègement élastique afin d'éviter la détérioration des qualités de vol et du confort du pilote.

Il y a lieu de procéder à une analyse intégrale de la mécanique du vol, des systèmes de pilotage, des charges statiques et dynamiques, du flottement et de l'aéroservoélasticité. Il est, par conséquent, nécessaire d'établir un modèle mathématique compatible de la dynamique couplée de la mécanique du vol, des systèmes de pilotage et de la dynamique structurale. De tels modèles (qui intègrent la description du domaine du temps et du domaine de fréquence), sont à la disposition de l'industrie aéronautique militaire pour la conception et l'homologation des systèmes de pilotage. Cependant, les systèmes de commande de vol et les structures sont, en principe, conçus séparément. Par conséquent, la conception interdisciplinaire intégrée des systèmes de commande de vol n'est en général guère faisable en raison de sa complexité. A l'heure actuelle, cette approche est utilisée uniquement pour améliorer le système de commande et la capacité structurale de certains composants critiques.

Les conclusions de cette réunion permettent d'envisager l'amélioration des méthodes de conception mises en œuvre dans le développement des avions de combat et de les appliquer à la conception des avions de transport militaires.

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† Paper not available at time of printing.

Theme

Aircraft are inherently flexible and flexibility can be used to advantage as a design feature for improved performance. Aeroservoelastic instability can also lead to a catastrophic failure of the aircraft as was shown lately on a F117 stealth aircraft accident similar to flutter accidents two decades ago. Limit cycle oscillations may placard fighter airplanes especially with various store configurations. This is most true to military transport and fighter aircraft. Flexible aircraft are subject to interactions between flight mechanics, structural dynamics and flight control system dynamics. The Meeting will look into the state of the art treating as well the underlying theory of the influencing factors and characteristics as also the existing capabilities of Nations for integrating the various factors in the design stage and the effects on aircraft layout and behaviour.

Flight control systems for the augmentation of stability or for the active control of low damped or unstable aircraft with rigid or flexible modes have additional coupling effects on flight mechanics and structural responses. These interactions have to be taken into consideration for the design of the airframe structure, flight control system and elastic alleviation systems in order to avoid bad handling qualities as well as bad ride comfort.

An integral analysis of flight mechanics, flight control, static and dynamic loads, flutter and aero-servo-elasticity has to be carried out. Therefore, a compatible mathematical model of the coupled dynamics of flight mechanics, flight control, and structural dynamics must be established. Such models (using the time and frequency domain description) are available in the military aircraft industry to assist in the design and clearance of flight control systems. However, the design of flight control systems and structures is in principle performed separately and integrated interdisciplinary design of flight control systems is in general not yet feasible due to its complexity. At present, it is used only to improve the control system and the structural capability of components in critical areas.

How the design methods used in the development of military fighter aircraft can be improved, and applied to transport aircraft design applications will be an outcome of this meeting.

Thème

Les aéronefs sont par nature flexibles et cette flexibilité peut être mise à profit au stade de la conception pour améliorer les performances. L'instabilité aéroservoélastique peut également conduire à une défaillance catastrophique de l'avion, comme il a été démontré récemment par l'accident du bombardier furtif F117, qui ressemble aux accidents dûs au flottement, survenus il y a deux décennies. Il se peut que le rayon d'action des avions de combat soit limité par les oscillations limites, et surtout dans le cas de certaines configurations d'emports. Ces phénomènes affectent particulièrement les avions de combat et de transport militaires. En raison de leur flexibilité, ces aéronefs sont sujets à des interactions entre la mécanique du vol, la dynamique structurale et la dynamique des systèmes de commande de vol. La réunion examinera l'état actuel des connaissances dans ce domaine, et traitera également des théories régissant les facteurs déterminants et les caractéristiques. Elle étudiera également les capacités actuelles des pays membres de l'OTAN à incorporer ces différents facteurs dans le processus de conception, ainsi que les effets sur la configuration et le comportement des aéronefs.

Les systèmes de commande de vol privilégiant soit l'augmentation de la stabilité, soit le contrôle actif d'aéronefs instables ou aux oscillations faiblement amorties ayant des modes rigides ou flexibles, peuvent créer des effets de couplage supplémentaires affectant la mécanique du vol et les réponses structurales. Ces interactions doivent être prises en compte lors de la conception de la cellule, des systèmes de commande de vol et des systèmes d'allègement élastique afin d'éviter la détérioration des qualités de vol et du confort du pilote.

Il y a lieu de procéder à une analyse intégrale de la mécanique du vol, des systèmes de pilotage, des charges statiques et dynamiques, du flottement et de l'aéroservoélasticité. Il est, par conséquent, nécessaire d'établir un modèle mathématique compatible de la dynamique couplée de la mécanique du vol, des systèmes de commande de vol et de la dynamique structurale. De tels modèles (qui intègrent la description du domaine du temps et du domaine de fréquence), sont à la disposition de l'industrie aéronautique militaire pour la conception et l'homologation des systèmes de commande de vol. Cependant, les systèmes de commande de vol et les structures sont, en principe, conçus séparément, et la conception interdisciplinaire intégrée des systèmes de commande de vol n'est guère encore faisable en raison de sa complexité. A l'heure actuelle, cette approche est utilisée uniquement pour améliorer le système de commande et la capacité structurale de certains composants critiques.

Les conclusions de cette réunion devraient permettre d'améliorer les méthodes de conception mises en œuvre dans le développement des avions de combat et de les appliquer à la conception des avions de transport militaires.

Publications of the RTO Applied Vehicle Technology Panel

MEETING PROCEEDINGS (MP)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Missile Aerodynamics
MP-5, November 1998

EDUCATIONAL NOTES

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

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

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

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

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

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

TECHNICAL REPORTS

Recommended Practices for Monitoring Gas Turbine Engine Life Consumption

TR-28, April 2000

Verification and Validation Data for Computational Unsteady Aerodynamics

TR-26, Spring 2000

A Feasibility Study of Collaborative Multi-facility Windtunnel Testing for CFD Validation

TR-27, December 1999

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REPORT DOCUMENTATION PAGE			
1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	RTO-MP-36 AC/323(AVT)TP/17	ISBN 92-837-0014-7	UNCLASSIFIED/ UNLIMITED
5. Originator	Research and Technology Organization North Atlantic Treaty Organization BP 25, 7 rue Ancelle, F-92201 Neuilly-sur-Seine Cedex, France		
6. Title	Structural Aspects of Flexible Aircraft Control		
7. Presented at/sponsored by	the Specialists' Meeting of the RTO Applied Vehicle Technology Panel (AVT) held in Ottawa, Canada, 18-20 October 1999.		
8. Author(s)/Editor(s)	Multiple		9. Date May 2000
10. Author's/Editor's Address	Multiple		11. Pages 298
12. Distribution Statement	There are no restrictions on the distribution of this document. Information about the availability of this and other RTO unclassified publications is given on the back cover.		
13. Keywords/Descriptors	Flight control Dynamic loads Military aircraft Flutter Flexibility Mathematical models Aeroelasticity Integrated systems Servomechanisms Control equipment Structural properties Transport aircraft Design Flexible structures Static loads		
14. Abstract	<p>The Specialists' Meeting dealt with Design Issues and more specifically Structural Aspects of Flexible Aircraft Control.</p> <p>Twenty six papers and a Keynote address were presented with the following objective: How the design methods used in the development of military fighter aircraft can be improved, and applied to transport aircraft design applications.</p> <p>There were three sessions covering the following topics:</p> <ul style="list-style-type: none"> – Aeroservoelasticity – Active Control of Flexible Structure I – Active Control of Flexible Structure II 		

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