RTO-EN-020
AC/323(AVT-083)TP/57

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RTO EDUCATIONAL NOTES 20

Active Control of Engine Dynamics

(Le contrôle actif pour la dynamique des moteurs)

The material in this publication was assembled to Support a RTO/VKI Special Course under the sponsorship of the Applied Vehicle Technology Panel (AVT) and the von Kármán Institute for Fluid Dynamics (VKI) presented on 14-18 May 2001, in Brussels, Belgium.

Published November 2002

Distribution and Availability on Back Cover

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Page intentionnellement blanche

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Published November 2002

ISBN 92-837-1081-9

Printed by St. Joseph Print Group Inc.
(A St. Joseph Corporation Company)
1165 Kenaston Street, Ottawa, Ontario, Canada K1G 6S1

Active Control of Engine Dynamics

(RTO EN-020 / AVT-083)

Executive Summary

Active control presents the opportunity to mitigate future challenges associated with design constraints and operational requirements in gas turbines, including control of compressor system and combustion system instabilities. Several programs are exploring this technology to address issues related to higher pressure and temperature operation for improved performance, volume reduction for increased thrust-to-weight ratio, and operation near lean blowout limits for reduced emission. The aim of the course was to present the state-of-the-art of this emerging technology, including the experimental and theoretical understanding of the control processes and control issues, and to describe the latest developments for its practical implementation.

The course started with an introduction into fundamental stability characteristics and active control approaches, followed by a lecture on control theory with special consideration of robustness and fundamental limits of controllers.

For combustion systems, fundamental flow and combustion processes that determine the behavior of system dynamics was described and different physics-based active and passive control approaches were developed. Subsequently, theory associated with the application of standard control laws and strategies to linear combustor dynamics was discussed, using the spatial averaging method to construct reduced-order models of the dynamics. In addition, models of the control processes and its application to active control were reviewed. The practical application to power gas turbines was described, including control approach, design issues, results from long-term experiments, and assessment of active control compared to passive control methods.

For compression system dynamics, analysis of hydrodynamics models for multi-mode pre-stall dynamics of axial compression systems was described, which include non-linear coupling between surge and stall. This was followed by the description of analytical and experimental techniques for diagnostics and control of compression instabilities. Different sensor and actuator architectures were discussed together with linear and non-linear techniques to optimize closed-loop performance and robustness. The course was concluded with R&D needs and an assessment of future prospects for active control.

In summary, the course has shown for combustion systems, that progress in actuator and sensor technologies and the increased understanding of the physical control processes associated with flow, combustion, and acoustics has made the active control approach a viable option even at full scale. The successful implementation of instability suppression in heavy duty power gas turbines and its continuing evaluation related to reliability, lifetime, and performance will enhance confidence for other applications such as aeroengines, for which active control needs have been established. Current efforts focus on reducing pattern factor and suppression of combustion instability associated with performance increases and emission reduction. To minimize the risk of implementing active control on aeroengines, life extension of combustors maybe the first practical application in conjunction with implementation of diagnostics and information technologies for health monitoring. For airbreathing missiles propulsion, suppression of combustion instabilities and extension of lean blowoff limits are viable options for active control applications. For future developments of "smart combustors" active control will play an enabling role when combined with distributed wireless sensors and distributed actuators.

For compression systems, significant progress has been made of coupling the actuation mechanism with the physics. A variety of actuation schemes have been developed and successfully demonstrated in systems ranging from low-speed, single stage rigs to full-scale engines, however active control has not been implemented in a practical system. One of the difficulties is obtaining low-weight and highly reliable actuators with sufficient control authority and frequency response. Given the difficulty in controlling stall and surge behavior on practical systems, diagnostic systems for detecting abnormal operational conditions may be the more important early application.

Le contrôle actif pour la dynamique des moteurs
(RTO EN-020 / AVT-083)

Synthèse

Le contrôle actif offre le moyen de réduire l'impact des futurs défis représentés par les contraintes de conception et les besoins opérationnels associés aux turbomoteurs, y compris le contrôle des instabilités des compresseurs et des systèmes de combustion. Ces technologies sont actuellement étudiées par le biais de différents programmes de recherche, ayant pour objectif d'examiner la possibilité de faire fonctionner les turbomoteurs à des températures et à des pressions plus élevées afin d'améliorer leurs performances, de réduire leur volume pour améliorer le rapport poussée-poids, et de fonctionner aux limites de l'extinction pauvre afin de réduire les émissions. Le cours a eu pour objectif de présenter l'état actuel des connaissances de ces technologies émergentes, y compris les connaissances théoriques et expérimentales dans le domaine du contrôle et de ses processus, et de décrire les derniers développements en ce qui concerne sa mise en œuvre concrète.

Le cours a commencé par une introduction aux caractéristiques fondamentales de stabilité et aux différentes approches du contrôle actif, suivi d'un cours sur la théorie du contrôle, qui a mis l'accent sur la robustesse et les limites intrinsèques des contrôleurs.

En ce qui concerne les systèmes de combustion, les processus fondamentaux de flux et de combustion qui déterminent le comportement de la dynamique du système ont été décrits, et différentes approches du contrôle actif et passif basées sur la physique ont été examinées en détail. Par la suite, la théorie associée à l'application de lois et de stratégies de contrôle normalisées à la dynamique des chambres de combustion linéaires a été discutée, en faisant appel à la méthode de moyenne spatiale pour construire des modèles réduits de la dynamique. Un certain nombre de modèles des processus de contrôle et leurs applications au contrôle actif ont été étudiés. Les applications pratiques aux turbomoteurs ont été décrites, y compris les approches du contrôle, la conception, certains résultats d'expériences à long terme et une évaluation du contrôle actif par rapport aux méthodes du contrôle passif.

En ce qui concerne la dynamique des systèmes de compression, l'analyse de modèles hydrodynamiques de la dynamique multi-mode de systèmes de compression axiale en prédécrochage a été présenté, y compris le couplage non-linéaire entre le pompage et le décrochage. Cette présentation a été suivie de la description de techniques analytiques et expérimentales pour le diagnostic et le contrôle des instabilités de compression. Différentes architectures de capteurs et d'actionneurs ont été discutés, ainsi que des techniques linéaires et non-linéaires permettant d'optimiser les performances en boucle fermée et la robustesse. Le cours a conclu par un tour d'horizon des besoins en R&D et une évaluation des perspectives futures en matière de contrôle actif.

En conclusion, le cours a démontré que grâce aux progrès réalisés dans le domaine des technologies des actionneurs et des capteurs, ainsi qu' aux nouvelles connaissances des processus physiques de contrôle des flux, de la combustion et de l'acoustique, le contrôle actif est une option valable, même en grandeur réelle. L'élimination des instabilités dans les grands turbomoteurs et son évaluation continue en ce qui concerne la fiabilité, le cycle de vie et les performances permettra de rehausser le niveau de confiance en vue d'autres applications telles que les moteurs d'avion, pour lesquels les besoins en contrôle actif ont été établis. Les efforts actuellement consentis dans ce domaine concernent principalement la réduction des écarts de température et l'élimination des instabilités de combustion, associées à l'amélioration des performances et la réduction des émissions. Afin de réduire au minimum les risques associés à l'application du contrôle actif aux moteurs d'avion, la première application concrète pourrait être le prolongement du cycle de vie des chambres de combustion, en parallèle avec la mise en œuvre des technologies du diagnostic et de l'information pour le contrôle de l'état de fonctionnement des moteurs. En ce qui concerne la propulsion des missiles aérobies, l'élimination des instabilités de combustion et l'extension des limites de l'extinction pauvre représentent des options valables pour d'éventuelles applications du contrôle actif. Le contrôle actif, associé à des capteurs sans fil et à des actionneurs répartis, est appelé à jouer un rôle habilitant dans le développement futur des «chambres de combustion intelligentes».

En ce qui concerne les systèmes de compression, des progrès appréciables ont été réalisés en couplant le mécanisme actionneur avec des aspects ayant trait à la physique. Diverses configurations d'actionneurs ont été développées et démontrées avec succès pour des systèmes allant de bancs d'essai basse vitesse à un seul étage à des moteurs réels, mais le contrôle actif n'a pas été mis en œuvre dans un système particulier. L'une des difficultés consiste à obtenir des actionneurs légers et hautement fiables dotés de suffisamment de contrôle et de réponse en fréquences. Etant donné les difficultés rencontrées pour contrôler le pompage et le décrochage dans des systèmes en service, il se pourrait que l'application prioritaire soit la détection de conditions de fonctionnement anormales.

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

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	RTO-EN-020 AC/323(AVT-083)TP/57	ISBN 92-837-1081-9	UNCLASSIFIED/ UNLIMITED

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

6. Title
Active Control of Engine Dynamics

7. Presented at/sponsored by
the Applied Vehicle Technology Panel (AVT) and the von Kármán Institute for Fluid Dynamics (VKI) in Brussels, Belgium, 14-18 May 2001.

8. Author(s)/Editor(s)	9. Date
Multiple	November 2002

10. Author's/Editor's Address	11. Pages
Multiple	402

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

Active control	Engine dynamics
Actuators	Engines diagnostics
Axial compression systems	Gas turbine engines
Combustion system dynamics	Passive control
Combustors	Reliability
Compression system dynamics	Requirements
Compressor instability	Robustness
Control equipment	Stability characteristics
Design constraints	State of the art reviews

14. Abstract

Active control can alleviate design constraints and improve the response to operational requirements in gas turbines. The Course presented the state-of-the-art including experimental, theoretical knowledge and practical information.

Topics treated: stability characteristics; active control approaches; robustness and fundamental limits; combustion systems processes; combustor dynamics; compression system dynamics models; diagnostics and control of compression instabilities; sensor and actuator architectures; R&D needs of future prospects.

The course has shown that for combustion systems, as well as in actuator and sensor technologies the active control approach is a viable option even at full scale with potential for aero engines and air breathing missiles.

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

Imprimé par Groupe d'imprimerie St-Joseph inc.
(Membre de la Corporation St-Joseph)
1165, rue Kenaston, Ottawa (Ontario), Canada K1G 6S1

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

Printed by St. Joseph Print Group Inc.
(A St. Joseph Corporation Company)
1165 Kenaston Street, Ottawa, Ontario, Canada K1G 6S1

ISBN 92-837-1081-9