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Measurement Techniques for High Enthalpy and Plasma Flows

(Techniques de mesure pour les écoulements de plasma et les écoulements à haute enthalpie)

This report is a compilation of the edited proceedings of the "Measurement Techniques for High Enthalpy and Plasma Flows" course held at the von Kármán Institute for Fluid Dynamics (VKI) in Rhode-Saint-Genèse, Belgium, 25-29 October 1999.

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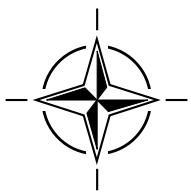

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Measurement Techniques for High Enthalpy and Plasma Flows

(RTO EN-8)

Executive Summary

The RTO AVT/VKI Special Course on "Measurement Techniques for High Enthalpy and Plasma Flows" gathered specialists in this area from Europe, USA and Russia who combined their efforts to produce this comprehensive set of notes. The following topics were covered: a review of various high enthalpy and plasma flow facilities, intrusive and non intrusive measurement techniques for the characterization of flows generated in these facilities and the utilization of plasma facilities for the evaluation of material catalysis properties.

Most of the facility types presently used to generate high enthalpy flows were reviewed. The first class of facilities currently used in the USA and in Europe are the arc jet type where the test gas is heated through an electric discharge between electrodes. In this case, high levels of enthalpy can be achieved for moderate levels of stagnation pressures (typically up to 100 bars). With respect to shock tube facility, arc-jet facilities provide a longer run time. In order to increase the Reynolds number while maintaining a level of enthalpy relevant for flight conditions, the combination of a free piston gun tunnel and a shock tube was developed. The facility produces a high Reynolds number and high enthalpy flow field over a very short time (typical of a shock tube level). In most of the previously discussed facilities, some particulate matter or residual electrode materials are present in the flow and may affect the determination of material catalysis. The approach taken by Russian scientists for this particular issue is to use an inductively coupled plasma generator which produces very clean plasma. However, since the flow conditions are subsonic and correspond to a low Reynolds value, a methodology of extrapolation of the plasmatron facility to flight conditions was presented.

In all the facilities presented, there is a considerable need for assessment of flow field properties to support numerical modeling of high enthalpy flows in its transposition to flight conditions. Accessing the details of the flow field (composition, state of the species, velocity, temperatures ...) requires an important investment in measurement techniques. The adaptation of intrusive measurement techniques to high enthalpy flow facilities which provide macroscopic information (pitot pressure and stagnation heat flux) were presented. These techniques provide a good initial screening for the determination of flow properties which require further development using non-intrusive measurement techniques. Techniques starting with pyrometry for the measurement of material sample temperature, to more sophisticated techniques based on spectroscopy (emission, absorption, laser induced emission) were discussed in their application to arc jet, free piston shock tunnel and inductively couple plasma facilities.

As illustrated by the requirements in terms of flow physics modeling at the beginning of the course, non-intrusive measurement techniques are essential for the qualification of numerical modeling. It was illustrated that the assessment of flow properties is not only important for validation of numerical modeling but also in the analysis of material catalysis. Consequently, a continuous effort should be devoted to the improvement and application of those techniques in high enthalpy and plasma flow facilities. In particular, problems associated with flow thermal and chemical non-equilibrium require more detailed information on the state of the species, the vibrational / chemical coupling, which require even more refined information on the flow.

The material assembled in this report was prepared under the combined sponsorship of the RTO AVT Panel, the Consultant and Exchange and the Partnership for Peace Programmes of RTO and the von Kármán Institute (VKI) for Fluid Dynamics. We wish to thank all the lecturers for their outstanding work, as well as the organizers of RTO and VKI.

Techniques de mesure pour les écoulements de plasma et les écoulements à haute enthalpie

(RTO EN-8)

Synthèse

Le cours spécial RTO/AVT « Techniques de mesure pour les écoulements à haute enthalpie et les plasmas » a réuni des spécialistes européens, américains et russes dans ce domaine qui ont mis leurs efforts en commun pour produire ces notes détaillées. Les sujets suivants ont été traités: revue des souffleries à haute enthalpie et à plasma, des techniques de mesures intrusives et non intrusives utilisées pour la caractérisation de ces écoulements et utilisation des souffleries à plasma pour l'étude des propriétés catalytiques des matériaux.

La plupart des types d'installations utilisées pour générer des écoulements à haute enthalpie ont été passées en revue. Une première classe d'installations utilisées fréquemment aux USA et en Europe est du type soufflerie à arc dans laquelle le gaz est chauffé grâce à un arc électrique entre deux électrodes. Dans ce cas, des niveaux importants d'enthalpie peuvent être atteints pour des niveaux de pression d'arrêt modestes (de l'ordre de 100 bars). Par rapport aux tubes à choc, les souffleries à arc offrent un temps d'essai plus long. De manière à accroître le nombre de Reynolds tout en gardant un niveau d'enthalpie significatif par rapport aux conditions de vol, la combinaison d'une soufflerie à piston libre et d'un tube à choc a été développée. Cette installation génère un écoulement à haute enthalpie avec un nombre de Reynolds élevé mais avec une durée d'essai très courte (typique d'un tube à choc). Dans la plupart des installations décrites jusqu'ici, des particules ou des résidus de matière provenant des électrodes sont présents dans l'écoulement et peuvent affecter la détermination des propriétés catalytiques des matériaux testés. De ce point de vue, l'approche des scientifiques russes est d'utiliser des générateurs de plasma de type inductifs qui produisent un plasma très pur. Néanmoins, comme l'écoulement de plasma ainsi créé est subsonique et correspond à un bas nombre de Reynolds, une méthodologie d'extrapolation des conditions du plasmatron vers le vol a été présentée.

Dans toutes les installations présentées, il y a un important besoin de connaissance des propriétés de l'écoulement pour supporter la modélisation numérique dans sa transposition aux conditions de vol. Accéder aux détails de l'écoulement (composition chimique, état des espèces, vitesse, températures ...) nécessite un investissement important dans les techniques de mesure. L'adaptation des techniques de mesure intrusives aux souffleries à haute enthalpie et à plasma qui fournissent des informations macroscopiques (pression pitot et flux de chaleur au point d'arrêt) a été présentée. Ces techniques permettent une bonne première approche décrivant les conditions d'écoulement qui cependant nécessite un approfondissement en utilisant des techniques de mesure non intrusives. Ces techniques, en commençant par la pyrométrie pour la mesure de température de surface d'échantillon de matériau puis les techniques plus sophistiquées basées sur la spectroscopie (émission, absorption, émission induite par laser) ont été discutées dans leur application aux souffleries à arc, aux tubes à choc à compression par piston et aux générateurs à plasma par induction.

Comme mis en évidence par les besoins en termes de modélisation physique au début du cours, les techniques de mesure non-intrusives sont essentielles dans le processus de qualification des modèles numériques. Comme illustré dans ce cours, une meilleure connaissance des écoulements à haute enthalpie n'est pas uniquement nécessaire pour la validation numérique mais aussi dans le processus d'analyse des propriétés catalytiques des matériaux. En conséquence, un effort continu et soutenu est nécessaire pour le développement et l'application de ces techniques dans les souffleries à haute enthalpie et à plasma.

Les notes assemblées dans ce rapport ont été préparées grâce au concours du panel RTO/AVT des programmes RTO des Consultants et des échanges et du Partenariat pour la Paix, et de l'Institut von Kármán (IVK) de dynamique des fluides. Nous voulons remercier tous les conférenciers pour l'excellent travail qu'ils ont accompli ainsi que les organisateurs du RTO et de l'IVK.

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COURSE DIRECTOR and LOCAL COORDINATOR

Professeur J-M. CHARBONNIER
Associate Professor Aeronautics/Aerospace Department
von Kármán Institute for Fluid Dynamics
Chaussée de Waterloo, 72
B-1640 Rhode-Saint-Genèse – Belgium

LECTURERS

Prof. M. CARBONARO
Director, von Kármán Institute for Fluid Dynamics
Chaussée de Waterloo, 72
B-1640 Rhode-Saint-Genèse - Belgium

Mr. F. GRISCH
ONERA/Dept Mesures Physiques
29, Avenue de la Division Leclerc
92320 Châtillon Cedex - France

Dr. L. ROBIN
Université de Rouen
CORIA/CNRS UMR 6614
Place Emile Blondel
76821 Mont Saint Aignan Cedex - France

Prof. Monika AUWETER-KURTZ
IRS, University of Stuttgart
Pfaffenwaldring 31
D-70569 Stuttgart - Germany

Dr. W. BECK
High Enthalpy Shock Tunnel HEG
Aerothermodynamics Department
Institute for Fluid Mechanics, DLR
Bunsenstrasse, 10
D-37073 Göttingen - Germany

Dr. Ing. Ali GÜLHAN
DLR Section Köln-Porz
Wind Tunnel Division
Porz-Wahnheide
Linder Höhe
D-51147 Köln - Germany

Dr. KOLESNIKOV
Institute for Problems in Mechanics (IPM)
Russian Academy of Sciences
Prospect Vernadskogo, 101-1
117526 Moscow - Russia

Dr. GORDEEV
Institute for Problems in Mechanics (IPM)
Russian Academy of Sciences/Plasma Laboratory
Prospect Vernadskogo, 101-1
117526 Moscow - Russia

Dr. D.G. FLETCHER
NASA Ames Research Center
Reacting Flow Environments Branch
MS 230-2
Moffett Field, CA 94035-1000

PANEL EXECUTIVE

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Mail from Europe:
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Velocity measurement
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Plasmatrons

14. Abstract

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