

*The 3rd International Conference on*

# **Green Propellant for Space Propulsion**

*In combination with the 9th International*

# **Hydrogen Peroxide Propulsion Conference**

17–20 September 2006  
Futuroscope, Poitiers, France

Funded and sponsored by  
**European Space Agency (ESA)**  
**Degussa, Germany**  
**SNECMA, France**

**Office National d'Études et de Recherches Aérospatiales (ONERA), France**  
**SNPE, France**

**European Space Agency**  
**Agence spatiale européenne**

## Technical Committee:

### Chairs

G. Saccoccia, ESA/ESTEC, The Netherlands,  
R. Bec, CNES, France  
J. Rusek, Purdue University, USA  
W. Koschel, DLR, Germany  
C. Kappenstein, LACCO (Conference Secretary)

### Members

K. Anflo, SSC, Sweden  
C. Bruno, University of Rome 'Sapienza', Italy  
F. Caramelli, ESA/ESTEC, The Netherlands  
A. Ciucci, ESA, France  
M. Ford, ESA/ESTEC, The Netherlands  
P. Fortunier, CNES, France  
D. Gibbon, SSTL, United Kingdom  
I. Gökalp, CNRS, France  
M. Grubelich, Sandia National Laboratory, USA  
O. Haidn, DLR, Germany  
N. Yaroshenko, RSC-AC, Russia  
C. Kappenstein, University of Poitiers, France  
T. Klapötke, University of Munich, Germany  
G. Langel, Astrium GmbH, Germany  
M. Lang, ESA/ESTEC, The Netherlands  
B. Lebret, CEA, France  
Y. Maisonneuve, ONERA, France  
M. McPherson, Aerojet, USA  
B. Mellor, Edotek Ltd, United Kingdom  
A.J. Musker, DELTACAT, UK  
T. Pardal, Omnidea, Portugal  
C. Pérut, SNPE-SME, France  
T. Sumrall, University of Florida  
D. Valentian, Snecma, France  
T. Zhang, Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China

### Local Organising Committee

Y. Batonneau, R. Brahmi, C. Kappenstein, L. Pirault-Roy (LACCO, Poitiers)

Publication	Proceedings of the '3rd Int. Conf. on Green Propellant for Space Propulsion and 9th Int. Hydrogen Peroxide Propulsion Conference', Poitiers, France, 17-20 Sept. 2006 (ESA SP-635, December 2006)
Edited by	C. Walker ESA Publications Division
Published and distributed by	ESA Publications Division ESTEC, Noordwijk, The Netherlands
Price	EUR 50
ISBN	92-9092-946-4
ISSN	1609-042X
Copyright	© 2006 European Space Agency

# CONTENTS

## Opening Session: Welcome and Introduction

*Conference opening by Giorgio Saccoccia*

*Prof. J.P. Gesson, President of the University of Poitiers*

*Dr. D. Duprez, Director of LACCO*

*Mr. G. Saccoccia, ESA/ESTEC*

*Prof. W. Koschel, DLR*

*Prof. C. Kappenstein, University of Poitiers*

## Keynote Lectures 1 and 2

*Chairs: A.J. Musker (DELTA CAT Ltd, UK) & C. Kappenstein (Poitiers, France)*

Producibility Criteria for Liquid/Gel Bipropellants Using Advanced Energetic Materials for Space Deployments

*M. McPherson (Aerojet, Culpeper, VA, USA)*

Future Hybrids and Solid Propellants for Space Applications

*C. Pérut (SNPE-SME, France)*

## Keynote Lecture 3

*Chairs: M. Lang (ESA) & N. Girard (CNES)*

Silanes: Combustion with Oxygen and Nitrogen

*A. Kornath, T. Klapötke, S. Hadjizadeh-Ziabari (Ludwig-Maximilians University, Munich, and University of Dortmund, Germany)*

## Keynote Lectures 4 and 5

*Chairs: M. McPherson (Aerojet, VA, USA) & M. Calabro (The Inner Arch, France)*

Achievements and Potential of Green Monopropellants for Space Propulsion, gained from 10 Years of Research & Development

*K. Anflo, P. Thormählen, G. Bergman, T. Hasanof (SSC, Solna, Sweden)*

Theoretical and Experimental Fundamentals of Catalysts and Catalytic Engines Creation on Pool Green Monopropellants. Some aspects of Combustion Self-Ignition Bipropellants.

*N.T. Yaroshenko (Russian Scientific Centre of Applied Chemistry (RSC-AC), St Petersburg, Russia)*

## Keynote Lecture 6

*Chairs: M. Lang (ESA) & C. Kappenstein (LACCO)*

Catalyst Design and Catalytic Process for Space Propulsion

*T. Zhang (Dalian Institute of Chemical Physics, Chinese Academy of Science, China)*

## Bipropellants

*Chairs: D. Valentian (Snecma) & M. Lang (ESA-ESTEC)*

Ignition of Kerosene and Hydrogen Peroxide in Combustion Chamber by Fire Jet

*V.N. Sadov (RSC-AC, St Petersburg, Russia)*

Methane/Oxygen Activities at DLR Lampoldshausen

*O.J. Haidn, G. Krühsel, M. Oswald, K. Schäfer (Institute of Space Propulsion, DLR, Germany)*

Test Bench Activities on Methane/Oxygen in DLR Lampoldshausen

*K. Schäfer, G. Krühsel, V. Schmidt, O.J. Haidn, M. Oswald, D. Suslov (Institute of Space Propulsion, DLR, Germany)*

LOX/Methane Transfer Stages for Future Launchers

*M. Calabro (The Inner Arch, France)*

Towards a Reduced Kinetic Scheme for LOX/Methane Combustion

*N.A. Slavinskaya, O.J. Haidn, J. Steelant (Institute of Combustion Technology, Stuttgart, Institute of Space Propulsion, Lampoldshausen, German Aerospace Center (DLR), Germany and ESTEC-ESA, The Netherlands)*

Ignition of Hydrogen Peroxide and Hydrocarbon Propellants (withdrawn)

*B.L. Austin, Jr., S.D. Heister, W. Anderson, S.E. Meyer (IN Space, LLC and Purdue University, West Lafayette, IN, USA)*

## Solids Propellants

*Chairs: F. Caramelli (ESA) & W. Koschel (DLR)*

Metallized Dual-Oxidizer Solid Propellants for Green Space Access

*S. Levi, L. Galfetti, L.T. DeLuca, S. Cianfanelli, V.A. Babuk, G.F. Klyakin, V.P. Sinditskii, A.B. Vorozhtsov (Politecnico di Milano; Avio, Colleferro, Italy; Baltic State Technical University; South-Russia Technical University; Mendeleev University and Tomsk State University, Russia)*

Solid Propellants Based on AN/AP Co-crystals for Green Space Access (late minute presentation)

*D. Signoriello, L. Galfetti, L.T. DeLuca, S. Cianfanelli, G.F. Klyakin, V.A. Babuk, V.P. Sinditskii, A.B. Vorozhtsov (Politecnico di Milano; Avio, Colleferro, Italy; Baltic State Technical University; South-Russia Technical University; Mendeleev University and Tomsk State University, Russia)*

Spray Prilling of ADN and Testing of ADN-Based Solid Propellants

*M. Johansson, J. de Flon, Å. Pettersson, M. Wanhatalo, N. Wingborg (Swedish Defence Research Agency, FOI, Sweden)*

Solid Propellants Containing Activated Aluminum

*N. Wingborg, M. Wanhatalo, M. Johansson, Å. Pettersson (Swedish Defence Research Agency, FOI, Sweden)*

Current Backbone for the Development of HNF-Based Propellants

*W.H.M. Welland, S. Cianfanelli, A.E.D.M. van der Heijden, W. Leeming (Aerospace Propulsion Products bv, The Netherlands, Avio SpA, Italy, TNO Defence, Security and Safety, The Netherlands and Nobel Energetics Ltd, UK)*

Green Propellants Based on Cryogenic Solids and the State of the Art of CSPS Using Solid H<sub>2</sub>O<sub>2</sub>

*R.E. Lo, H. Adirim, N. Eisenreich, S. Glaeser, V. Weiser, (Aerospace Institute, Berlin, ICT, Pfinztal, Germany)*

## **Micropropulsion and Future**

*Chairs: C. Pérut (SNPE-SME) & N.T. Yaroshenko (RSC-AC, Russia)*

Thermal and Chemical Efficiencies of a Mesoscale Combustor for Propulsive or Power Generation systems

*F. Cozzi, A. Coghe, A. Olivani (Politecnico di Milano, Italy)*

Small Thrusters for Microsatellites with Hydrogen peroxide as a Monopropellant

*S. An, S. Kwon (Division of Aerospace Engineering, KAIST, Korea)*

Silanes/H<sub>2</sub>O<sub>2</sub> Bipropellant System and Spin-off Applications

*B. Hidding, M. Pfitzner, D. Simone, C. Bruno (Heinrich-Heine-Universität Düsseldorf, Universität der Bundeswehr, Munich, Germany and University 'La Sapienza', Rome, Italy)*

In situ Electroreduction of the Mars Atmosphere

*T. Pardal, M. Gonçalves, J. Condeço, M. Lang (Omniidea Lda, Lisbon, Portugal, and ESA, The Netherlands)*

Preliminary tests of a CO<sub>2</sub>/Magnesium rocket engine

*I. Coxhill, D. Gibbon, S. Mistry, M. Lang, M. Calabro, C. Chauveau, I. Gökalp (SSTL, Surrey, UK; ESTEC, NL; The Inner Arch, France; LCSR-CNRS, Orléans, France)*

Green Propellants Perspectives for Future Missions

*D. Valentian (Snecma, Vernon, France)*

## **Hybrid Propellants**

*Chairs: Y. Maisonneuve (ONERA, France) & T. Pardal (Omniidea, Portugal)*

A Numerical Code for Hybrid Space Propulsion Design and Tests

*N. Pelletier, Y. Maisonneuve (ONERA, Toulouse, France)*

The Oxidizer Injection in Hybrid Rockets. A Means to Control Motor Performance

*C. Carmicino, A. Russo Sorge (University of Naples, Italy)*

A Simplified Theory for Liquefying Fuel Hybrid Rocket Motor (late minute presentation)  
*C. Oiknine (CEO, Global Engineering)*

## **Nitrous Oxide**

*Chair: Y. Batonneau (Poitiers, France)*

Perspective Catalysts for N<sub>2</sub>O Decomposition

*T.P. Gaidey, A.I. Kokorin, N. Pillet, M.E. Srukova, V.N. Sadov, B.H. Gardens, E.S. Haustova, G.G. Shmurak, N.T. Yaroshenko (RSC-AC, St Petersburg, Russia, Institute N. Semenova, Moscow)*

Performance of 1N Model Thruster on Nitrous Oxide

*V.N. Sadov, N.T. Yaroshenko, T.P. Gaidey, S. Filatov, A. Kokorin, N. Pillet (RSC-AC, St Petersburg, Russia, Institute N. Semenova, Moscow and CNES, Toulouse, France)*

Superior Performance of Iridium Hexaaluminate Catalysts for Nitrous Oxide Decomposition

*S. Zhu, X. Wang, Y. Cong, A. Wang, T. Zhang (Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China)*

Satellite Microthrusters where Catalysts are Fed with Green Premixed N<sub>2</sub>O-Hydrocarbon Mixes

*R. Saunders, P.A. Sermon, J. Wallbank (Chemistry, SBMS, University of Surrey, UK)*

N<sub>2</sub>O Propulsion Research at Tsinghua: 2006

*V. Zakirov, W. Ke, C. Tang, F. Shan, H. Zhang, L. Li (Tsinghua Space Centre, Beijing, China)*

## **Ionic Liquids**

*Chairs: K. Anflo (SSC, Sweden) & O. Haidn (DLR, Germany)*

Reaction Balance of Thermal and Catalytic Decomposition of HAN Solutions

*D. Amariei, S. Rossignol, C. Kappenstein (LACCO, France)*

Catalytic Decomposition of HAN-Based Monopropellant at Room Temperature over Ir/SiO<sub>2</sub> Catalyst

*X. Ren, A. Wang, D. Xu, Y. Cong, Xiaodong Wang, Tao Zhang (Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)*

ADN-Based Liquid Monopropellants: Propellant Selection and Initial Thruster Development

*N. Wingborg, M. Johansson, L. Bodin (Swedish Defence Research Agency)*

Preparation and Use of Ammonium and Sodium Azide as a Fuel Additive to Ionic Oxidizer

*K. Fahrat, Y. Batonneau, O. Florea, C. Kappenstein (LACCO, France)*

# Hydrogen Peroxide Monopropellant

*Chairs: T. Zhang (Dalian, China) & M. Grubelich (Sandia National Laboratory, USA)*

Modeling Hydrogen Peroxide Decomposition in Monolithic beds

*S. Bonifacio, A. Russo Sorge (Universities of Capua and Naples, Italy)*

Monopropellant Thruster Development: Investigation of Decomposition Efficiencies

*C. Scharlemann, M. Schiebl, R. Amsüss, M. Tajmar, P. Miotti, C. Kappenstein, Y. Batonneau, R. Brahmi, C. Hunter (ARC, Mechatronic GmbH, Austria, LACCO, France and ESTEC-ESA)*

Development of Green Hydrogen Peroxide Monopropellant Rocket Engines and with Advanced Catalytic Beds

*A. Cervone, L. Torre, L. d'Agostino, A.J. Musker, G.T. Roberts, G. Saccoccia (Alta S.p.A., Italy; Università di Pisa, Italy, DELTACAT Ltd, University of Southampton, UK, ESA-ESTEC)*

Development of a Rocket Engine Igniter Using the Catalytic Decomposition of Hydrogen Peroxide

*W.A. Jonker, A.E.H.J. Mayer, B.T.C. Zandbergen (TNO and Delft University, The Netherlands)*

An Exploratory Study of Some Liquid Catalysts for Use with Hydrogen Peroxide

*A.J. Musker, G.T. Roberts (DELTACAT Ltd and University of Southampton, UK)*

Mechanistic Aspects of Redox Activity of Manganese Oxide-Based H<sub>2</sub>O<sub>2</sub> Decomposition Catalysts

*A.K.H. Nohman (Minia University, Egypt)*

Hydrogen Peroxide - from Bridesmaid to Bride (special paper)

*A.J. Musker, J.J. Rusek, C. Kappenstein, G.T. Roberts (DELTACAT Limited, UK, Swift Enterprises Ltd, IN, USA, Université de Poitiers, France, University of Southampton, UK)*

## **Closing Session: Round Table, Discussion and Conclusions**

*Chair: M. Lang (ESA)      Writer: D. Valentian (Snecma, France)*

## **List of Participants**