A Full-Day Pre-Congress Workshop for 2014 IFAC World Congress (IFAC WC'14)

Cape Town, South Africa | 24-29 August 2014

Fault Diagnosis, Fault-tolerant Control, and Cooperative Control of Manned and Unmanned Aircraft Systems

Brief statement of the workshop goals:

Unmanned systems including Unmanned Aerial Vehicles/Systems (UAVs or UAS), Unmanned Ground Vehicles (UGVs), and Unmanned Surface/Underwater Vehicles (USVs/UUVs) etc are gaining more and more attention during the last a few years due to their important contribution and cost-effective application in several tasks such as surveillance, search, rescue missions, geographic studies, military and security applications. Health management and fault-tolerant control of manned aerial vehicles have a long history since the initial research on self-repairing flight control systems in US Air Force and NASA begun in mid-1980s. However, due to safety of manned aerial vehicles to the pilot, experimental test and further practical research and development have been bounded due to such constraints. Benefited from the recent and significant advance and development of UAVs, development and application of fault- tolerant control as well as cooperative control techniques have been emerged and developed quickly in recent years, since UAVs provide a cheap and operative experimental test-bed for development, implementation, and testing the latest developed fault-tolerant and cooperative guidance, navigation and control techniques. Based on the experiences gained by the 14 different participating organizations ranging from academic institutions, research organization, and industry of the leading groups in Canada, USA, France, Italy, Spain, and UK, the workshop will demonstrate the state- of-the-art techniques and development in health management, fault diagnosis, fault-tolerant guidance, navigation and control, safety and reliability, as well as multi-vehicle cooperative guidance, navigation and control techniques.

In this workshop, overview of past, current and future research activities and research outcomes on the health management, fault diagnosis, fault-tolerant control, and cooperative control applications with emphasis to UAVs, civilian aircraft and spacecraft will be presented, which include quadrotor rotary and fixed-wing UAVs etc. Linear and nonlinear techniques for modeling, fault diagnosis, fault-tolerant control, path and trajectory planning/re-planning, cooperative/formation flight guidance, navigation and control, based on a quadrotor helicopter UAV and several fixed-wing aircraft and UAVs testbeds will be presented in the workshop. Furthermore, fault diagnosis, fault-tolerant control, and cooperative control strategies development with practical application scenarios on persistent surveillance and coverage control with multiple unmanned systems will be presented. Multiple UAS operations toward verifiable autonomy and assessment of the potential insertion of UAS in the air transportation system will also be discussed.

Audience will gain information and knowledge on the latest development and applications on the active research topics in health management, fault detection and diagnosis, fault-tolerant control and cooperative control of manned and unmanned aerial vehicles by world-leading researchers from both academia and industry.

Presenters (in alphabetical order sequence for co-organizers)**:**

The workshop consists of 13 presenters from the leading research groups in the relevant fields of the above workshop title in North American [Canada (2) and USA (1)], Asia [China (1)], Europe [France (2), Italy (2), Spain (1) and UK (4)], where 12 presenters are from academia and 1 presenter is from industry. Most of presenters have worked on the relevant areas for a long time and made significant contributions in the field, which are evidenced by several first books published in the relevant areas worldwide as can be seen at the end of the proposal, as well as many research publications which can be found from the webpage of each presenter. Detailed contacting information and brief biography of each presenter are given as follows:

Youmin Zhang, PhD, Associate Professor, SM.AIAA, SM.IEEE, M.AUVSI/USC, M.CASI
Department of Mechanical and Industrial Engineering & Concordia Institute of Aerospace Design and Innovation
Concordia University
1515 St. Catherine W, Montreal, Quebec H3G 2W1, Canada
Tel: +1 (514) 848-2424 ext. 5225; Fax: +1 (514) 848-3175
E-mail: ymzhang@encs.concordia.ca; Web: http://users.encs.concordia.ca/~ymzhang/

Paolo Castaldi, PhD, Assistant Professor
Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi", University of Bologna
School of Aerospace Engineering
Via Fontanelle, 47121 Forlì, Italy
Tel: +39 0543 37 4460; Fax: + 39 0543 37 4403
E-mail: paolo.castaldi@unibo.it; Web: http://www.unibo.it/SitoWebDocente/default.htm?mat=030930

YangQuan Chen, PhD, Director
Mechatronics, Embedded Systems and Automation (MESA) Lab
School of Engineering, University of California, Merced
5200 North Lake Road, Merced, CA 95343, USA
Tel: +1 (209)228-4672, Fax: +1 (209)228-4047
E-mail: ychen53@ucmerced.edu; Web: http://scholar.google.com/citations?user=RDEIRbcAAAAJ&hl=en

Christopher Edwards, PhD, Professor
College of Engineering, Mathematics and Physical Sciences, The University of Exeter
Exeter, Devon UK EX4 4SB, United Kingdom
Tel: +44 (0) 1392 726632
E-mail: C.Edwards@exeter.ac.uk; Web: http://emps.exeter.ac.uk/engineering/staff/ce255

Philippe Goupil, PhD, R&T Engineer
M0142/4 - EYCCC Flight Control System
Airbus Operations S.A.S.
316, route de Bayonne
31060 Toulouse Cedex 09, France
Tel.: +33 (0)5 6118 3803
E-mail: philippe.goupil@airbus.com

Qinglei Hu, PhD, Professor
Department of Control Science and Engineering, Harbin Institute of Technology
Harbin 150001, China
Tel.: +86-451-8640 2726
E-mail: huqinglei@hit.edu.cn

Hugh H.T. Liu, PhD, Professor
Institute for Aerospace Studies, University of Toronto
4925 Dufferin Street, Toronto, Ontario M3H 5T6, Canada
Tel: +1 (416) 667-7928
E-mail: liu@utias.utoronto.ca; Web: http://arrow.utias.utoronto.ca/~liu/people.htm

Andrés Marcos, PhD, Senior Lecturer
Aerospace Engineering Department, University of Bristol
Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom
Tel: +44 (0) 117 954 5607
E-mail: andres.marcos@bristol.ac.uk

Ron J Patton, Professor, Fellow IEEE, SM.AIAA, CEng, FInstMC
Professor of Control & Intelligent Systems Engineering
Faculty of Science and Engineering, University of Hull
Cottingham Road, Hull HU6 7RX, United Kingdom
Tel: 0044 (0) 1482 46 5117/5891; Fax: 0044 (0) 1482 46 6664;
E-mail: R.J.Patton@hull.ac.uk; Web: http://www2.hull.ac.uk/science/engineering_research/cise.aspx

Vicenç Puig, PhD, Professor
Advanced Control Systems Research Group, Universitat Politècnica de Catalunya
Barcelona, Spain
Tel: 93 401 69 74 / 93 739 85 63
E-mail: vicenc.puig@upc.edu; Web: http://sac.upc.edu/people/academic-and-research-staff-1/dr.-vicenc-puig-cayuela-1

Silvio Simani, PhD
Dipartimento di Ingegneria, Università di Ferrara
Via Saragat,1 44100 Ferrara, Italy
Tel: +39 0532 97 4844; Fax: +39 0532 97 4870
E-mail: sivlio.simani@unife.it; Webpage: http://www.ing.unife.it/simani

Didier Theilliol, PhD, Professor
CRAN UMR 7039, CNRS, University of Lorraine
54506 Vandoeuvre-les-Nancy, France
Tel: +33 383 684 465; Fax: +33 383 684 462
E-mail: Didier.Theilliol@cran.uhp-nancy.fr; Web: http://page-perso.cran.uhp- nancy.fr/Perso_Theilliol/CV_Theilliol_CRAN.htm

Antonios Tsourdos, PhD, Professor, Head of Autonomous & Intelligent Systems Group
Department of Engineering Physics, Cranfield University
Defence Academy of the United Kingdom
Shrivenham, Swindon SN6 8LA, United Kingdom
Tel: +44 (0) 1793 785841; E-mail: a.tsourdos@cranfield.ac.uk

Brief biographies of presenters:

Youmin Zhang is with the Department of Mechanical and Industrial Engineering and the Concordia Institute of Aerospace Design and Innovation (CIADI) at Concordia University, Canada. His main research interests and experience are in the areas of condition monitoring, fault diagnosis and fault-tolerant (flight) control systems; cooperative guidance, navigation and control of unmanned aerial/ground/surface vehicles; dynamic systems modeling, estimation, identification and control; and advanced signal processing techniques for diagnosis, prognosis and health management of safety-critical systems, renewable energy systems and manufacturing processes. He has published 4 books (including a book on "Active Fault Tolerant Control Systems: Stochastic Analysis and Synthesis" (2003) and a book on "Fault Diagnosis and Fault Accommodation for Control Systems" (2009)), over 280 journal and conference papers. His comprehensive review paper published at Annual Reviews in Control on "Bibliographical Review on Reconfigurable Fault-tolerant Control Systems" has gained significant impact in the field worldwide. The paper has been ranked No. 1 in the "Most Cited Articles" published since 2007 and the highest citation ever in the journal after the paper published in Dec. 2008 (currently 383 citations in Scopus). Dr. Zhang has been invited to give international conference plenary talks and research seminars worldwide for more than 40 times since 2005. He is a senior member of AIAA, senior member of IEEE, a member of the IFAC Technical Committee on Fault Detection, Supervision and Safety for Technical Processes, a member of the AIAA Infotech@Aerospace Program Committee (PC) on Unmanned Systems, a member of the IEEE Robotics and Automation Society Technical Committee (TC) on Aerial Robotics and Unmanned Aerial Vehicles, and a member of the ASME/IEEE TC on Mechatronics and Embedded Systems and Applications (MESA). He is an Editorial Board Member and/or (Associate) Editor of several international journals (including the three newly launched journals on Unmanned Systems, International Journal of Intelligent Unmanned Systems, and Journal of Unmanned System Technology; and a Senior Editor for Journal of Intelligent & Robotic Systems). He is also an Editor-in-Chief of the new Journal of Instrumentation, Automation and Systems. He has served as a General Chair, Program Chair, Program Vice-chair of several conferences and IPC member of many international conferences, including The 10th International Conference on Intelligent Unmanned Systems (ICIUS 2014, http://www.icius2014.org/), September 29-October 1, 2014, Montreal, Quebec, Canada and 2014 International Conference on Unmanned Aircraft Systems (ICUAS 2014, http://www.uasconferences.com), Orlando, FL, USA, May 27-30, 2014, as the General Chair and Program Chair respectively.

Paolo Castaldi is the author of about 90 articles published on International Journals and on the proceedings of International Congresses; he is also an author of one book. He is designed editor for Control Engineering Practice and Applied Mathematics and Computer Science journals. He has been awarded as outstanding reviewer of Automatica. The research activities of Paolo Castaldi include the development of new methodologies for: nonlinear FDI and FTC for aircrafts, UAVs and satellites; the integration of guidance laws and FTC; landing in wind shear conditions; FDI, FTC and advanced control systems for wind turbines.

YangQuan Chen earned his Ph.D. degree in advanced control and instrumentation from Nanyang Technological University, Singapore, in 1998. Dr. Chen was on the Faculty of Electrical and Computer Engineering at Utah State University before he joined the School of Engineering, University of California, Merced in 2012. His current research interests include mechatronics for sustainability, cognitive process control and hybrid lighting control, multi-UAV based cooperative multi-spectral "personal remote sensing" and applications, applied fractional calculus in controls, signal processing and energy informatics; distributed measurement and distributed control of distributed parameter systems using mobile actuator and sensor networks. He is a member of AMA, AWRA, AUVSI, ASME, IEEE, and ASEE. He is an Associate Editor for Acta Montanistica Slovaca, Fractional Calculus and Applied Analysis (Springer), Fractional Differential Calculus, International Journal of Advanced Robotic Systems, ASME Journal of Dynamical Systems, Measurement and Control, IEEE Transactions of Control Systems

Technology, ISA Transactions, IFAC journals Mechatronics and Control Engineering Practice. He is also a founding editorial board member for Unmanned Systems (World Scientific), a senior editor for Journal of Intelligent & Robotic Systems (Springer), and a member of editorial board of An International Journal of Optimization and Control: Theories & Applications.

Christopher Edwards was a Professor of Engineering in the Department of Engineering at the University of Leicester. He has been a Professor at The University of Exeter since 2012. He graduated from Warwick University in 1987 with first class honor in Mathematics and was appointed as a Lecturer in Control Engineering at Leicester in 1996, promoted to Senior Lecturer in 2004, Reader in 2008 and awarded a personal chair in 2010. He has an international reputation for his work on advanced fault-tolerant control, with particular application to aerospace systems. He is the author of over 240 refereed papers, 14 chapter contributions to edited monographs and three books: "Sliding mode control: theory and applications" (1998), "Fault tolerant flight control: a benchmark challenge" (2010), and "Fault detection and fault tolerant control using sliding modes" (2011).

Philippe Goupil received a PhD degree in signal processing. He works at the Airbus design office in Toulouse, France. He has acquired a strong experience in Flight Control System monitoring through several Airbus programs. He is mainly in charge of R&T activities for developing advanced fault detection and diagnosis (FDD) algorithms, for real-time industrial applications. In particular, he works on model-based approaches. He has been involved in the European GARTEUR Flight Mechanics Action Group FM-AG16 (2004-2008, www.garteur.org) on Fault Tolerant Control (FTC) and in the French project SIRASAS (https://extranet.ims-bordeaux.fr/External/SIRASAS/accueil.php) which dealt with innovative and robust strategies for spacecraft autonomy (2007-2010). He was the AIRBUS representative in the FP7 European Project ADDSAFE (2009-2012) which focused on Advanced Fault Detection and Diagnosis towards a more Sustainable Flight Guidance and Control (http://addsafe.deimos-space.com/). He is currently the AIRBUS representative in the FP7 EU project RECONFIGURE which deals with FDD and FTC technologies that facilitate the automated handling of offnominal/abnormal events and optimize the aircraft status and flight. He is the author or co-author of 14 industrial international patents and of about 40 conference or journal articles. He has been the industrial supervisor of three PhD students. Dr. Goupil is a member of the IFAC Technical Committee on Aerospace and of the IFAC Technical Committee Safeprocess. He served many time as IPC member and reviewer for several conferences and journal.

Qinglei Hu obtained his B. Eng. degree in 2001 from the Department of Electrical and Electronic Engineering at the Zhengzhou University, P. R. China, and M. Eng. and Ph.D. degree from the Department of Control Science and Engineering at the Harbin Institute of Technology with specialization in controls in 2003 and 2006, respectively. Since 2003, he has been with the Department of Control Science and Engineering at Harbin Institute of Technology and was promoted to the rank of Associate Professor in 2007 and Professor in 2012. His research interests include the design and control of spacecraft attitude system, variable structure control for flexible system, and fault tolerant control to aerospace systems. He has published significantly on the subjects with over 100 technical papers while enjoying the application of the theory through astronautic consulting. He has been actively involved in various technical professional societies such as AIAA, ASME, JSASS and IEEE, as reflected by member of JSASS, and session chair of many international conferences, and also Associate Editor of Journal of the Franklin Institute.

Andrés Marcos is from Córdoba, Spain. Received his Aerospace Engineering B.Sc. from St. Louis University (USA) in 1997 and M.S. and Ph.D. degrees in 2000 and 2004 respectively from the University of Minnesota (USA) in the group of Prof. Gary Balas. From 2004 to 2006, he was a research associate in the group of Prof. Ian Postlethwaite at the University of Leicester (UK) working with Dr. Declan Bates in a Group for Aeronautical Research and Technology in Europe (GARTEUR) project related to nonlinear flight control clearance. From 2006 to August 2013 he was with Deimos-Space S.L.U. (Spain) working as lead control engineer for control and autonomy research and development projects for the European Space Agency (ESA) and the European Community (EC). He has joined the Aerospace Engineering Department at the University of Bristol in October 2013, where he focuses on research & development of robust control techniques for aerospace vehicles in the fields of: (i) fault detection and isolation (FDI) and fault tolerant control (FTC); (ii) flight control design and verification & validation (V&V); and (iii) research on linear fractional transformation (LFT) & linear parameter varying (LPV) techniques for modeling, design and analysis.

Hugh H.T. Liu is a Professor at the University of Toronto Institute for Aerospace Studies (UTIAS), Toronto, Canada, where he also serves as the Associate Director, Graduate Studies. His research work over the past several years has included a number of aircraft systems and control related areas, and he leads the "Flight Systems and Control" (FSC) Research Laboratory. Dr. Liu is an internationally leading researcher in the area of aircraft systems and control. He has published over 100 technical papers in peer reviewed journals and conference proceedings, and he has received one US/Canada patent of his work on motion synchronization. Dr. Liu has made significant research contributions in autonomous unmanned systems development, cooperative control, and integrated modeling and simulation. He also serves on editorial boards and technical committees of international professional societies. Before his academic appointment, Dr. Liu has several years' industrial experience where he participated and led development projects of aircraft environmental control systems. Dr. Liu received his Ph.D. in mechanical engineering of the University of Toronto in 1998. He is an active member of IEEE, AIAA, CASI, and Fellow of CSME. Dr. Liu is also a registered Professional Engineer in Ontario.

Professor Ron J Patton graduated at Sheffield University with BEng (1971), MEng (1974) and PhD degrees (1980) in Electrical & Electronic Engineering and Control Systems. He has held a number of posts in industry and universities. From 1981 to 1994 he was leader of Control Research at York University, UK. Since 1995 Ron has held the Chair in Control & Intelligent Systems Engineering at Hull University. He has made a substantial contribution to the field of modelling in fault diagnosis and the design of robust methods for FDI/FDD in dynamic systems as author of 348 papers, including 114 journal papers and 6 books. He is Subject Editor in System Supervision: Fault-tolerant Control & Diagnosis for the Wiley Journal of Adaptive Control & Signal Processing and is a member of the editorial board for the Journal of Applied Mathematics and Computer Science. Ron chaired the International Programme Committees for IFAC Safeprocess'97, UKACC Control'98 and the 16th Mediterranean Control Conference, Med'08 and was Vice-chair of *Tooldiag '94* in Toulouse. He was chair of the IFAC Technical Committee on Safety & Supervision of Technical Processes during 1996 to 2002 and was member of the IFAC Policy committee [2005-2011], as vice chair from 2008-2011. Ron initiated and led the fault-tolerant control theme group in the European Science Foundation project Complex Control Systems. For the EC he was rapporteur for the committee reporting on the need for European research on Control in Embedded Systems. Ron coordinated the FP4 and FP5 research projects IQ^{2}FD [1997-2000] and DAMADICS [2000-2004] and participated in the FP6 and FP7 projects NeCST [2004-2007] and ADDSAFE [2009-2012]. His research interests are: Robust Fault detection and Isolation (FDI) for dynamic systems, multiple-model strategies for FDI/FDD & FTC (Fault-Tolerant Control), Reconfigurable flight control, FTC of de- centralized systems and FTC for offshore wind turbines. Ron is IEEE Fellow, senior member of AIAA and Fellow of InstMC.

Vicenç Puig is a Professor and Head of the Advanced Control Systems Group at Technical University of Catalonia in Barcelona (Spain) since 2001. Prof. Puig got the Engineering in Telecommunications at Universitat Politècnica de Catalunya (UPC) in 1993 and the PhD degree at the same University in the Automatic Control Department in the PhD Programme in "Automatic Control, Vision and Robotics" in 1999. The research interests of SAC and Prof. Vicenç Puig cover several fields of advanced control systems, such as model identification, predictive control and supervision of complex systems. In particular, he has important scientific contributions in areas of fault diagnosis and fault tolerant control His recent scientific production is very active, he has published than 60 articles in international journals and more than 300 papers in international conferences.

Silvio Simani's research interests have been focused mainly on Systems and Control Theory, and he has been mainly involved in robust fault diagnosis and sustainable fault tolerant control in nonlinear dynamic processes via model-based and model-free methodologies, system modelling and identification, as well as the interaction issues between identification, fault diagnosis and robust fault tolerant control. Since 2002, he is assistant professor at the Department of Engineering at the University of Ferrara, and working on several national and international projects regarding the field of fault diagnosis and sustainable fault tolerant control in dynamic systems, dynamic system identification, fuzzy logic, neural networks and nonlinear system identification for fault diagnosis (hybrid systems). Dr. Simani is author of more than 150-refereed journal and conference papers and two books on these topics. He has served as reviewer for several international journals and conferences. From 2006 he is Senior IEEE member of the IEEE Institute of Electrical & Electronic Engineers, and from 2000 member of the IFAC Technical Committee
SAFEPROCESS.

Didier Theilliol received the Ph.D. degree in Control Engineering from Nancy-University (France) in 1993. Since September 2004, he is a full Professor in Research Centre for Automatic Control of Nancy (CRAN) at Nancy-University where he co-ordinates and leads national, European and international R&D projects in steel industries, wastewater treatment plant, or aerospace domain. His current research interests include sensor and actuator model- based fault diagnosis method synthesis and active fault-tolerant control system design for LTI, LPV, multi-linear systems and also reliability analysis of components. Prof. Theilliol published over 100 journal/conference papers and is co-author of a new book entitled "Fault-tolerant Control Systems: Design and Practical Applications" (2010).

Antonios Tsourdos is a Professor and Head of the Autonomous & Intelligent Systems Group at Cranfield University, Defence Academy of the United Kingdom. He was member of the Team Stellar, the winning team for the UK MoD Grand Challenge (2008) and the IET Innovation Award (Category Team, 2009). Antonios is an editorial board member of the Proceedings of the IMechE Part G J. of Aerospace Engineering, the Int. J. of Systems Science, the IEEE Trans. on Instrumentation and Measurement, the Int. J. on Advances in Intelligent Systems, the J. of Mathematics in Engineering, Science and Aerospace (MESA) and the Int. J. of Aeronautical and Space Sciences. Professor Tsourdos is a member of the Expert Advisory Group on Precision, Navigation and Networking for the

Complex Weapons Centre of Defence Technology, a member of the A|D|S Autonomous Systems Strategy Group and the ADD KTN National Technical Committee on Autonomous Systems. Prof. Tsourdos is also a member of the IFAC TC on Aerospace Control, the IFAC TC on Networked Systems, the AIAA TC on Guidance, Control & Navigation (AIAA GNC TC), The AIAA Unmanned Systems Programme Committee, the IEEE Control System Society TC on Aerospace Control (TCAC) and the IEEE TC on Aerial Robotics and Unmanned Aerial Vehicles. Prof. Tsourdos is also member of IET Robotics & Mechatronics Executive Team. He is co-author of the book "Cooperative Path Planning of Unmanned Aerial Vehicles" and over 100 conference and journal papers.

Description of the intended audience:

- Graduate students and researchers in electrical engineering, mechanical & aerospace engineering interesting in UAS and fault-tolerant control and cooperative control.
- Researchers on UAS/UAV investigation and development; interesting in new techniques on fault diagnosis, health management, fault-tolerant guidance, navigation and control, and cooperative guidance, navigation and control.
- Managers, practitioners and developers on UAS, and with interests to fault diagnosis, health management, fault- tolerant guidance, navigation and control, and cooperative guidance, navigation and control.
- Researchers or engineers in the fields of surveillance, search, rescue missions, geographic studies, military and security applications interesting in the use of UAS/UAV.
- Since the proposed workshop is currently an interesting and active research topic, one of evidence is that one of presenters, Dr. Zhang's survey paper on Bibliographical Review on Reconfigurable Fault-tolerant Control Systems published in 2008 at IFAC "Annual Reviews in Control" gains the highest citation among the articles published since 2008 and even in the history of the journal, it is expected there are more than 30-50 enrollments for the workshop.

Tentative workshop schedule and presentation titles (A full-day workshop for a plan of 8 hours; then each presentation is about 35 min) (List below may change in the final presentation)

*** Morning:**
08:30 - 09:05: Introduction to Health Management, Fault-tolerant Control and Cooperative Control: Motivation, Concept, History, Existing and Future Developments (Dr. Zhang)
09:05 - 09:40: Developments on Fault Diagnosis, Fault-tolerant Control and Cooperative Control with Applications to Fixed- wing and Quadrotor UAVs Testbeds (Dr. Zhang)
09:40 - 10:15: Iterative Design Towards Improved Fault Tolerance:A Framework for Improved SUAS Airworthiness (Dr. Chen)
10:15 - 10:30: **Coffee Break**
10:30 - 11:05: Sliding Mode Schemes for Fault Detection and Fault Tolerant Control (Dr. Edwards)
11:05 - 11:40: Fault Diagnosis and Fault Tolerant Control for Civil Aircraft: Industrial State-of-Practice for Flight Control Systems (Dr. Goupil)
11:40 - 12:15: Observed-based Fault Diagnosis Incorporating Online Control Allocation for Spacecraft Attitude Stabilization under Actuator Failures (Dr. Hu)

*** Lunch** (12:15 - 13:30)

*** Afternoon:**
13:30 - 14:05: Recent Progress on Tolerant Flight Control for Damaged Aircraft (Dr. Liu)
14:05 - 14:40: H_{∞} Detection, Isolation and Tolerant Control: A Tutorial on Aerospace Applications (Dr. Marcos)
14:40 - 15:15: Reconfigurable Flight Fault Tolerant Control for Nonlinear Unmanned Aerial Vehicles (Dr. Patton)
15:15 - 15:50: Fault Diagnosis and Tolerant Control of Aerospace Systems using LPV Techniques (Dr. Puig)
15:50 - 16:05: **Coffee Break**
16:05 - 16:40: Nonlinear Fault Tolerant Control Schemes for Aerospace Applications (Dr. Castaldi and Dr. Simani)
16:40 - 17:15: Design of Fault-tolerant Control Methods Based on Reliability (Dr. Theilliol & Dr. Zhang)
17:15 - 17:50: Multiple UAS Operations: Toward Verifiable Autonomy (Dr. Tsourdos)
17:50 - 18:00: Summary, Discussion, and Feedback

Workshop abstract (List below is not in the final sequence of presentation)

- Introduction to Fault-tolerant Control and Cooperative Control: Motivation, Concept, History, Existing and Future Developments, and Applications to a Multiple Quadrotor UAVs Testbed (Dr. Zhang): Unmanned systems including Unmanned Aerial Vehicles (UAVs) are gaining more and more attention during the last few years due to their important contribution and cost effective application in several tasks such as surveillance, search, rescue, military and security applications. A team of researchers at the Department of Mechanical and Industrial Engineering of Concordia University, with the support from three Canadian-based industrial partners (Quanser Inc., Opal-RT Technologies Inc., and Numerica Technologies Inc.), have been working on a Networked Fault-Tolerant Cooperative Autonomous Vehicles (NFTCAV) research project as well as for "Flight Control Systems" and "Fault Diagnosis and Fault Tolerant Control Systems" courses teaching using multiple quadrotor helicopter UAVs. The main objective of the project is to provide theoretical and experimental results on on-line and on-line UAV modeling, cooperative decision-making and tasks assignment, trajectory and path planning, formation flight, fault diagnosis and fault-tolerant control, and at the same time to transfer quickly the research outcomes to the undergraduate and graduate courses teaching. A set of unmanned vehicles testbeds with several quadrotor UAVs have been built at the Department of Mechanical and Industrial Engineering of Concordia University based on the financial support of NSERC (Natural Sciences and Engineering Research Council of Canada) since 2007, with the help of Quanser Inc. for the testbed development. In this presentation, brief introduction to the concept on fault-tolerant control and cooperative control will be given first. Historical development and new challenges in this active research area will be outlined. An overview of our past, current and future research activities and research outcomes on fault diagnosis, fault- tolerant control, path and trajectory planning/re-planning and cooperative control with applications to unmanned systems including the quadrotor helicopter UAV, NASA's GTM fixed-wing UAV and an Airbus A380 model UAV, will be presented.
- Iterative Design Towards Improved Fault Tolerance: A Framework for Improved SUAS Airworthiness (Dr. Chen) In order to guarantee the airworthiness of a SUAS, there are some redundancies that need to be implemented in the design of UAS. But too many redundancies place a hard condition on the payload of UAS. This presentation aims at providing recommendation on what kind of faults in actuators are forbidden that we should make a backup in the design of UAS and what kind of faults are allowed without affecting the performance of UAS. It is common that when design a feedback controller the physical property of system are often overlooked. In this presentation, we put the 'physics' of UAV back in the design of fault tolerant controller for a fixed-wing test-bed and we try to find what are the maximum faults that can be tolerated in this kind of UAS. The results presented are intended to support the ongoing discussion on airworthiness and SUAS integration into the National Airspace System. Simulation results with different faults are also presented to validate the effectiveness of the presented fault tolerant controllers and other related airworthiness techniques.
- Sliding Mode Schemes for Fault Detection and Fault Tolerant Control (Dr. Edwards) Sliding mode methods have been historically studied because of their strong robustness properties to a certain class of uncertainty. This is achieved by employing nonlinear control/injection signals to force the system trajectories to attain in finite time a motion along a surface in the state-space. The associated reduced order dynamics, whilst constrained to the surface is called the sliding motion, and possess strong robustness properties. This talk will consider how these ideas can be exploited for fault detection (specifically fault signal estimation) and subsequently fault tolerant control. The talk will also describe an application of these ideas to aerospace systems. It will describe flight simulator results associated with the EL-AL 1862 Bijlmermeer scenario studied as part of the GARTEUR AG16 action group on fault tolerant control. The controller design was carried out without any knowledge of the types of faults/failures occurring on the aircraft, and employs sliding mode methods. The results demonstrate the successful real-time implementation of the proposed fault tolerant control scheme on a motion flight simulator configured to represent the EL-AL aircraft.
- Fault Diagnosis and Fault Tolerant Control for Civil Aircraft: Industrial State-of-Practice for Flight Control Systems (Dr. Goupil) This presentation deals with industrial practices and strategies for Fault Tolerant Control (FTC) and Fault Detection and Diagnosis (FDD) in civil aircraft by focusing mainly on a typical Airbus Electrical Flight Control System (EFCS). This system is designed to meet very stringent requirements in terms of safety, availability and reliability that characterized the system dependability. Fault tolerance is designed into the system by the use of stringent processes and rules, which are summarized in the presentation. The strategy for monitoring (fault detection) of the system components, as a part of the design for fault tolerance, is also described in this paper. Real application examples and implementation met hodology are outlined. Finally, future trends and challenges are presented. A focus is made on the global optimization of the future aircraft towards a more sustainable flight guidance and control. Indeed, highlighting the link between aircraft sustainabil ity and FDD, it can be demonstrated for example that improving the fault diagnosis performance in flight control systems allows to optimize the aircraft structural design (resulting in weight saving), which in turn helps improve aircraft performance and to decrease its environmental footprint.
- Observed-based Fault Diagnosis Incorporating Online Control Allocation for Spacecraft Attitude Stabilization under Actuator Failures (Dr. Hu) This work proposes a novel observed-based fault diagnosis incorporating online control allocation scheme for an orbiting spacecraft in the present of actuator faults/failures, unexpected disturbances and even input saturation. The proposed scheme solves a difficult problem of spacecraft fault tolerant control design that compensates for severely total loss of actuator effectiveness failure and even time-varying fault so that the overall system is stable even further under external disturbances and input saturation as well. This is accomplished by

developing an observer-based fault diagnosis mechanism to reconstruct or estimate the actuator faults/failures. Accordingly, an online control allocation scheme is then used to redistribute the control signals to the healthy actuators in the case of faults/failures without reconfiguring the controller, in which the control signal distribution is based on the reconstructed actuator effectiveness level. Simulation results using a rigid spacecraft model show good performance in fault, even certain total actuator failure scenarios and external disturbance as well as actuator input saturation, which validates the effectiveness and feasibility of the proposed scheme.

- Recent Progress on Tolerant Flight Control for Damaged Aircraft (Dr. Liu) Based on previous work on passive fault tolerant control to aircraft that suffers from vertical tail damage, it investigates recent progress both in theoretical development and in application front. Theoretical development includes the parameterization in fault detection and filter design; the extension of passive fault tolerant control to active FTC; as well as a recent work in time-variant domain. In application front, nonlinear aircraft model has been developed to test the applicability of the proposed design. Different application cases as well as flight simulation results are also introduced.
- H_∞ Detection, Isolation and Tolerant Control: A Tutorial on Aerospace Applications (Dr. Marcos) The fields of fault detection and isolation (FDI) and fault tolerant control (FTC) have attracted much attention from control engineers, especially in the (aeronautical and space) flight control community during the last thirty years. The most common approach to provide a system with FDI/FTC functionality is to use hardware redundancy and voting schemes. The main drawbacks with this approach are the added complexity and the costs resulting from the additional weight and volume of the redundant elements, which especially critical in aerospace systems. Model-based FDI approaches address those drawbacks using a mathematical model of the monitored system to detect, identify and compensate or correct abnormal behaviour. Since no mathematical model is exact, robustness to modeling uncertainty becomes a critical issue. Among the model-based methods, those based on H_∞ optimization are increasingly of interest due to the explicit treatment of uncertainty in its formulation. In this tutorial a practical look is presented to the design of open -loop H_∞ FDI filters and integrated H_∞ FTC controllers for aerospace applications.
- Reconfigurable Flight Fault Tolerant Control for Nonlinear Unmanned Aerial Vehicles (Prof. Patton) Aircraft with unconventional flight control configurations can potentially benefit from having adaptive control elements. Potential beneficiaries of these advanced control designs are Unmanned Aerial Vehicle (UAV) systems which are now rapidly having extended mission capability beyond target drone and air reconnaissance toward air combat and air -to-ground combat roles. These vehicles must contain systems with substantially smaller mass compared with manned vehicles, and in addition the UAV control designs may use minimal or no aerodynamic data. Hence, adaptive flight control systems should be designed to achieve required performance by dealing with uncertainties in the flight systems environment. Control reconfiguration is an active approach in control theory to achieve Fault Tolerant Control (FTC) for dynamic systems. In addition to loop-restructuring, the controller parameters must be adjusted to accommodate changing plant dynamics. To achieve this, controller designs using adaptive Neural Network (NN) and dynamic inversion based on geometric control theory are investigated where the NN plays a key role as the principal element of adaptation to approximately cancel the effect of the inversion error, system uncertainty and even certain faults and disturbances acting on the system. This form of active FTC dealing with faults as well as uncertainty can provide robustness in nonlinear dynamic regimes. In recent decades, there has been significant research effort to improve NN algorithms in nonlinear adaptive control designs for achieving desired system performance. An expanded reconfigurable flight FTC strategy using a Sliding Mode Control (SMC) training concurrent learning NN strategy will be presented based on an enhancement of a traditional adaptive flight control scheme comprising a feedback linearization form of baseline controller. Implemented as a learning algorithm, SMC treats the NN as a controlled system and allows a stable, dynamic calculation of the learning rates. While considering the system's stability, this robust online learning method therefore offers a high speed of convergence whilst achieving improved reconfigurable flight FTC dynamics in a much easier application concurrent adaption strategy.
- Fault Diagnosis and Tolerant Control of Aerospace Systems using LPV Techniques (Dr. Puig) The problem of robust fault detection is addressed using an adaptive threshold generation for non-linear systems described by means of LPV models. Adaptive thresholds are generated using an interval LPV observer that generates a band of predicted outputs taking into account the parameter uncertainties bounded using zonotopes. The in terval LPV observer is designed via pole placement using Linear Matrix Inequalities (LMI). LPV fault sensitivity analysis is used to characterize th e minimum detectable fault as well as to determine the limitations of proposed FDI strategy. The isolation t ask uses the fault estimation to isolate the faults. Fault estimation relies on the knowledge about the faulty system behavior using the fault sensitivity concept. On the other hand, the FTC problem is addressed using three approaches. The first one is a L PV FTC design based on Admissible Model Matching (AMM), where a set of admissible models is used, which provide stability/performance guarantees. The main contribution of this approach is to accommodate the controller guarantying that the system closed-loop behavior is in the set of admissible behaviors. This accommodation involves the on-line controller reconfiguration in presence of parametric faults and the fault estimation. This estimation is considered as a scheduling variable that allows the reconfiguration of the controller. The second approach consists in adapting the faulty plant to the nominal controller instead of adapting the controller. That is, the faulty plant together with the reconfigurati on block allows to the controller to see the same plant as before the fault. When a sensor fault is considered, an observer is used to calculate a replacement value. This approach is known as "virtual sensor". By duality, the results can also be applie d to derive a "virtual actuator" when the actuator fault is considered. Finally, an integrated FTC design procedure for LPV systems that considers the fault estimation using an unknown input observer and a virtual actuator is proposed. The FTC controller is implemented as a state feedback controller. This controller is designed such that it can stabilize the faulty plant using LPV techniques and LMIs. The effectiveness and performances of the FDI/FTC methods will be illustrated with several examples with special emphasis in a two-degree of freedom helicopter.

- Nonlinear Fault Tolerant Control Schemes for Aerospace Applications (Dr. Castaldi and Dr. Simani) In general, a nonlinear fault tolerant control system consists of a guidance and control system, as well as a fault detection and diagnosis module. They are designed on the basis of the mathematical model of the system under investigation. It should be clear that the better is the model describing the system to be controlled, the better is the performance of both the guidance and control system and the fault detection and diagnosis module. It is clear that the increasing performance requirement for highly nonlinear systems, such as aircrafts, implies the need of nonlinear methods for both the guidance and control system, and the fault detection and diagnosis module. The proposed issue will describe different mathematical models of aerospace systems. Particular attention will be paid to the description of environmental disturbances, as they will affect the performance of the complete system design. After this issue, the attention will be focused on nonlinear methods for the design of guidance and control systems. Two main categories can be considered: the classical approach, and the purely nonlinear methodology. Unfortunately, in case of fault, the considered nonlinear systems can be affected by unpredictable behaviors. Therefore, the so-called fault tolerant control systems must be considered. Therefore, the design of a fault detection and diagnosis module is discussed, which is able to determine the fault, and to estimate its magnitude. Different techniques are considered, which are already available in the related literature, even if the main point is to provide also a set of purely nonlinear methods. Thus, the nonlinear geometric approach will be described in more detail, and applied to the considered aerospace models. Finally, simulation results with high-fidelity technological demonstrators will show the performance of the overall systems.
- Design of Fault-tolerant Control Methods Based on Reliability (Dr. Theilliol & Dr. Zhang) Faults or failures such as defects in components, instruments, controllers and/or control loop can cause undesired rea ctions and consequences such as damages to technical parts of the plant, to human life or to the environment. Traditionally, the objective of Fault Tolerant Control System (FTCS) is to maintain its current performance close to the desired one and preserve its stability conditions despite of component and/or instrument faults; in some circumstances a reduced performances may have to be accepted as a trade-off leading to a sub-optimal outcome. Design of control systems to achieve fault-tolerance for closed-loop control of safety-critical systems has been an active area of investigation for many years. It becomes more and more clear that there are certain trades-offs between achievable normal performance and fault-tolerance capability. However, despite of the many efforts in control community, most of the contributions did not consider or take into account the reliability of components, algorithms or soft computing structures to guarantee such performance and to reduce the gap between nominal and faulty case. This contribution aims at presenting new and innovative research results on how to design Fault Tolerant Control Systems with particular attention to consider and combine reliability analysis in the design procedure and/or real-time control synthesis. Current and future research is presented in order to solve the above challenging research problems devoted to safety-critical systems such as flying vehicles, unmanned aerial vehicles (UAVs), missiles, airships etc.
- Multiple UAS Operations: Toward Verifiable Autonomy (Dr. Tsourdos) There are many applications using autonomous systems such as unmanned aerial vehicles: surveillance/attacking, traffic monitoring, search and rescue, and so on. Nowadays the applications and missions become so various and complex that the systems become more complicated. Those missions are related not only with civil purpose but also with military one so usually safety-critical. Diverse sensors are equipped in the systems for safety and redundancy, furthermore, a group of autonomous systems has been recently considered for more effective mission performance. As the systems are complicated, reliability of systems must be verified at the design level. There are some methods to verify the reliability of systems at the design level such as a simulation in a virtual environment, a test with a mock-up, and formal methods. Firstly, test with a mock-up costs a lot of money and time to perform and doesn't always guarantee the safety during it processes. Simulation costs less money and time than for the test, but it is not always easy to consider all the possible scenarios and situations. In contrast formal methods are based on solid mathematical techniques and offer quantifiable answers to questions related with reliability of systems, and thus they are widely used to verify the safety-critical or high-autonomy systems. Model-checking is an automatic technique based on formal methods for verifying finite state system. It checks whether the system satisfy the properties or not automatically. There are three parts of process in model-checking: modeling, specification, and verification. This contribution aims at presenting new and innovative research results on how to model multiple UAS systems as multi-agent systems using formal methods to captures their specifications that would enable to validate their performance and finally how to verify their performance in the presence of faults.

Workshop references and materials (Author with **bold face** is one of the speakers at this workshop):

- A. Zolghadri, D. Henry, J. Cieslak, D. Efimov, **P. Goupil**, Fault Diagnosis and Fault-Tolerant Control and Guidance for Aerospace Vehicles - From Theory to Application, Series: Advances in Industrial Control. Springer. 2014, XVI.
- Halim Alwi, **Christopher Edwards**, and Chee Pin Tan, Fault Detection and Fault Tolerant Control using Sliding Modes, Springer, 2011.
- **Antonios Tsourdos**, Brian White, and Madhavan Shanmugavel, Cooperative Path Planning of Unmanned Aerial Vehicles, Wiley, 2011.
- **Christopher Edwards**, Thomas Lombaerts, and Hafid Smaili (Eds.) Fault Tolerant Flight Control: A Benchmark Challenge, Springer, 2010.
- Hassan Noura, **Didier Theilliol**, Jean-Christophe Ponsart, and Abbas Chamseddine, Fault-tolerant Control
- Systems: Design and Practical Applications, Springer, 2009.

- Mufeed Mahmoud, Jin Jiang, and **Youmin Zhang**, Active Fault Tolerant Control Systems: Stochastic Analysis and Synthesis, Springer, 2003.
- **Youmin Zhang** and Jin Jiang (2008), Bibliographical Review on Reconfigurable Fault-tolerant Control
- Systems, Annual Reviews in Control, vol. 32, no. 2, Dec. 2008, pp. 229-252 (Ranked No. 1 in the "Most Cited Articles" published since 1996 in the journal).
- **Youmin Zhang**, A. Chamseddine, C.A. Rabbath, B.W. Gordon, C.-Y. Su, S. Rakheja, C. Fulford, J. Apkarian, and P. Gosselin (2013), Development of Advanced FDD and FTC Techniques with Application to an Unmanned Quadrotor Helicopter Testbed, Journal of the Franklin Institute, vol. 350, no. 9, pp. 2396-2422 (Ranked #2 in the "Most Downloaded Articles" in the journal, as of 2013-11-19; http://www.journals.elsevier.com/journal-of-the-franklin-institute/most-downloaded-articles/).
- Other references or workshop materials will be provided during the workshop to participants.