MAY 15-18, 2017

PROGRAM GUIDE

COMBUSTION INSTITUTE CANADIAN SECTION

SPRING TECHNICAL MEETING 2017

MCGILL UNIVERSITY

General Information

Welcome to McGill University

The Alternative Fuels Laboratory at McGill University welcomes you to the Spring Technical Meeting of the Combustion Institute - Canadian Section (CICS 2017). The technical program includes three plenary lectures and approximately 80 presentations exposing the remarkable diversity of the combustion research performed in Canadian laboratories. The social program of CICS 2017 features a welcome reception on Monday evening at the McGill Faculty Club and a banquet, Wednesday evening, at the Érablière Charbonneau in Mont St-Grégoire where a traditional Québec meal will be served.

The CICS organizing committee wish you a pleasant stay in Montréal.

- Jeffrey M. Bergthorson, co-chair
- Gilles Bourque, co-chair
- Philippe Julien

Acknowledgements

We want to acknowledge the generous technical and financial support of our sponsors:
- Siemens Canada Limited,
- the Department of Mechanical Engineering, McGill University,
- the Faculty of Engineering, McGill University.

Thanks also to the students of the Alternative Fuels Laboratory for their help in organizing the meeting.

Welcome Reception

Participants are invited to a welcome reception on Monday May 15, starting at 6 pm. The event will be held at the McGill Faculty Club housed in a historic building on the campus (see map). Refreshments and hors d'oeuvres will be served.

Registration Desk and Information Table

The registration desk will be open:
- Monday, May 15 from 6 to 9 pm during the reception at the McGill Faculty Club,
- Tuesday, Wednesday, and Thursday, from 7:30 am to 5:00 pm, in McConnell 12.

Conference Banquet

The CICS Banquet will be held on Wednesday, May 17, at the Érablière Charbonneau in Mont St-Grégoire. A traditional Québec meal will be served at the cabane à sucre, along with maple syrup to accompany the dishes.

More information about the sugar shack and the menu can be found on the website. Buses will start loading at 6 pm on Wednesday at the location shown on the map. The last bus will depart at 6:30 pm.

Proceedings

Each registrant will receive a USB flash drive containing the proceedings. A link is embedded in the title of each paper in the program that will open the corresponding manuscript. For Adobe Acrobat Reader users, in order for the program not to close every time a paper is opened, uncheck the box *Open cross-document links in same window* under *Edit* / *Preferences* / *Documents*.

Wireless Internet Access

Wireless internet is available through Eduroam using your home institution's login information. For participants without access to Eduroam (outside of academia), individual username and password, valid for the duration of the meeting, can be obtained at the registration desk.

If further assistance is required, please contact the McGill IT Service Desk by email or call 514-398-3398.

Parking

Limited pay parking is available in the courtyard behind the McConnell Engineering Building. Parking is also possible behind the Percival Molson Memorial Stadium, or in the streets surrounding McGill University. Details can be found at: https://www.mcgill.ca/transport/parking/downtown/visitors.

Plenary Lectures and Technical Sessions

All conference talks will be presented in the McConnell Engineering Building (see map). Plenary lectures will be held in room McConnell 204, and technical sessions in rooms McConnell 11 (ground floor), McConnell 13 (ground floor), and McConnell 204 (second floor).

Instruction for Presentations

A computer (Windows operating system) and a projector are provided in each room. Each paper in the technical sessions has been allotted 20 minutes: 15 minutes for the presentation, 3 minutes for the question period, and 2 minutes for setup of the next presentation. Speakers are asked to bring their presentation on a USB flash drive and to upload it on the computer during the break preceding their session. Those using Apple computers are invited to test their presentation beforehand, or to bring their own computer along with the appropriate adapter to the VGA cable.

CICS 2017 will use the same computer timing system that has been utilized in previous meetings. The countdown clock will be green during the first 13 minutes of the presentation, then change to yellow at the end of the presentation and during the question period (next 5 minutes), and finally to red during the changeover (2 minutes). Please respect the time limit for your presentation.

Speakers should arrive at least 15 minutes before their session is scheduled to start in order to meet the Session Chair, and upload their presentation on the computer.

Coffee Breaks

Coffee breaks take place on Tuesday (morning and afternoon), Wednesday (morning and afternoon) and Thursday (morning) in room McConnell 12.

Lunch

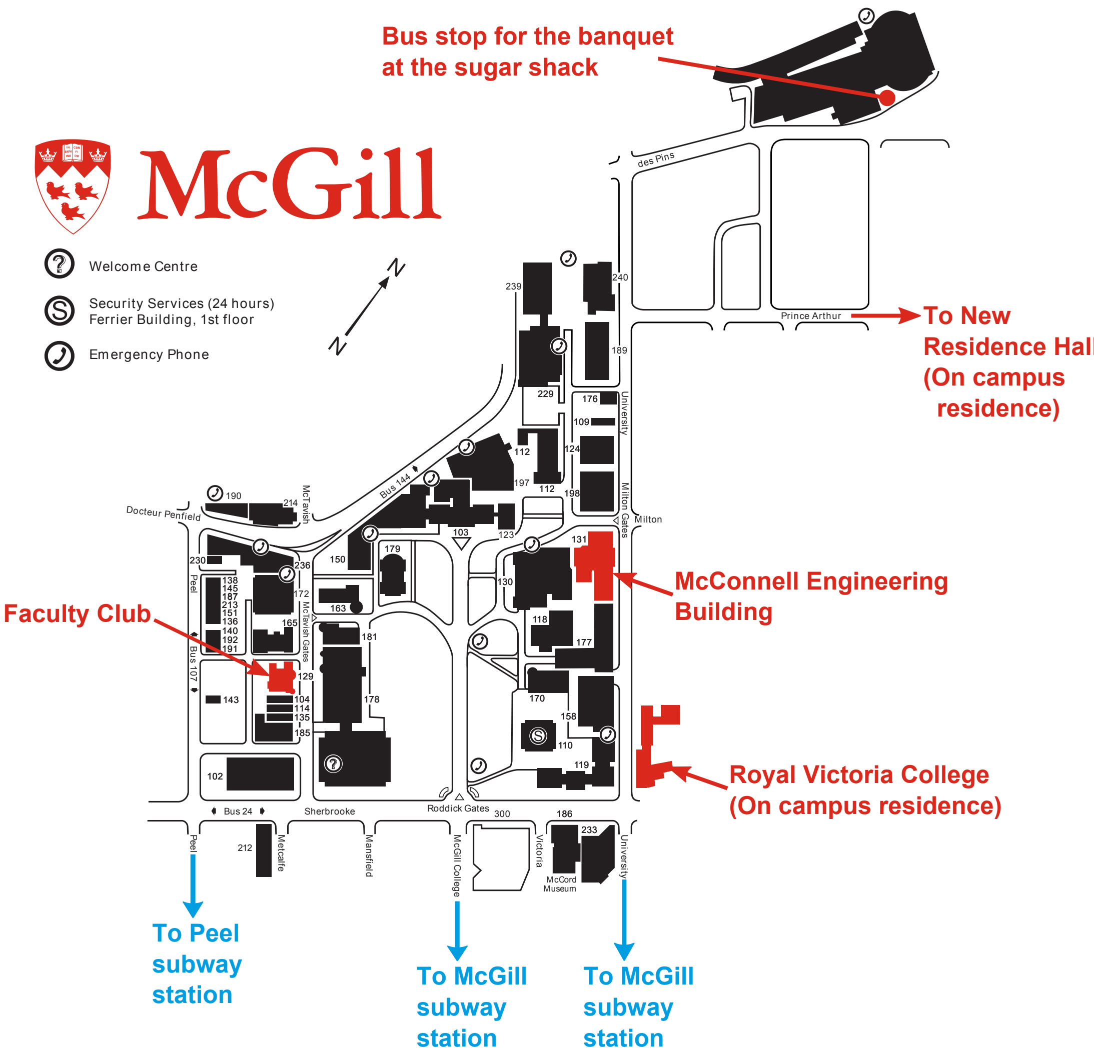
Lunch **is not** provided with your registration. Many restaurants are at walking distance from the campus:

- Tim Hortons,
- Falafel Avenue,
- Vua,
- Les Trois Brasseurs,
- Lola Rosa Café (vegetarian restaurant),
- Amelias Pizza (closed on Monday),
- Second Cup,
- Numerous restaurants in the Eaton Center,
- and so on.

Facebook Page

A facebook page has been created for the CICS Spring Technical Meeting 2017. Please follow the page and share pictures of your work and taken during the conference! You can post your questions and comments on the wall.

Campus Map



Additional information about the campus and its neighbourhood is provided in this interactive map.

Program

Monday May 15, 2017

15:30-18:00	Informal CICS Board Meeting (McGill Faculty Club / Gold Room)
18:00-21:00	Registration and Reception (McGill Faculty Club)

Tuesday May 16, 2017

7:30-8:00	On-site registration (McConnell 12)	
8:00-8:10	Welcome and Opening Remarks (McConnell 204)	
8:10-9:00	**Plenary Lecture 1 (McConnell 204): Tailoring the Ignition and Combustion of Aluminum in Propellants** **Prof. Steven F. Son**, School of Mechanical Engineering Purdue University Chair: Jeffrey M. Bergthorson	
	McConnell 204	**McConnell 11**
	Heterogeneous and spray combustion Chair: John Z. Wen	**Pollutant formation** Chair: Murray J. Thomson
9:10-9:30	**Effect of Nozzle Exit Conditions on the Near-Field Behavior of a Liquid Jet in a Uniform Cross Airflow** *M. Broumand and M. Birouk*	**Gas turbine emissions and contrail microphysics at different operating conditions using complex chemistry and microphysics** *J. Garcia Lopez, P. Seers, F. Garnier and X. Vancassel*
9:30-9:50	**A Thermophysical Approach to the Ignition of Particles** *M. Soo, X. Mi, S. Goroshin, A.J. Higgins and J.M. Bergthorson*	**Effect of different preparation and structure of Iron doped Cerium oxide catalyst on soot combustion** *B. Li, H. Zheng, J.Z. Wen and E. Croiset*
9:50-10:10	**Evaporation of Droplets of Mixtures of *n*-Paraffins and *n*-Alkanols** *W. Hallett, A. Tanner and N. McLellan*	**The effect of pressure on the primary soot particle size in nitrogen diluted ethylene diffusion flames determined by thermophoretic sampling at pressures up to 20 bar** *P.H. Joo, M. Christensen, E. Griffin, B. Gigone and Ö.L. Gülder*

10:10-10:30	**Reaction mechanism of layered Al/CuO nano-thermite composite** *H. Sui and J.Z. Wen*	**Thermochemical mechanism optimization for accurate predictions of CH concentrations in premixed flames of C1-C3 alkane fuel** *P. Versailles, G.M.G. Watson, A. Durocher, G. Bourque and J.M. Bergthorson*
10:30-10:50	Coffee break in McConnell 12	
	New technology concepts Chair: Larry W. Kostiuk	**IC and gas-turbine engine combustion** Chair: Cécile Devaud
10:50-11:10	**Hydrothermal Gasification of Biomass in Diamond Anvil Cell** *S. Nanda, A.K. Dalai, I.S. Butler and J.A. Kozinski*	**Chemical Imaging in a Diesel-Ignited Optical Engine Using High-Speed Infrared Narrowband Imaging** *M. Gagnon, E. Mancaruso, L. Sequino, P. Tremblay, S. Savary and V. Farley*
11:10-11:30	**The influence of empirical bed modeling on CO emissions in a small-scale grate firing biomass furnace** *Z. Taban, M. Farokhi and M. Birouk*	**Completness of Combustion in a Natural Gas Fueled Split-Cycle Engine** *S.G. Dal Bello and A. Sobiesiak*
11:30-11:50	**CFD analysis of a Variable Compression Ratio HCCI Rotary Engine** *P. Panchal, G. Ciccarelli, P. Mottaghian and R. Fanara*	**Flame liftoff and reattachment dynamics in a linear multi-swirler combustor array** *W.Y. Kwong and A.M. Steinberg*
11:50-12:10	**A novel method of calculating mass fraction of coated black carbon** *K.N. Broda, J.S. Olfert, M. Irwin, G. Schill, G. McMeeking, E. Schnitzler and W. Jäger*	**Study of the Promotion Effect of Hydrocarbon on NO-NO2 Conversion Process during Diesel Low-Temperature Combustion Cycles** *X. Yu, T. Gao, K. Xie, S. Yu and M. Zheng*
12:10-12:30	**Preliminary experimental study of methane decarbonization using a laminar premixed flame** *F. Falahati, M.J. Afroughi, J.S. Olfert and L.W. Kostiuk*	**Analysis of intermittent thermoacoustic oscillations in a liquid-fueled aeronautical gas turbine combustor at elevated pressure** *S. Kheirkhah, J.M. Cirtwill, P. Saini, K. Venkatesan and A.M. Steinberg*

12:30-14:00	**Lunch (On your own, see suggestion list)** **Board of Directors Meeting (Macdonald 267)**	
	McConnell 13	**McConnell 11**
	Laminar flames Chair: W. Kendal Bushe	**Diagnostics** Chair: Mathieu Picard
14:00-14:20	**Evaluation of Maximum-Entropy Moment Closures for Predicting Radiation Transport Phenomena** *J.A.R. Sarr and C.P.T. Groth*	**Simultaneous laser Rayleigh and filtered laser Rayleigh scattering thermometry of heated air** *K. Teav, N.E. Gowland and A.M. Steinberg*
14:20-14:40	**Numerical Simulation of Laminar Diffusion Flames with an Aliphatic Collision Inception Model** *N. Ceranic and S.B. Dworkin*	**Parametric study of effects of density ratio and fuel composition on coupled dynamics of hydrodynamic instability and flame lift-off** *Q. An and A.M. Steinberg*
14:40-15:00	**Prediction of Laminar Diffusion Co-Flow Flames Coupled with Conjugate Heat Transfer Using a Partitioned Approach** *W. Syed and C.P.T. Groth*	**Assessment of Thermal Oxidation Stability Characteristics of Biojet Fuels Using a New Technique** *N.G. Young, F.T.C. Yuen and Ö.L. Gülder*
15:00-15:20	**Modeling soot formation with Flamelet-Generated-Manifold (FGM) method** *L. Zimmer, F.M. Pereira, J.A. van Oijen and L.P.H. de Goey*	**Assessment of a Novel Optical Diagnostic to Quantify Emissions from a Heated Methane Plume** *S.J. Grauer, B.M. Conrad, R.B. Miguel and K.J. Daun*
15:20-15:40	Coffee break in McConnell 12	
	McConnell 13	**McConnell 11**
	Turbulent flames Chair: Clinton P.T. Groth	**Detonations, explosions, and supersonic combustion** Chair: Gaby Ciccarelli
15:40-16:00	**Large Eddy Simulation of turbulent lifted flame** *M. Mortada and C. Devaud*	**Visualization of Detonation Propagation in a Round Tube Equipped with Repeating Orifice Plates** *G. Rainsford and G. Ciccarelli*
16:00-16:20	**Effect of Burner Geometry and Swirl Strength on the Blowoff Limit of Lean Premixed Biogas Flame** *A. Al-Abbasi, M.M. Abdelazim, M. Saediamiri and M. Birouk*	**Dynamics of $2H_2/O_2/2Ar$ Detonations in Channels with Constant Area Divergence** *Q. Xiao, J. Chang, M. La Flèche and M.I. Radulescu*
16:20-16:40	**The Effects of Differential Diffusion on Turbulent Counter-flow Premixed Flames with Increasing Turbulence** *S.D. Salusbury, E. Abbasi-Atibeh and J.M. Bergthorson*	**Experimental Study of Shock-Flame Complex in a Hele-Shaw Cell** *M. La Flèche, Q. Xiao and M.I. Radulescu*

Wednesday May 17, 2017

8:00-8:10	Announcements (McConnell 204)	
8:10-9:00	**Plenary Lecture 2 (McConnell 204): Thermodynamic and Optical Combustion Characterization of Natural Gas Fuelling Strategies for Compression Ignition Engines** **Prof. Patrick Kirchen**, Department of Mechanical Engineering University British Columbia Chair: Gilles Bourque	
	McConnell 204	**McConnell 11**
	Diagnostics Chair: Adam M. Steinberg	**Detonations, explosions, and supersonic combustion** Chair: Matei I. Radulescu
9:10-9:30	**Simultaneous detection and partition between soot and PAHs in a laminar flame of methane by Single-Excitation Wavelength TIme-REsolved Laser Induced Incandescence and Fluorescence (SEW-TIRE LII/LIF)** *A. Hospital and R. Lemaire*	**Single-head Detonation Propagation in a Partially Obstructed Square Channel** *M. Kellenberger and G. Ciccarelli*
9:30-9:50	**Approximating model error for enhancement of soot morphology inference through multi-angle light scattering** *S. Talebi Moghaddam and K.J. Daun*	**Near-limit detonations propagating in a medium with randomly distributed reactive sources** *X. Mi, A.J. Higgins, H.D. Ng, C.B. Kiyanda and N. Nikiforakis*
9:50-10:10	**Application of an In-Cylinder Line of Sight Two-Colour Pyrometry Probe in an Optical Pilot-Ignited Direct Injection Natural Gas Engine** *J. Yeo, M. Khosravi, J. Rochussen and P. Kirchen*	**Numerical Investigation of Flow Field Inhomogeneities in a Rotating Detonation Engine** *K.P. Grogan and M. Ihme*
10:10-10:30	**Development of a research-grade cylinder head with modular injector mounting and access for multiple in-cylinder diagnostics** *J. Rochussen, J. Son, J. Yeo, M. Khosravi and P. Kirchen*	**Simultaneous inference of temperature and intensity scaling factor in laser-induced incandescence** *T.A. Sipkens, R. Mansmann, J. Menser, K.J. Daun, T. Dreier and C. Schulz*
10:30-10:50	Coffee break in McConnell 12	
	Laminar flames Chair: Patrick Kirchen	**Fire research** Chair: Larry W. Kostiuk
10:50-11:10	**Impact of the numerical initial pertubations and kinetic schemes on a flame instability CFD model** *L. Le Corvec, D. Lapalme and P. Seers*	**Heat Flux Measurments During a Full-Scale House Fire** *M. Fulton, M. Fauchoux, D. Torvi and A. Beitel*

11:10-11:30	**Numerical and experimental study of sooting propensity of ethanol in laminar diffusion flames at elevated pressures** *W. Syed, P.H. Joo, Ö.L. Gülder and C.P.T. Groth*	**Extinguishing a flame with water droplets** *M. Mosavati, R. Carriveau and D.S. Ting*
11:30-11:50	**Soot Particle Concentration Estimator Applied to a Transient Sooting Ethylene/air System** *L. Zimmer, R. Alexander and S.B. Dworkin*	**Numerical simulations of an underventilated compartment fire** *D.P. Wilson and C. Devaud*
11:50-12:10	**Numerical Investigation of Transfer Function Models of a Laminar Premixed Flame Using Frequency Response Analysis** *M. Sahafzadeh, L.W. Kostiuk and S.B. Dworkin*	**The effect of wind shear and turbulence on flame extinction** *J. Shen, R. Carriveau and D.S. Ting*
12:10-12:30	**Mechanism Reduction of Methane-Air Flames Using Quasi Steady-State Approximation** *A. Durocher, P. Versailles, J.M. Bergthorson and G. Bourque*	**Comparison of Temperatures Measured During Sprinklered and Unsprinklered Public Fire Demonstrations** *M. Fulton, M. Fauchoux, D. Torvi and A. Beitel*
12:30-14:00	**Lunch (On your own, see suggestion list)**	
	McConnell 13	**McConnell 11**
	Heterogeneous and spray combustion Chair: Seth B. Dworkin	**New technology concepts** Chair: Matthew R. Johnson
14:00-14:20	**A Microgravity Spaceflight Experiment to Examine the Discrete Regime of Flame Propagation: PERWAVES** *J. Palecka, S. Goroshin, J.M. Bergthorson and A.J. Higgins*	**Coupled simulations of partial oxidation of methane in mixed ionic-electronic conducting membrane reactors** *D. Sommer and P. Kirchen*
14:20-14:40	**Spherically-Expanding Flames in Hybrid Aluminum-Methane-Oxidizer Mixtures** *J.E. Vickery, P. Julien, S. Goroshin, D.L. Frost and J.M. Bergthorson*	**Highly preheated premixed combustion for gas turbine applications** *A. Landry-Blais, B. Picard, J. Dufault, T. Parent-Simard, M. Charette, F. Ebacher, F. Marois and M. Picard*
14:40-15:00	**Hypergolic droplet ignition of liquefying hybrid rocket propellants with hydrides fuel additives** *B. Elzein and É. Robert*	**Dynamic Response of a Lean-Premixed Flame to Diffuse Non-Equilibrium Plasma at Atmospheric Pressure** *M.D.G. Evans, S. Coulombe and J.M. Bergthorson*

15:00-15:20	**Fabrication and characterization of magnetron sputtered Cu2O, Cu, and Al thermite nanolaminates** *L. LeSergent, J.Z. Wen and C. Ren*	**Characteristics of an Atmospheric Pressure Diffuse Nanosecond Pulsed Discharge for Methane Dissociation** *P. Diaz Gomez Maqueo, M. Maier, M.D.G. Evans, S. Coulombe and J.M. Bergthorson*
15:20-15:40	Coffee break in McConnell 12	
	McConnell 13	**McConnell 11**
	Turbulent flames Chair: William L. Hallett	
15:40-16:00	**Numerical simulation of premixed propane-air flame propagation in a straight rectangular duct using XiFoam** *Z. Movahedi, I. Gallage and A. Sobiesiak*	
16:00-16:20	**Locally Adaptive Tabulation of Low-Dimensional Manifolds using Bézier Patch Reconstruction** *M. Yao, M. Mortada, C. Devaud and J. Hickey*	
16:20-16:40	**Flamelet Modeling of Premixed Methane-Hydrogen Fuel Combustion in an Multiple-Swirl Flame Configuration** *S. Jella, J.M. Bergthorson, W.Y. Kwong and A.M. Steinberg*	
17:00-18:00	Annual Business Meeting of the Canadian Section (McConnell 204)	
18:00-18:30	Buses will start loading at 18:00, and the last one will leave at 18:30, for the sugar shack. See map for the gathering point.	
19:00-21:30	Banquet at Érablière Charbonneau	
21:30-22:30	Buses return to McGill University	

Thursday May 18, 2017

8:00-8:10	Announcements (McConnell 204)	
8:10-9:00	**Plenary Lecture 3 (McConnell 204): The detonation paradox: the influence of diffusive processes in controlling the burning rate in detonations** **Prof. Matei Ioan Petru Radulescu**, Department of Mechanical Engineering University of Ottawa Chair: Jeffrey M. Bergthorson	
	McConnell 204	**McConnell 11**
	Heterogeneous and spray combustion Chair: Madjid Birouk	**Turbulent flames** Chair: Kyle J. Daun
9:10-9:30	**Propagation Limits of Particulate Systems and Geometric Scaling** *F. Lam, X. Mi and A.J. Higgins*	**Application of inter-ensemble regularization to the CSE model for turbulence-chemistry interaction** *G.R. Hendra and W.K. Bushe*
9:30-9:50	**Evaluation of an Eulerian-Lagrangian Spray Atomization (ELSA) Model for Nozzle Flow: Modeling of Coupling Between Dense and Disperse Regions** *T.F. Leung, C.P.T. Groth and J.T.C. Hu*	**Validation of the assumptions underlying CSE using experimental data** *W.K. Bushe*
9:50-10:10	**A Fourteen-Moment Bi-Gaussian Closure for the Simulation of Disperse Liquid Fuel Sprays** *J. Laplante, C.P.T. Groth, F. Laurent and A. Vie*	**Lyapunov exponent as a metric to determine the quality and predictability of large-eddy simulations of turbulent combustion** *J. Labahn, G. Nastac, L. Magri and M. Ihme*
10:10-10:30	**Establishing Critical Design Parameters for the Optimization of Internally Mixed Air-Blast Nozzles for Pyrolysis Liquid Biofuels** *S. Albert-Green and M.J. Thomson*	
10:30-10:50	Coffee break in McConnell 12	
	Pollutant formation Chair: Ömer L. Gülder	**IC and gas-turbine engine combustion** Chair: Andrzej Sobiesiak
10:50-11:10	**Soot Concentration Estimation Using Lagrangian Post-Processing for Laminar Flames of Varying Dilution and Pressures** *R. Alexander and S.B. Dworkin*	**Investigating the effect of temperature on NOx sensor cross sensitivity to ammonia using a physics based model** *M. Aliramezani, K. Ebrahimi, C.R. Koch and R.E. Hayes*

11:10-11:30	**Dependence of soot particle size on pressure in methane-air diffusion flames determined by thermophoretic sampling at pressures up to 20 bar** *P.H. Joo, M. Christensen, E. Griffin, B. Gigone and Ö.L. Gülder*	**An experimental and numerical study of natural gas/diesel dual-fuel engine at low load: Effect of diesel fuel injection timing** *A. Yousefi, M. Birouk and H. Guo*
11:30-11:50	**The Effect of Sodium Chloride Additive on the Evolution of Particles in a Diffusion Flame** *A. Moallemi, M. Kazemimanesh, L.W. Kostiuk and J.S. Olfert*	**Effects of Karlovitz number on Localised Forced Ignition of Turbulent Combustible Mixtures: A DNS Study** *D. Patel*
11:50-12:10	**Exploratory Experiments of Effects of Water, Hydrochloric Acid, and Sodium Chloride Solutions on Lab-Scale Flare Emissions** *A.M. Jefferson and M.R. Johnson*	**Wood Pyrolysis Oil for Fueling Diesel Engine** *M. Khan, M. Rafiq, V. Sookarah and M.J. Thomson*
12:10-12:30	**Measurements of Benzene Destruction Efficiency in a Lab-Scale Flare** *N.T. Brooker, M.R. Johnson and B.M. Crosland*	

Plenary Lecture: Tuesday May 16, 2017

Tailoring the Ignition and Combustion of Aluminum in Propellants

Steven F. Son
School of Mechanical Engineering, Purdue University

Aluminum is used widely in solid propellants, and other energetic materials, because it yields significant impulse performance gains and improved stability at reasonable cost and good storage life. Generally, particle size and morphology are all that can be changed. Nanoscale metal fuels do offer potential advantages, including faster burning rates and more complete combustion. Motivated by this, replacing micrometer-scale aluminum in energetic materials with nanoscale aluminum has been studied for more than two decades, including studies involving aluminium-water propellants that will be reviewed in this talk. However, simply substituting micrometer-scale particles with nanoscale particles in solid propellants can lead to drawbacks including poor rheology and mechanical properties. Nanoscale aluminum also has a relatively thick oxide layer that reduces the performance. Indeed, examples of fielded propellants containing nanoscale aluminum are not currently found and may likely never be. A key question is how one can obtain the advantages of nanoscale fuels without the drawbacks. Recently, efforts have focused on micrometer-scale aluminum particles with an intraparticle nanoscale structure. The ideal solution may be a micrometer-sized composite particle that has significantly lower ignition temperature and, when ignited, produces much smaller particles/droplets. In multiphase liquid combustion, "micro-explosion" can occur for some miscible liquids and also in emulsions. A key requirement for this to occur is for one of the constituents to be more volatile than the others. For miscible liquids, a disparity between the liquid-phase mass and thermal diffusion is necessary in establishing droplet dynamics. Emulsions, such as fuel oils and water, can also yield self-atomization, or micro-explosion dynamics. In an analogy to liquid fuels, metal alloys are similar to miscible liquid fuels in that the atoms or molecules are mixed intimately to form a single phase, eutectic, or solid solution. Likewise, inclusions of more volatile materials within a metal fuel (*e.g.*, a polymer in aluminum) are the equivalent to an emulsion where multiple phases are intertwined together, but not atomically or molecularly mixed. The intertwining of phases in a metal can be achieved using milling processes, which can result in lower particle ignition temperatures and dispersive dynamics. This method is also inexpensive and readily scalable. Another approach to achieve a similar outcome, which has also been pursued, could be the direct bottom-up fabrication of nanoscale fuel particles held together with a more volatile binder. In this talk I will review our efforts to tailor the ignition and combustion of aluminum in propellants. This has applications to other metals and other combustion systems. I will also discuss new directions that could allow even more tailoring of the combustion, including additive manufacturing applied to solid propellant fabrication.

Plenary Lecture: Wednesday May 17, 2017

Thermodynamic and Optical Combustion Characterization of Natural Gas Fuelling Strategies for Compression Ignition Engines

Patrick Kirchen
Department of Mechanical Engineering, University British Columbia

In light of the significant North American natural gas (NG) reserves, NG is considered an attractive alternative fuel for internal combustion engines. Relative to combustion of diesel or gasoline, NG combustion results in lower CO_2 emissions, and potentially lower NO_x and particulate emissions. Beyond this, NG is often viewed as a transitional fuel, as technologies suitable for use with NG may be well suited for renewable natural gas (RNG), which is of particular interest for heavy-duty and large-bore engine applications, where alternatives such as electrification are not as attractive for de-carbonization. While NG is an attractive alternative fuel, it is nonetheless plagued by significant methane emissions, which can account for a significant increase in greenhouse gas emissions. In the case of spark ignited engines, NG requires high ignition energies, particularly for lean operation, resulting in limited spark plug life. For heavy duty applications, compression ignition NG fuelling strategies are preferred due to their higher efficiencies and improved ignition robustness, relative to spark ignited approaches.

In this work, two NG compression ignition fuelling approaches are considered. In both approaches, the combustion of a second fuel, such as conventional diesel, is used for the ignition of the NG. In "dual-fuel" strategies, a premixed air-NG mixture is compressed and ignited near top dead center by the combustion of a small, direct-injected diesel "pilot". Depending on the relative quantities of air, premixed NG, and direct-injected diesel, as well as the diesel pilot injection pressure, the fuel conversion efficiency and emissions can vary significantly. High Pressure Direct Injection (HPDI) of NG provides an alternative dual fuel strategy with the potential for significantly lower methane emissions and higher efficiency. During HPDI operation, NG is injected directly into the combustion chamber when the piston is near top dead center. Similar to premixed dual fuel combustion, a small diesel pilot combustion event is used to ignite the NG, resulting in a mixing controlled combustion process. Due to the non-premixed nature of HPDI combustion, higher compression ratios and fuel conversion efficiencies are possible, as are lower methane emissions.

A convertible thermodynamic (*i.e.*, metal) and optical single cylinder engine is used here to characterize the combustion and emissions performance of premixed dual fuel and HPDI combustion strategies. Of particular interest is the effect of fuelling parameters on the combustion mode, which was observed to include (partially) premixed flame propagation, multipoint autoignition, and/or mixing controlled combustion, depending on the fuelling approach. For premixed dual-fuel combustion, regimes of flame-propagation and non-flame-propagation were identified on the basis of heat release rate characteristics and high-speed OH* chemiluminescence imaging. The fuelling conditions resulting in these combustion modes are identified using an equivalence ratio - diesel substitution rate map. In addition, the sensitivity of the reaction zone evolution (ignition, propagation, and growth) to the pilot injection pressure is demonstrated through the use of OH* chemiluminescence and visible luminosity imaging.

A preliminary characterization of HPDI combustion was also carried out to identify the influences of injection parameters (injection pressure, relative NG and diesel injection timings) on the combustion process. Due to the large size and high-pressure fuel supply requirements of the HPDI injector, a new cylinder head was developed to accommodate the HPDI injector, and additionally included accesses for in-cylinder diagnostics. Here, this access was used for pyrometric and infrared absorption probes to characterize the local in-cylinder particulate matter concentration and temperature, and methane concentration, respectively. Through this preliminary characterization, high-speed OH* and natural luminosity imaging were used to provide the first in-cylinder optical characterization of HPDI NG combustion.

Plenary Lecture: Thursday May 18, 2017

The detonation paradox: the influence of diffusive processes in controlling the burning rate in detonations

Matei Ioan Petru Radulescu
Department of Mechanical Engineering, University of Ottawa

Traditionally, detonation waves have been assumed as being governed by the reactive inviscid Euler equations. Transport phenomena, which govern the propagation of low-speed reactive waves (flames) are neglected. In recent years, with the growth in the numerical resources available, Euler simulations have been possible with high resolution. These results have demonstrated a fundamental paradox when compared to experiments. While experiments have demonstrated that more unstable detonations can be initiated easier and are more difficult to fail, the predictions based on the Euler equations have shown clearly the opposite trend. The paradox is not unlike the well-known d'Alembert paradox in fluid mechanics, whereby inviscid potential flow fails to capture the experimentally observed drag forces on an object.

My talk will highlight the physics of unstable turbulent detonation waves for which diffusive phenomena (amplified by turbulence) control the burning rate of gases inside the reaction zone structure of detonations. Due to the inherent cellular instability of detonations, the stronger shocks provide auto-ignition events, while the weaker shocks give rise to unburned pockets. These are surrounded by reactive gas in what resembles a distributed regime of turbulent combustion. These pockets burn out by surface turbulent flames.

I review detailed experiments of the detonation structure, which reveal the main mechanisms promoting turbulent mixing: Kelvin-Helmholtz on shear layers, Richtmyer-Meshkov from shock-flame interactions and internal strong jet formation associated with shock reflections.

The paradox identified points to the necessity of modeling not only the detonation instability, which provides the driving mechanism of turbulence, but also the dissipation of turbulence, which controls the reaction rate of approximately half the gas processed by the detonation front.

Given the unique character of detonation waves, which require a proper description of turbulent flame propagation by transport, auto-ignition phenomena and gas dynamics, typical tools used in LES of turbulent combustion (*e.g.*, flamelet or thickened flame approaches) are not possible. I highlight our recently demonstrated computational methodology for detonations based on the Linear Eddy Model for turbulent combustion and its extensions to compressible flow in the context of Large Eddy Simulations.