25th International Colloquium on the Dynamics of Explosions and Reactive Systems

Sunday 2nd - Friday 7th August 2015
Leeds UK

Technical Program

Program Committee chairs:
M. I. Radulescu (Chair), A. Kasimov, A. Matsuo & A. Sanchez

Message from the Program Committee

We invited submissions in the main areas of interest to this colloquium, namely the dynamics of deflagration and detonation waves. Five speakers were invited to deliver plenary lectures on each morning of the colloquium:

Paul Clavin, Nonlinear dynamics of shock waves and cellular detonations in gases,
Vladimir Fortov, High explosives for extreme states of matter generation,
Andrew Higgins, Approaching detonation dynamics as an ensemble of interacting waves,
Richard Saurel, Modelling shocks and detonations in heterogeneous high explosives, and,
Richard Yetter, Nanoenergetics and combustion.

Special sessions with invited speakers and topical reviews were organized, as follows:

Sergey Frolov & Jiro Kasahara, Detonation applications in propulsion,
Benjamin Akih-Kumgeh & Eric Petersen, Progress and outstanding challenges in shock tube ignition,
Aslan Kasimov, Simplified models and analogs of detonation, and,
Alexei Poludnenko, Thermonuclear deflagrations and detonations, and astrophysical explosive phenomena.

Close to the colloquium, we learned with great sadness the passing of Professor Norbert Peters, who intended to participate in the colloquium. A memorial session was organized in his honor, chaired by Professor Derek Bradley, with tributes given by Professors Heinz Pitsch, Forman Williams and Amable Liñán.

Of the submitted contributions, 211 were selected for oral presentation and 63 for poster presentation, while 2 submissions were rejected. All extended abstracts submitted were peer-reviewed. Further 43 abstracts were accepted for presentation as Work-in-Progress posters. The Program Committee wishes to thank the reviewers and authors for their contributions to the program and the paper selection process.

The extended abstracts of papers presented at the colloquium are published on the web and in electronic format as the Proceedings of the 25th ICDERS, 2015.

Authors of papers presented at this meeting are encouraged to submit full-length versions to one of these journals: *Combustion Science and Technology*, *Combustion Theory and Modeling*, and *Shock Waves*. Submitted manuscripts will be peer reviewed according to individual journal standards but will be identified as ICDERS work individually or as part of a special issue.

Matei I. Radulescu
Chair of the Program Committee, 25th ICDERS

Program Committee:
M. I. Radulescu (Chair), A. Kasimov (Co-Chair), A. Matsuo (Co-Chair), A. Sanchez (Co-Chair), B. Akih Kumgeh, N. Chaumeix, A. Chinnayya, S. Frolov, S. I. Jackson, J. Kasahara, E. Petersen and A. Poludnenko

Monday 3 August 2015 - AM

8:30	**Welcome**			
8:50	**Plenary Lecture** ***Paul Clavin*** Non linear theory for the dynamics of shock fronts and cellular detonations in gases *F. Williams* (Chair) Room M1			
	Room M1	Room E1	Room C1	Room EG
	DDT 1 *G. Ciccarelli & S. Dorofeev*	**Rapid compression machines** *R. Hanson & Y. Mahmoudi*	**Flames: electro-magnetic effects 1** *V. Kourdyumov & J. Yanez*	**Diffusion flames 1** *D. Dunn-Rankin & U. Maas*
10:00	Engine hot spots: decay, deflagration, auto-ignitive propagation, or detonation? (184) *L. Bates, D. Bradley, G. Paczko, N. Peters*	A RCM study on DME-methane-mixtures under stoichiometric to fuel-rich conditions (226) *M. Werler, R. Schießl, U. Maas*	Experimental study on free jet flow with applied electric fields (88) *K. GyeongTaek, W. Lee, J. Park, O. Kwon, S. Keel, J. Yun, M. Kim, S. Lee*	A study on self-excitations in laminar lifted coflow-jet flames (44) *K. Van, W. Lee, J. Park, J. Yun, S. Keel, I. Lim, M. Kim, S. Lee*
10:25	On Chapman-Jouguet deflagrations (266) *M. Radulescu, W. Wang, M. Saif Al Islam, L. Maley, M. Levin, A. Pekalski*	Mild ignition phenomena in rapid compression machines (50) *K. Grogan, S.S. Goldsborough, M. Ihme*	A study of flame enhancement by microwave induced plasma: the role of dilution inert (145) *H. Li, P. Huang, Y.-C. Chao*	On blow-out of jet spray diffusion flames (67) *B. Greenberg, N. Weinberg*
10:50	Investigation of quasi-detonation propagation using simultaneous soot foil and schlieren photography (279) *M. Kellenberger, G. Ciccarelli*	Interpretation of auto-ignition delay times measured in different rapid compression machines (194) *D. Bradley, M. Lawes, M. Materego*	Experimental study on spreading flame over inclined electrical wire with AC electric fields (33) *S. Lim, M. Kim, J. Park, O. Fujita, S. Chung*	Experimental study on micro diffusion flame of liquid fuels from a micro tube (100) *J. Li, Z. Qiu, R. Yao, N. Wang*
11:15	Break			
	DDT 2 *G. Ciccarelli & S. Dorofeev*	**Ignition modeling** *D. Bradley & F. Marra*	**Flames: electro-magnetic effects** *V. Kourdyumov & J. Yanez*	**Diffusion flames 2** *U. Maas*
11:45	Experimental study of 2D-instabilities of hydrogen flames in flat layer (313) *M. Kuznetsov, J. Grune, S. Tengah, J. Yanez*	Effects of mixture distribution on localised forced ignition of stratified mixtures: A Numerical Investigation (65) *D. Patel, N. Chakraborty*	Non-premixed impinging flames and CO release under the influence of an electric field (149) *Y. Chien, D. Escofet-Martin, D. Dunn-Rankin*	Effects of oxy-enriched oxidizer and nitrous oxide addition on characteristics of laminar methane jet diffusion flame (138) *H. Lin, G. Chen, T. Cheng, Y. Li, Y.-C. Chao*
12:10	Deflagration-to-detonation transition in narrow channels: Hydraulic resistance vs. flame folding (1) *L. Kagan, G. Sivashinsky*	Non-equilibrium reaction rates in hydrogen combustion (244) *S. Voelkel, V. Raman, P. Varghese*	The effect of pulse electric discharge on the stabilization of turbulent lifted jet flames (227) *C. Tzu-Wei, T. Cheng, Y. Chao, G. Chen*	Global linear instability analysis of diffusion-flame flickering (218) *D. Moreno-Boza, W. Coenen, A. Sevilla, J. Carpio Huertas, A. Liñan, A. Sanchez*
12:35	Large eddy simulation of flame acceleration and transition from deflagration to detonation (174) *C. Wang, Y. Zhao*	Simplifying ignition delay prediction of chemical kinetic models by means of ignition correlations (248) *A. Zhou, T. Dong, B. Akih Kumgeh*	Magnetic effects on flickering laminar methane/air diffusion flames (215) *P. Gillon, W. Badat, V. Gilard & B. Sarh*	Flame propagation in the stratified mixing layer between CH_4 and CO_2/O_2 stream (58) *C. Wu, K. Chen, W. Yu*
13:00	Lunch			

Monday 3 August 2015 - PM

	Room M1	Room E1	Room C1	Room EG
	DDT 3 *M. Kuznetsov & E. Oran*	**Flame dynamics 1** *S. Navarro-Martinez & A. Sanchez*	**Detonations in propulsion 1** *S. Frolov and J. Kasahara*	**Reaction dynamics 1** *F. Williams*
14:20	Numerical simulation of flame acceleration and fast deflagrations using artificial thickening flame approach (217) *S. Emami, K. Mazaheri, A. Shamooni, Y. Mahmoudi*	Acceleration and extinction of flames in channels with cold walls (222) *C. Dion, B. Demirgok, V. Akkerman, D. Valiev, V. Bychkov*	**Invited Review**: Present status of pulse and rotating detonation engine research (304) *J. Kasahara, S. Frolov*	On the combustion characteristics of a novel biofuel: heat of combustion and vaporization rate (108) *M. Birouk, I. Chowdhury, L. David, M. Sailer, J. Sorensen*
14:45	Visualization of deflagration-to-detonation transitions in a channel with repeated obstacles (176) *S. Maeda, S. Minami, D. Okamoto, T. Obara*	Flame propagation in narrow channels at varying Lewis number (258) *J. Wongwiwat, J. Gross, P. D. Ronney*	Design and testing of a rotating detonation engine for open-loop gas turbine integration (19) *A. Naples, M. Fotia, T. Scott, J. Hoke, F. Schauer*	The effects of carbon dioxide in oxy-fuel atmosphere on catalyst reaction in a small-scale channel (163) *Y. Li, G. Chen, Y.-C. Chao*
15:10	Shock wave - boundary layer interaction driven auto-ignition and DDT (289) *E. Dzieminska, J. Misawa, A. Hayashi*	The effect of mixture fraction on edge flame propagation speed (268) *P. Wang, H. Song, R. Boles, H. Prahanphap, J. Piotrowicz, W. Li, P.D. Ronney*	Analysis of experimental research of continuous detonation of fuel-air mixtures (26) *F. Bykovskii, S. Zhdan*	A comprehensive and compact mechanism for the oxidation of methyl-decanoate (101) *X. Wang, L. Seidel, T. Zeuch, F. Mauss*
15:35	Break			
	DDT 4 *M. Kuznetsov & E. Oran*	**Shock tube ignition 1** *B. Akih-Kumgeh & E. Petersen*	**Detonations in propulsion 2** *S. Frolov & J. Kasahara*	**Fires** *S. Dorofeev and J. Wen*
16:05	Front tracking of DDT from ultra-high speed video films (192) *D. Bjerketvedt,A. Gaathaug, K. Vaagsaether, G.O. Thomas*	**Invited Review**: Advances in shock tube techniques for fundamental studies of combustion kinetics (260) *R. Hanson, D. Davidson*	3D numerical simulation on rotating detonation engine: effects of converging-diverging-nozzle on thrust performance (132) *S. Eto, N. Tsuboi, Y. Watanabe, T. Kojima, A. Hayashi*	Interaction between cross-wind and aviation-fuel fire engulfing an aircraft – numerical study (51) *H. Wang, G. Wang*
16:30	X-ray radiographic studies of the deflagration to detonation transition in porous beds of explosives (116) *L. Smilowitz, B. Henson, M. Holmes, L. Vaughan, G. Parker*	Development of hot spots and ignition behind reflected shocks in $2H_2+O_2$ (20) *A. Khokhlov*	Numerical investigations of tail Laval nozzle effects on rotating detonation engines (49) *D. Wu, R. Zhou, S.-J. Zhang, J.-P. Wang*	Dynamic behavior and structure of wind-blown flames (144) *M. Gollner, W. Tang, D. Gorham, M. Finney, S. McAllister, J. Cohen, J. Forthofer*
16:55	Application of high-speed OH-PLIF to DDT experiments (159) *L. Boeck, T. Fiala, J. Hasslberger, T. Sattelmayer*	Ignition delay-time study of fuel-rich CH_4/air and CH_4/additive/air mixtures over a wide temperature range at high pressure (191) *J. Herzler, M. Fikri, O. Welz, C. Schulz*	Numerical investigation on the airbreathing continuous rotating detonation engine (157) *S. Liu, W. Liu, L. Jiang, Z. Lin*	Modeling optical emissions from HE fireballs (122) *D. Grote, A. Kuhl, J. Bell, V. Beckner*
17:20	**Adjourn**			

Monday 3 August 2015 - All day

Posters 1

Chair: N. Chaumeix

PI-1	The combustion process of ADN-based liquid propellant in attitude control engine (2) *L. Jing, J. Huo, X. You, M. Zhu, Yao*
PI-2	Minimum ignition temperature of hybrid mixtures of burnable dusts and gases (3) *A. Emmanuel, D. Gabel, U. Krause*
PI-3	Simulation of suspended mixed RDX and Al dust in one dimension with the CESE method (5) *W. Zan, T. Hong, H. Dong*
PI-4	Superadiabatic temperatures in processes of homogeneous combustion of gases (12) *V. Babkin*
PI-5	Reactive flow modeling of density effect on diverging JB-9014 detonation impelling (8) *X. Yu*
PI-6	The influence of magnetic field on RM instability of circular heavy gas eruption (11) *Z. Lin, Z. Chen*
PI-7	Experiments and mechanisms of gas explosion suppression with foam ceramics (18) *B. Nie, L. Yang*
PI-8	Explosion behavior of methane - dimethyl ether /air mixtures (21) *B. Zhang, H. Ng*
PI-9	Numerical simulation of detonations in suspensions of RDX particles (25) *H. Dong, T. Hong, X. Zhang*
PI-10	Numerical simulation for the thermal response of the PBX-2 explosive with confinement on fire (27) *X. Zhang, T. Hong, H. Dong, J. Lou, J. Li*
PI-11	Dynamics of secondary breakup of emulsified fuel drop (32) *O. Girin*
PI-12	Energies of prechamber initiation of detonation in propane-butane-oxygen and acetylene-oxygen mixtures (39) *V. Golub*
PI-13	The effect of oxygen concentration on the burning characteristics of kerosene droplets using spark ignition (40) *S. Yang, M. Wu*
PI-14	Flame disturbance growth induced by a radial flow (42) *T. Tsuruda*
PI-15	Towards second-order algorithm for the pulsating detonation wave modeling in the shock-attached frame (46) *A. Lopato, P. Utkin*
PI-16	Al/CuO nanothermite shell assembled via depositing aluminum nanoparticles onto CuO nanowire array on a copper wire (59) *M. Wu, Y. Chiang*
PI-17	Some aspects of rotated detonation waves (61) *A. Vasil'ev*
PI-18	Influence of a dispersed ignition in the explosion of two-phase mixtures (70) *J. Pascaud*
PI-19	Modes of chocked flame instability and transition to detonation defined by the peculiarities of combustion kinetics at rising pressure (71) *A. Kiverin, I. Yakovenko*
PI-20	Development of the constant volume spray combustion chamber for ignition quality testing of Diesel-like fuel (72) *C. Wu, K. Chen, T. Hsu*
PI-21	A re-evaluation of lamppost deflection data in the Buncefield Explosion (265) *R. Rogers, J. Venart*

Tuesday 4 August 2015 - AM

8:30	**Plenary Lecture** ***Vladimir Fortov*** Extreme states of matter and rarefaction, generated by explosive driven shock waves *A. Kasimov* (Chair) Room M1			
	Room M1	Room E1	Room C1	Room EG
	Astrophysical and terrestrial combustion 1 *A. Poludnenko & V. Gamezo*	**Detonation dynamics 1** *A. Matsuo & H.D. Ng*	**Detonations in propulsion 3** *T. Endo*	**Flame acoustic interactions 1** *F. Mauss & K. Vågsæther*
9:40	**Invited Review**: Astrophysical combustion: from a laboratory flame to a thermonuclear supernova (276) *A. Poludnenko*	Research on detonation propagation in a 90-degree bifurcated tube (204) *L. Li, C. Teo, J. Li, P. Chang, V. Nguyen, B. Khoo*	Development of a liquid-purge method for valvelss pulse detonation combustor using liquid fuel and oxidizer (81) *K. Matsuoka, K. Muto, J. Kasahara, H. Watanabe, A. Matsuo, T. Endo*	Direct and indirect combustion noise in an idealised combustor (114) *Y. Mahmoudi, A. Dowling, S. Stow*
10:05	Understanding ignition in Type Ia Supernovae (Invited) (103) *M. Zingale, A. Jacobs, A. Almgren, J. Bell, A. Nonaka, C. Malone, S. Woosley*	Modeling of Rayleigh scattering imaging of detonation waves (288) *G. Bechon, R. Mevel, D. Davidenko, J. Shepherd*	Heating and acceleration of particles by high-frequency pulsed detonations (165) *T. Endo, R. Obayashi, T. Tajiri, K. Kimura, Y. Morohashi, T. Johzaki, K. Matsuoka*	Finite amplitude disturbance interaction with premixed laminar flames (57) *M. Aslani, J. Regele*
10:30	Shock and adiabatic compression ignitions of inhomogeneous gas and two-phase flows (Invited) (197) *O. Penyazkov*	Experimental measurement of cell size at high pressure (14) C. Stevens, J. Hoke, F. Schauer	Gas dynamics in the inlets of a valveless micro pulse detonation engine (292) *Z. Chen, M. Wu*	Methane/hydrogen/air flame oscillations in open ended tubes (99) *C. Ebieto, N. Amaludin, R. Woolley*
10:55	Break			
	Astrophysical and terrestrial combustion 2 *F. Williams & A. Poludnenko*	**Detonation dynamics 2** *A. Matsuo & H.D. Ng*	**Detonations in propulsion 4** *T. Endo*	**Flame acoustic interactions 2** *F. Mauss & K. Vågsæther*
11:25	Turbulent combustion in astrophysical systems (Invited) (24) *F. Roepke*	Ethylene-air detonation in water spray (300) *G. Jarsale, F. Virot, A. Chinnayya*	Experimental testing of a rotating detonation engine coupled to nozzles at conditions approaching flight (15) *M. Fotia, F. Schauer, J. Hoke*	Effects of variation of the flame area and natural damping on primary acoustic instability of downward propagating flames in a tube (153) *S.H. Yoon, O. Fujita*
11:50	Expanding statistically spherical premixed turbulent flames and astrophysical combustion (Invited) (170) *A. Lipatnikov*	Influence of mechano-activation on detonation parameters of perchlorate based mixtures (53) *A. Dolgoborodov, V. Kirilenko, A. Shevchenko, M. Brazhnikov, V. Teselkin*	Influence of gradual expanding channel cutoff on propagation of the toroidal detonation wave (69) *M. Wakita, T. Himono, K. Kikuchi, S. Kameyama, T. Totani, H. Nagata*	Effects of gas compressibility on the dynamics of premixed flames in long narrow channels (36) *V. Kurdyumov, M. Matalon*
12:15	Rayleigh-Taylor Unstable Flames: Speed and Structure (224) *E. Hicks*	Impact of nitromethane addition on the detonation properties of n-Heptane / oxygen mixtures (311) *N. Chaumeix, B. Imbert, S. Abid, L. Catoire, C. Paillard*	Modeling of non-stationary gas flow in annular nozzle (22) *V.A.Levin, N.E.Afonina, V.G.Gromov, I.S.Manuylovich, G.D.Smekhov, A.N.Khmelevsky, V.V.Markov*	Interaction between thermoacoustic oscillation and vortical motions in turbulent swirling premixed flame (206) *K. Aoki, M. Shimura, Y. Naka, M. Tanahashi*
12:40	Lunch			

Tuesday 4 August 2015 - PM

	Room M1	Room E1	Room C1	Room EG
	Astrophysical and terrestrial combustion 3 *E. Oran & A. Poludnenko*	**Explosions 1** *A. Kuhl & M. Lawes*	**Detonations in propulsion 5** *N. Tsuboi & J. Wang*	**Flame dynamics 2** *P. Clavin*
14:00	Mechanisms of DDT in terrestrial systems (invited) (301) *V. Gamezo, A. Poludnenko*	Observation of flame propagation and knock in a constant volume vessel (291) *Y. Nagano, T. Kitagawa*	Towards exhaust gas emissions from rotating detonation engines (75) *K. Kailasanath, D. Schwer*	Towards identifying flame patterns in multiple injection schemes on a single cylinder optical diesel engine (315) *C. Hong, D. Touloupis, C. Keramiotis, G. Ramaswamy, N. Soulopoulos, G. Vourliotakis, M. Founti, Y. Hardalupas, A. Taylor*
14:25	Distributed burning in chemical and themonuclear flames (invited) (310) *A. Aspden*	Suppression of a propane-air explosion using a powdered suppressant (229) *J. Chao*	Visualization study on the flowfield of rotating detonation (152) *W. Lin, J. Zhou, S. Liu, Z. Lin*	Flame extinction in buoyancy suppressed methane-air non-premixed counter triple co-flow burner (78) *J. Park, J. Park, O. Kwon, J. Yun, S. Keel*
14:50	*Discussions*	Turbulent explosions in H_2 enriched CO and CH_4 mixtures (232) *T. Li, F. Hampp, P. Lindstedt*	Propagation characteristics of continuous rotating detonation wave under different temperature air (154) *C. Wang, W. Liu, S. Liu, L. Jiang, Z. Lin*	Reduced order modeling of self-igniting reaction-diffusion system based on POD technique and k-means clustering (213) *K. Bizon, S. Lombardi, G. Continillo*
15:15	Break			
	Astrophysical and terrestrial combustion 4 *V. Gamezo & M. Radulescu*	**Explosions 2** *A. Kuhl & M. Lawes*	**Detonations in propulsion 6** *N. Tsuboi & J. Wang*	**Combustion dynamics 1** *G. Continillo & J. Yoh*
15:45	Incomplete detonation in Type Ia supernovae (invited) (297) *A. Khokhlov, I. Dominguez*	Flame propagation of pulverised biomass crop residues and their explosion characteristics (66) *M. Saeed, G. Andrews, H. Phylaktou, D. Slatter, H. Medina, B. Gibbs*	Numerical study of propulsive performance of different injection patterns in rotating detonation engine (73) *S. Yao, Y. Liu, J. Wang*	Nonlinear two-time-scale perturbation theory for transverse combustion dynamics (48) *W. Sirignano*
16:10	Reaction rate closure for turbulent detonation propagation through CLEM-LES (225) *B. Maxwell, S. Falle, G. Sharpe, M. Radulescu*	The suppression effect of ultra-fine water mist on methane/air explosion in the closed Vessel (97) *J. Ren, P. Zhang, Y. Zhou, M. Bi*	OH* chemiluminescence images of detonations propagating through the annular channel of a nonpremixed rotating detonation engine (17) *B. Rankin, D. Richardson, A. Caswell, A. Naples, J. Hoke, F. Schauer*	REDIM based reduced modeling of transient premixed combustion regimes (236) *A. Neagos, V. Bykov, U. Maas*
16:35	**Adjourn**			

Tuesday 4 August 2015 - All day
Work-in-Progress posters 1
Chair: A. Kasimov

WIP-1.	Combustion modeling using EUROPLEXUS code (317) *A. Velikorodny*
WIP-2.	Experimental investigation of detonation behaviors in a non-uniform composition (318) *S. Boulal, P. Vidal, R. Zitoun*
WIP-3.	Gas generators are based on carbonaceous materials (362) *A. Atamanov, S. Tursyn, M. Tulepov, D. Baiseitov, P. Gulnar, Y. Kazakov, Z. Mansurov*
WIP-4.	Small-scale experiments in focusing of shock waves using timing delays and shadowgraphs (270) *E. Morris, A. Farmer*
WIP-5.	Blow-out stability of gaseous non-premixed jet flames (316) *A. Palacios*
WIP-6.	A unified model to evaluate the effect of strain rate on extinction of premixed and diffusion flames (319) *A. Snegirev*
WIP-7.	The dynamic behavior of cellular premixed flames generated by hydrodynamic and diffusive-thermal instabilities under the low temperature conditions (320) *S. Kadowaki, T. Washio, T. Katsumi, W. Yamazaki*
WIP-8.	Investigation of low voltage spark ignition in explosion protection applications (321) *R. Shekhar, C. Uber, U. Gerlach*
WIP-9.	Quenching and recovering of a lean premixed disk shaped flame by a pulsating nitrogen diluted fuel jet (322) *N. Kotake, Y. Fujikawa, Y. Yahagi, I. Makino*
WIP-10.	Turbulent flame speed of spherical flame in a fan-stirred closed vessel (323) *J. Goulier, N. Chaumeix*
WIP-11.	Experimental determination of critical conditions for hydrogen-air detonation propagation in partially confined geometry (324) *W. Rudy, K. Dziubanii, M. Zbikowski, A. Teodorczyk*
WIP-12.	Detonation development induced by fuel concentration non-uniformity (327) *C. Qi, Z. Chen*
WIP-13.	Detonation combustion of anthracite particles in an air flow (328) *F. Bykovskii, S. Zhdan, E. Vedernikov, Y. Zholobov*
WIP-14.	Chemiluminescence Spectroscopy to Explore the Flame Temperature (329) *Y. Kawasoe, H. Hashimoto, O. Moriue, E. Murase, J. Furukawa*
WIP-15.	Jet fire computational fluid dynamics simulations: validation from an industrial & consultancy perspective (330) *S. Malkeson, T. Jones, R. English*
WIP-16.	The "GraVent DDT database" (331) *L. Boeck, P. Katzy, J. Hasslberger, A. Kink, T. Sattelmayer*
WIP-17.	The dynamic of detonation failure in different geometries, and the extension of the critical diameter criterion (332) *R. Sorin, O. Bozier, N. Desbiens, V. Dubois*
WIP-18.	Energies of prechamber initiation of detonation in propane-butane-oxygen and acetylene-oxygen mixtures (333) *V. Golub, G. Bivol, S. Golovastov*
WIP-19.	Reaction-diffusion and G-equation approaches reconciled for turbulent premixed combustion modelling (334) *G. Pagnini, R. Akkermans, A. Mentrelli, N. Buchmann*
WIP-20.	Linear stability analysis of detonation models by direct numerical computations (337) *D. Kabanov, A. Kasimov*
WIP-21.	The critical transition length from Chapman-Jouguet deflagrations to detonations (338) *M. Saif Al Islam, M. Radulescu, M. Levin, A. Pekalski*
WIP-22.	Oxygen Fuel MILD Combustion by Reactant Injection Conditions (339) *P. Lee, C. Cha, H. Lee, S. Hwang*

Wednesday 5 August 2015 - AM

8:30	**Plenary Lecture** ***A. J. Higgins*** Approaching detonation dynamics as an ensemble of interacting waves *M. Short* (Chair) Room M1			
	Room M1	Room E1	Room C1	Room EG
	Detonations with losses *J. Bdzil & L. Bauwens*	**Explosions 3** *J. Chao & N. Chaumeix*	**Reactive systems 1** *F. Marra & S. Shy*	**Combustion dynamics 2** *G. Continillo & J. Yoh*
9:40	High explosive detonation propagation in slab and rate-stick geometries near the Chapman-Jouguet velocity (128) *M. Short, S. Jackson, C. Chiquete*	Numerical investigation of constant volume propane-air explosions in a 3.6-metre flame acceleration tube (251) *T. Skjold, H. Hisken*	Fuel reforming using counter-current heat-recirculating (141) *S. Trivedi, S. Koli, A. Lawson, C. Chen, H. Pearlman, P. Ronney*	Discrete model of filtrational gas combustion (86) *F. Sirotkin, R. Fursenko, S. Minaev*
10:05	Numerical simulations of mildly unstable gaseous detonations in small channels (245) *A. Sow, A. Chinnayya, A. Hadjadj*	Numerical investigation and comparison of hydrogen/air and propane/air explosion by hot jets (306) *A. Ghorbani, S. Fischer, G. Steinhilber, D. Markus, U. Maas*	A study of methane hydrate combustion phenomenon using a novel porous cylindrical burner (135) *F. Wu, G. Chen, Y. Li, Y. Chao*	DMD analysis of experimental PIV data of a swirled jet (208) *S. Lombardi, K. Bizon, A. Coghe, F. Cozzi, G. Continillo*
10:30	Velocity deficits in thin channels for a cylindrically expanding detonation (223) *H. Ng, J. Wang, J. Lee*	Experimental investigation on micro- and nano-PMMA dust explosion venting (181) *W. Gao, J. Li, X. Zhang, X. Yan, W. Ji, J. Yu*	Gas turbine burner reactor network construction and application (160) *T. Nilsson, C. Perlman, H. Lehtiniemi, D. Lörstad, S. Möller, F. Mauss*	Methane combustion dynamics in a diabatic PSR with global, reduced and detailed reaction mechanisms (295) *L. Acampora, F. Marra, E. Martelli*
10:55	Break			
	Detonations with losses 2 *J. Bdzil & L. Bauwens*	**Explosions 4** *J. Chao & N. Chaumeix*	**Reactive systems 2** *F. Marra & S. Shy*	**Spray combustion** *W. Sirignano & T. Skjold*
11:25	Dynamics of detonations with constant mass divergence (257) *B. Borzou, T. Phenix, B. Maxwell, M. Radulescu*	Determination of flammability limits of diluted H2/CO/CH4/air mixtures in spherical bomb (237) *R. Grosseuvres, A. Comandini, J. Biet, M. Idir, A. Bentaïb, N. Chaumeix*	Swirl motion effects on flame dynamic of pulverized olive cake in vertical furnace (302) *A. Elorf, N. Mradkoched, S. Bostyn, B. Sarh, I. Gökalp, B. Izrar, J. Chaoufi*	Thermodynamic analysis for combustion at high gas densities (146) *A. Jorda Juanos, W. Sirignano*
11:50	The effect of radius of curvature on the detonation propagating to the unconfied space (179) *T. Hayashi, A. Matsuo, J. Kasahara*	Large eddy simulations of syngas and biogas explosions accounting for high temperature and pressure effects (299) *V. Rao, J. Wen*	Numerical study of a laser-induced ethane pyrolysis in a wall-less reactor using a reduced kinetic scheme (303) *J. Yang, O. Matar, O. Stadnichenko, V. Snytnikov*	Numerical and theoretical investigation of the scalar dissipation rate in laminar counterflowing spray flames (94) *H. Olguin, E. Gutheil*
12:15	Detonation mode and frequency variation under high loss conditions (134) *S. Jackson, B. Lee, J. Shepherd*	Detonation hazard classification based on the critical orifice plate diameter for detonation propagation (241) *M. Cross, G. Ciccarelli, P. Thibault*	Sooting behavior of ethane in a micro flow reactor with a controlled temperature profile (284) *A. Dubey, T. Tezuka, S. Hasegawa, H. Nakamura, K. Maruta*	Statistical analysis of the reaction progress variable and mixture fraction gradients in flames propagating into droplet mist: A DNS analysis (54) *D. Wacks, N. Chakraborty, E. Mastorakos*
12:40	**Norbert Peters, 1942-2015** Speakers: ***H. Pitsch, F. Williams & A. Liñán*** *D. Bradley* (Chair) Room M1			
13:10	Lunch			

Wednesday 5 August 2015
Posters 2
Chair: A. Matsuo

PI-22.	The effect of side relief on detonation propagation in a rotating detonation engine (85) *R. Fievisohn, K. Yu*
PI-23.	Kinetic analysis of the mechanisms of ignition and combustion of blended fuels comprising hydrocarbons and hydrogen (98) *N. Titova, S. Torokhov, I. Chechet, O. Favorskii, A. Starik*
PI-24.	Two-line OH PLIF temperature measurements of flames near a quenching plate (104) *D. Escofet-Martin, Y. Chien, D. Dunn-Rankin*
PI-25.	Methane hydrate combustion (105) *J. Santacana Vall, D. Dunn-Rankin*
PI-26.	The time of effective energy input for direct detonation initiation in spark discharge (115) *K. Korytchenko, L. Zavada, D. Kudin, S. Rodionov*
PI-27.	Numerical investigation of shock wave – dense particles cloud interaction (118) *P. Utkin*
PI-28.	Ignition transient of supercritical oxygen/kerosene combustion system (119) *D. Kim, K. Lee, J. Koo*
PI-29.	A study on N_2O formation/destruction behavior in sewage sludge combustor (127) *A. Nakamura, S. Kinoshita, T. Denda, T. Iwasaki, K. Ishii*
PI-30.	Numerical simulations of the diameter effect for nitromethane using ignition and growth model (133) *Y. Sugiyama, K. Wakabayashi, T. Matsumura, Y. Nakayama*
PI-31.	Numerical study on direct initiation of cylindrical detonation in H_2/O_2 mixture: influence of higher-order scheme (136) *T. Niibo, Y. Morii, N. Tsuboi, M. Asahara, A. Hayashi*
PI-32.	Explosion damage in the unit 4 reactor building of Fukushima Daiichi nuclear power plant (162) *T. Tsuruda*
PI-33.	Influence of the temperature of a heterogeneous mixture on the DDT in a small-size pulsed detonation combustor (164) *K. Alhussan, M. Assad, O. Penyazkov*
PI-34.	Detonations in capillary tubes with nitrous oxide as an oxidizer (168) *T. Meye, E. Brandes, U. Krause*
PI-35.	Turbulent premixed hydrogen flames at high Karlovitz number: A DNS study (172) *Y. Chen, K. Luo*
PI-36.	Two-dimensional simulation on detonation wave supported by the cylindrical inner wall injecting premixed gas (178) *J. Fujii, A. Matsuo, J. Kasahara*
PI-37.	Study of the morphological properties of ammonium nitrate and decomposition with dextran (182) *Z. Mansurov*
PI-38.	Numerical investigation of hydrogen-air mixtures ignition near lean flammability limit (185) *A. Smygalina, M. Ivanov*
PI-39.	Flame spread along a paper disk in a narrow channel (193) *T. Daitoku, T. Takahashi, T. Tsuruda*
PI-40.	Numerical simulations of ignition and combustion of RDX mixed with gaseous additives (195) *M. Mar, P. Gillard, L. Courty*
PI-41.	Ignition delay times of primary reference fuels (196) *M. Fikri*
PI-42.	Numerical Simulations of CNG, LPG & H_2 lean premixed deflagrating flames (198) *M. Abdel-Raheem, S. Ibrahim, W. Malalasekera, M. Bragin*

Thurday 6 August 2015 - AM

8:30	**Plenary Lecture** ***Richard Saurel*** Modelling shocks and detonations in heterogeneous high explosives *J. Boris* (Chair) Room M1			
	Room M1	Room E1	Room C1	Room EG
	Gasdynamics of explosions 1 *A. Chinnayya*	**Detonation dynamics 3** *O. Penyazkov*	**Ignition 1** *Y.-C. Chao & V. Golub*	**Flame instabilities 1** *J. Regele & A. Sanchez*
9:40	Theory of weak-shocks interactions with transonic mixing layers (264) *C. Huete, A. Sanchez, F. Williams, J. Urzay*	The Possibility of Detonation Stabilization in a Supersonic Flow of a Combustible Gas Mixture without Any Expenditure of Energy (41) *V. Levin, T. Zhuravskaya, I.S. Manuylovich*	Effects of natural convection on thermal explosions in spherical vessels (263) *I. Iglesias, A. Sanchez, F. Williams, A. Liñán*	Diffusive-thermal instabilities of high Lewis number flames in micro flow reactor (47) *T. Miroshnichenko, V. Gubernov, S. Minaev, K. Maruta*
10:05	Viscous solutions of the triple shock reflection problem (238) *S. Lau-Chapdelaine, G. Sharpe, M. Radulescu*	A hydrodynamic simulation on reactive shock attenuation in the large-scale gap test of heavily aluminized RDX (129) *B. Kim, M. Kim, J. Yoh*	Effect of Equivalence Ratio on Ignition and Flame Propagation of n-Hexane-Air Mixtures using Moving Hot Particles (281) *S. Coronel, J. Shepherd*	Diffusive-thermal instability of low-Lewis-number premixed flames in stretched flow of two slot burners (35) *R. Fursenko, S. Mokrin, S. Minaev, K. Maruta*
10:30	Mach reflection during the oblique interaction of a condensed-phase explosive detonation reaction zone with a rigid wedge (125) *J. Bdzil, M. Short, J. Quirk*	Behavior of Methane/Oxygen Gas Detonation near Propagating Limit in Small Diameter Tube:Effect of Tube Diameter (139) *K. Yoshida, K. Hayashi, Y. Morii, K. Murakami, A. Susa, N. Tsuboi, A. Hayashi*	Hot surface ignition and flow separation (267) *J. Melguizo Gavilanes, J. Shepherd*	Numerical study of interaction between Darrieus-Landau instability and spatially periodic shear flow (247) *D. Valiev, A. Gruber, C. Law, J. Chen*
10:55	Break			
	Detonation analogs 1 *A. Kasimov & A.J. Higgins*	**Detonation initiation and failure** *S. Jackson & J. Melguizo Gavilanes*	**Ignition 2** *Y.-C. Chao & V. Golub*	**Flame instabilities 2** *J. Regele & A. Sanchez*
11:25	**Invited Review**: Detonation analogs revisited (312) *A. Kasimov*	Study of small scale experiments of detonations in an aqueous foam confinement (77) *F. Ballanger, D. Counilh, N. Rambert, A. Lefrançois, J. Haas, A. Chinnayya*	Laser-induced ignition of methane and biogas near the lean flammability limit (254) *N. Peters, H. Morrow, B. Akih Kumgeh*	An analysis of flame instabilities based on Sivashinky equation (261) *J. Yanez, M. Kuznetsov*
11:50	Detonation wave driven by energy of carbon condensation (38) *A. Eremin*	Higher order DSD calibration of ammonium nitrate/fuel oil (123) *C. Chiquete, M. Short, S. Jackson, J. Bdzil*	Comparison of the formation of ignition sources due to continuous and repetitive metallic friction (180) *L. Meyer, M. Beyer, U. Krause*	Formation and evolution of distorted tulip flames (64) *H. Xiao, R. Houim, E. Oran, J. Sun*
12:15	Modelling microbial chemo-tactic waves using adaptive mesh refinement (52) *S. Falle*	Method of characteristic analysis of gaseous detonations bounded by an inert gas (200) *R. Fievisohn, K. Yu*	Chemical kinetics of ignition of n-Hexane by a moving hot sphere (290) *R. Mevel, J. Melguizo Gavilanes, S. Coronel, J. Shepherd*	Critical Peclet numbers for the onset of Darrieus-Landau instability in atmospheric-pressure methane-air flames (231) *C. Bauwens, J. Bergthorson, S. Dorofeev*
12:40	Lunch			

Thursday 6 August 2015 - PM

	Room M1	Room E1	Room C1	Room EG
	Detonation analogs 2 *A. Kasimov & A. Higgins*	**Gasdynamics of explosions 2** *C. Chiquete & K. Kailasanath*	**Ignition 3** *R. Mevel & R. Yetter*	**Turbulent flames 1** *B. Maxwell & V. Gamezo*
14:00	Magnetic detonation in cystals of nanomagnets (126) *M. Modestov, V. Bychkov, O. Yukhymenko, M. Marklund*	Investigation of the pressure wave and hot gas kernel induced by low energy electrical discharges (167) *S. Essmann, D. Markus, U. Maas*	Ignition delay and flame radius for single particle combustion in high-temperature flammable gas/air mixtures (256) *C. Cloney, R.C. Ripley, M.J. Pegg, P.R. Amyotte*	Turbulent diffusion of combustion gaseous admixtures (79) *T. Elperin, N. Kleeorin, M. Liberman, I. Rogachevskii*
14:25	Analog system of detonations with losses and pressure-dependent reaction rate (117) *X. Mi, Y. Sun, J. Zhang, P. Hu, C. Wang*	An immersed boundary method to simulate compressible reactive flows featuring shock-wave interactions with three-dimensional solid obstacles (214) *R. Boukharfane, B. Bouvelle, Z. Bouali, A. Mura*	Reaction front propagation initiated by a hot spot in premixed n-heptane/air mixture at low temperature (30) *P. Dai, Z. Chen*	A jet-stirred apparatus for turbulent combustion experiments(308) *A.A. Davani, P.D. Ronney*
14:50	Chaos in a third order nonlinear evolution equation for pulsating detonations using fickett's model (240) *A. Bellerive, M. Radulescu*	Long distance propagation of shock waves in the open atmosphere (234) *C. Proust, K. Vilalta*	Auto-ignition of premixed methane/air mixture in the presence of dust (60) *V. Leschevich, O. Penyazkov, S. Shimchenko*	Flame speeds and self-similar propagation of expanding premixed turbulent flames at high eynolds numbers (95) *S. Shy, L. Chen, H. Huang, W. Li*
15:15	Break			
	Detonation analogs 3 *A. Kasimov & A. Higgins*	**Detonation initiation** *A. Teodorczyk & N. Smirnov*	**Ignition 4** *R. Mevel & R. Yetter*	**Turbulent flames 2** *B. Maxwell & V. Gamezo*
15:45	Weakly nonlinear dissipative detonations (296) *L. Faria, A. Kasimov, R. Rosales*	Numerical simulation of direct detonation initiation in H_2/O_2/ar mixtures with detailed chemistry (45) *C. Qi, Z. Chen*	Numerical simulation of ignition in ABC – flow modeling 3D turbulence using a GPU-based approach (202) *E. Sereshchenko, R. Fursenko, S. Minaev, S. Shy*	Sensitivity of scaling exponents for turbulent burning velocity to evaluation method: a numerical study (91) *S. Verma, A. Lipatnikov*
16:10	Laser supported detonation in silica-based optical fibers (307) *V. Efremov, A. Frolov, V. Fortov*	Energy input into the spark at the direct detonation initiation (112) *K. Korytchenko, V. Golota, D. Kudin, A.V. Sakun*	Wall film evaporation causing pre-ignition in turbocharged gasoline engines (10) *N. Peters, G. Paczko, H. Pitsch*	Transported joint PDF simulation of a turbulent ethanol spray flame combined with a spray flamelet model (96) *Y. Hu, H. Olguin, E. Gutheil*
16:35	Spectral and nonlinear stability of viscous strong and weak detonation waves in Majda's qualitative model (283) *G. Lyng*	Detonation onset in acetylene – oxygen mixture (209) *N. Smirnov, V.F. Nikitin, Yu.G. Phylippov, J. Koo*	End-gas autoignition in premixed hydrogen/air mixture (23) *H. Yu, Z. Chen*	Simulation of turbulent lifted flames and their transient propagation (121) *S. Ruan, Z. Chen, N. Swaminathan*
17:00	A toy model for multi-dimensional cellular detonations (294) *L. Faria, A. Kasimov, R. Rosales*	On analogy of 2D and 3D combustible mixture flows (250) *V. Levin, I. Manuylovich, V.V. Markov*	Experimental and kinetic modeling of the oxidation of synthetic jet fuels and surrogates (62) *P. Dagaut, F. Karsenty, G. Dayma, Z. Serinyel*	Enhancing the stability limits of a low swirl nonpremixed turbulent lifted biogas flame (110) *M. Saediamiri, M. Birouk, J. Kozinski*
17:25	**Adjourn**			

Thursday 6 August 2015 - All day
Work-in-Progress posters 2
Chair: M. Radulescu

WIP-23.	Improvement of lean H_2 combustion CFD modeling for nuclear safety (340) *P. Katzy, L. Boeck, J. Hasslberger, T. Sattelmayer*
WIP-24.	The development of tubular platinum-emitter reactor for a small-scale thermophotovoltaic power system (341) *J. Hong*
WIP-25.	Experimental and numerical study of oxygen enrichment on methane diffusion flame in a triple port burner (342) *J. Wu*
WIP-26.	Influence of turbulent Markstein number on flame front structure and burning rate in premixed turbulent flames (343) *P. Tamadonfar, O. Gulder*
WIP-27.	Ignition of waste / biomass mixtures deposited as dust layers (344) *N. Fernandez-Anez, N. Dameto de Espana, J. Garcia Torrent, L. Medic Pejic*
WIP-28.	Revision of the detonation cell sizes from detailed chemical kinetic calculations prediction model (350) *A. Gavrikov, A. Efimenko*
WIP-29.	More on high pressure ignition kernel development and minimum ignition energy measurements in different regimes of premixed turbulent combustion (346) *W. Li, Y. Shiu, S. Shy*
WIP-30.	Flame development in pulverised biomass (351) *D. Slatter, M. Saeed, G. Andrews, H. Phylaktou, B. Gibbs*
WIP-31.	Influence of biomass pellet composition on the pulverised pellet flame propagation and minimum explosion concentration (353) *M. Saeed, G. Andrews, H. Phylaktou, B. Gibbs*
WIP-32.	Study on reflected shock bifurcation dynamics (354) *U. Niedzielska, R. Mevel, J. Shepherd, A. Teodorczyk*
WIP-33.	Dynamics of OH*, CH* and CO_2* chemiluminescence in methane and n-Hexane mixtures (355) *N. Urszula, R. Mevel, J. Shepherd, A. Teodorczyk*
WIP-34.	Molecular dynamics simulations of flame propagation of monopropellant PETN embedded with carbon nanotubes (356) *G. Mo, S. Jain, L. Qiao*
WIP-35.	A zone model for fast verification of release of ultrafine water mist for fire extinction in compartments (357) *F. Marra*
WIP-36.	Detonation propagation in the limit of discretized energy sources (360) *X. Mi, E. Timofeev, A. Higgins*
WIP-37.	Shock in reactive cross-flow under partial confinement (361) *J. Burr, K. Yu*
WIP-38.	Influence of a DC electric field on the stability of a diffusion flame (363) *W. Badat, P. Gillon, V. Gilard, B. Sarh*
WIP-39.	Combustion of olive residues in a fluidized bed: Optimization of biomass moisture and operating conditions (364) *B. Sarh, T. Boushaki, M. Asbik, E. Abdallah, S. Bostyn, I. Gökalp*
WIP-40.	Ignition transient of supercritical oxygen/kerosene combustion system (366) *D. Kim, K. Lee, J. Koo*
WIP-41.	WSD EOS calibration procedure (369) *L. Darrell, T. Aslam, M. Short*
WIP-42.	Modling cookoff of a melt-castable explosive in several geometries (370) *M. Hobbs, M. Kaneshige, M. Anderson*
WIP-43.	Response of premixed laminar flames to equivalence ratio and pressure oscillations using detailed chemistry (TARDIS) (372) *N. Malik*

Friday 7 August 2015 - AM

8:30	**Plenary Lecture** ***Richard Yetter*** Nano-energetics and combustion *A.J. Higgins* (Chair) Room M1			
	Room M1	Room E1	Room C1	Room EG
	Detonation structure *L. Bauwens & M. Short*	**Shock tube ignition 2** *B. Akih Kumgeh & E. Petersen*	**Laminar flames 1** *P. Ronney*	**Dust combustion 1** *M. Liberman & F. Williams*
9:40	The influence of high-frequency instabilities on the direct initiation of two-dimensional gaseous detonations (56) *H. Ng, C. Kiyanda, G. Morgan, N. Nikiforakis*	Shock tube measurements of species time-histories during jet fuel pyrolysis and oxidation (262) *Y. Zhu, S. Wang, D. Davidson, R. Hanson*	Studying the effect of H_2, O_2 and CO_2/N_2 Addition on the laminar flame speed of CH_4/LPG-air mixtures (7) *A. Ibrahim, S. Ahmed*	Effect of radiation on the propagation of planar coal dust flames in air (84) *R. Houim, E. Oran*
10:05	A unifying thermodynamic model for the rate of energy release in the reaction zone of solid secondary explosives (107) *B. Henson, L. Smilowitz*	Investigation of ignition behavior of dimethyl and ethyl isomers of cycloalkanes and furans (269) *M. Eldeeb, B. Akih Kumgeh*	Premixed flame propagation between two closely spaced parallel plates (166) *D. Fernandez-Galisteo, J. Gross, V. Kurdyumov, P. Ronney*	Comparison of combustion characteristics of magnesium and aluminum powders (137) *R. Lomba, S. Bernard, F. Halter, C. Chauveau, P. Gillard, C. Mounaim-Rousselle, T. Tahtouh, O. Guezet*
10:30	Acoustic timescale characterization of unreacted pockets in unstable detonation waves (31) *J. Regele*	Nitromethane ignition behind reflected shock waves (55) *O. Mathieu, B. Giri, J. Mertens, E. Petersen*	Laminar flame speeds of pentanol isomers : an experimental and modeling study (221) *D. Nativel, M. Barone, F. Gourmel, M. Idir, N. Chaumeix*	On conditions for self-sustained combustion of pulverised coal particle-laden mixtures following localised forced ignition: A Direct Numerical Simulation (190) *T. Brosh, F. Marincola, D. Patel, D. Wacks, N. Chakraborty*
10:55	Break			
	DDT 5 *D. Bjerketvedt & L. Boeck*	**Shock tube ignition 3** *B. Akih Kumgeh & E. Petersen*	**Laminar flames 2** *P. Ronney*	**Dust combustion 2** *M. Liberman & F. Williams*
11:25	Effects of boundary layer on flame propagation generated by forced ignition behind an incident shock wave in DDT process (275) *S. Ishihara, S. Tamura, K. Ishii, H. Kataoka*	Experimental and numerical study of 1-Pentanol pyrolysis in a shock tube at high pressure and high temperature (63) *D. Nativel, R. Grosseuvres, A. Comandini, S. Abid, N. Chaumeix*	Burning velocities of CH_4/air/water-mist premixed flames near the extinction limit (158) *Y. Ogami, M. Ito, T. Daitoku, T. Tsuruda*	Neutralization of airborne contaminants (371) *J. Boris, G. Patnaik*
11:50	Influence of water mist on flame acceleration, transition to detonation and detonation propagation in H_2-air mixtures (161) *L. Boeck, A. Kink, D. Oezdin, J. Hasslberger, T. Sattelmayer*	Shock-tube study of the addition effect of CF_2BrCl on the ignition of light hydrocarbons (43) *O. Mathieu, C. Gregoire, E. Petersen*	Laminar burning speeds of alpha-pinene/benzene/air mixtures involved in the combustion in forest fires (171) *B. Coudour, K. Chetchouna, F. Halter, C. Mounaim-Rousselle, J.-P. Garo*	Influence of radiative preheating on flame propagation in gaseous mixtures seeded with inert particles (82) *M. Liberman, M. Ivanov, A. Kiverin*
12:15	Influence of blockage ratio on the DDT and detonation propagation limits for an orifice plate filled tube (243) *M. Cross, G. Ciccarelli*	Shock tube and modeling study of chemical ionization in the oxidation of acetylene and methane mixtures (37) *G. Agafonov, D. Mikhailov, V. Smirnov, A. Tereza, P. Vlasov, I. Zhil'tsova*	Experimental and modeling investigation of laminar flame speeds of styrene (106) *A. Comandini, N. Chaumeix*	Simultaneous mist and flame propagation characterisation studies in a fully-confined bomb (242) *D. Pugh, P.J. Bowen, A.P. Crayford, D. De la Rosa, L. Bernard*
12:40	Lunch			

Friday 7 August 2015 - PM				
	Room M1	Room E1	Room C1	Room EG
	DDT 6 *A. Gaathaug & L. Boeck*	**Turbulent flames 3** *A. Lipatnikov & D. Valiev*	**Ignition 5** *I.-S. Jeung & K. Ishii*	**Dust combustion 3** *R. Houim & S. Jackson*
14:00	Numerical simulation on mechanism of flame acceleration and deflagration to detonation transition for ethylene-oxygen system (189) *W. Han, C. Wang, C. K. Law*	Modelling of progress variable variance transport in head on quenching of turbulent premixed flames: a direct numerical simulation analysis (92) *J. Lai, N. Chakraborty*	Ignition delay and MIE measurement for n-decane/air mixture induced by laser-spark (187) *N. Mokrani, S. Rudz, P. Gillard*	Experimental investigation of the mechanisms of cellular instabilities developing on two-phase flames (235) *R. Thimothée, C. Chauveau, F. Halter, I. Gökalp*
14:25	Large Eddy Simulation of deflagration to detonation transition using artificial thickening (169) *S. Yu, S. Navarro-Martinez*	Structures of turbulent bunsen flames in the corrugated-flamelet regime (29) *J. Furukawa, Y. Yoshida, F.A. Williams*	Initiation of detonation in iso-octane/air mixture under high pressure and temperature condition in closed cylinder (90) *Z. Wang, X. He, H. Liu, Y. Qi, P. Zhang, J. Wang*	An attempt to observe the discrete flame propagation regime in aluminum dust clouds (228) *A. Wright, S. Goroshin, A. Higgins*
14:50	Transition to detonation in non-uniform H_2-air: chemical kinetics of shock-induced strong ignition (156) *L. Boeck, J. Hasslberger, T. Sattelmayer*	Numerical investigation of turbulent lean premixed hydrogen-carbon monoxide combustion at elevated pressures (80) *R. Dinesh, H. Shalaby, K.H. Luo, D. Thevenin*	Experimental investigation of co-flow effect on ignition process of a methane jet diffusion flame (147) *Q. Wang, J. Yang, Y. Wang, Y. Zhang, C. Zhao*	Combustion time and ignition temperature of iron particles in different oxidizing environments (259) *A. Wright, S. Goroshin, A. Higgins*
15:15	Break			
	Reaction dynamics 2 *P. Dagaut & P. Varghese*	**Turbulent flames 4** *A. Lipatnikov & D. Valiev*	**Shock ignition** *S. Coronel & I.-S. Jeung*	**Heterogeous combustion** *S.Minaev & K. Maruta*
15:45	An approximate method for solving the problem of the establishment of chemical equilibrium in the products of explosion of gas mixture (177) *V. Shargatov, S. Gubin, A. Krivosheev*	Premixed flame propagation in high-intensity turbulence: investigating the role of detailed chemistry (28) *G. Nivarti, S. Cant*	Numerical study of shock-induced combustion in a hypersonic non-uniformly premixed hydrogen/air flow (13) *K. Iwata, S. Nakaya, M. Tsue*	On numerical model of two-dimensional heterogeneous combustion in porous media (68) *N. Lutsenko*
16:10	Elevated pressure and temperature effect to laminar flame speed of acetone/air mixture (201) *Y. Wu, V. Modica, F. Grisch*	Relevance of basic turbulent premixed combustion models for accurate simulations of v-shaped flames (211) *K. Kha, C. Locier, V. Robin, A. Mura, M. Champion*	Explosion-induced ignition and combustion of acetylene clouds (120) *A. Kuhl, H. Reichenbach, J. Bell, V. Beckner*	Effect of the initial diameter on the vaporization rate of fuel droplet in turbulent atmosphere: experimental data (111) *M. Birouk, P. Toews, I. Chowdhury*
16:35	A novel application of an isoconversional method for thermal decomposition kinetics of heavily aluminized RDX (130) *Y. Kim, J. Yoh, J. Park*	Influence of heat release in a premixed flame on weakly turbulent flow of unburned gas: a DNS study (74) *A. Lipatnikov, J. Chomiak, V. Sabelnikov, S. Nishiki, T. Hasegawa*	Self-ignition of high-pressure hydrogen released by reproducible rupture of diaphragm (155) *W. Kaneko, K. Hayashi, K. Ishii*	Asymptotic analysis of quasi-steady heptane droplet combustion supported by cool-flame chemistry (175) *K. Seshadri, N. Peters, F. Williams, V. Nayagam*
17:00	Continuation analysis of complex chemical mechanisms for jet-fuels combustion in PSR (298) *L. Acampora, E. Mancusi, F. Marra*	Blow-off characteristics of turbulent premixed flames in curved-wall jet burner (89) *M. Mansour, O. Mannaa, S. Chung*	Effects of opening conditions on the self-ignition of high pressurized hydrogen released through a tube (314) *H. Lee, S. Lee, J. Park, I. Jeung*	Effects of droplet size on hypergolic combustion of hydrazine spray (293) *H. Tani, H. Terashima, R. Kurose, A. Kitano, M. Koshi, Y. Daimon*
17:25	**Farewell**			

Friday 7 August 2015 - All day
Posters 3
Chair: A. Sanchez

PI-43.	A novel flame chemiluminescence measurement using a digital colour camera (199) *J. Yang, Z. Ma, Y. Zhang*
PI-44.	Modeling and numerical simulation of layered coal-dust explosions behind a propagating shock wave (203) *T. Kanno, A. Matsuo*
PI-45.	Burning velocity blending laws for methane/air and hydrogen/air blends (212) *T. Al-Mughanam, D. Bradley, M. Lawes, R. Mumby*
PI-46.	Criterions for the stability of flame propagation and deflagration detonation transition of carbon monoxide-oxygen mixture (216) *Y. Sun, C. Wang*
PI-47.	Modeling study of pulsed and continuous detonation in propane/air mixture (220) *V. Kopchenov, D. Babushenko, P. Kuleshov, N. Titova, A. Starik*
PI-48.	Shock in reactive cross-flow under partial confinement (230) *J. Burr, K. Yu*
PI-49.	Multi-dimensional transport: dns analysis and incorporation into the reaction-diffusion manifold (REDIM) method (233) *R. Schießl, V. Bykov, U. Maas*
PI-50.	Thermal radiation contribution to metal dust explosions (239) *R. Ben Moussa, C. Proust, M. Guessasma, K. Saleh, J. Fortin*
PI-51.	Two-dimensional numerical simulations of cellular detonation diffraction in channels (246) *J. Li, H.D. Ng, N. Jianguo, J.H.S. Lee*
PI-52.	Numerical simulation of multidimensional modes of gaseous detonation (249) *V.A. Levin, I.S. Manuylovich, V.V. Markov*
PI-53.	2D and 3D detonation in layered reacting mixtures (252) *V.A. Levin, I.S. Manuylovich, V.V. Markov*
PI-54.	Detached eddy simulation of high turbulent swirling reacting flow in a premixed model burner (253) *Z. Mansouri, M. Aouissi, E. Abdallah, T. Boushaki*
PI-55.	O-Revealer: Novel technology for demining of histosols by the controlled use of smouldering combustion (255) *G. Rein, X. Huang, F. Restuccia, T. McArdle, P. Idoux*
PI-56.	Development of file format and database infrastructure for high explosive reference data (83) *C. Kiyanda, M. Boyce, H.D. Ng*
PI-57.	Three-dimensional cellular structure and propagation process of spherical detonation (273) *R. Iida, M. Asahara, A. Hayashi, N. Tsuboi*
PI-58.	Thrust performance evaluation of a rotating detonation engine with a conical plug (274) *K. Ishihara, Y. Kato, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki*
PI-59.	Study on intensity of blast wave generated from vessel bursting by gas explosion (277) *T. Matsunaga, T. Mogi, R. Dobashi*
PI-60.	The application of Krylov implicit integration factor method in numerical simulation of deflagration to detonation (287) *C. Wang, Y. Bi, J. Ding*
PI-61.	Experimental and numerical study of oxygen enrichment on methane diffusion flame in a triple port burner (285) *Y. Li, C. Wu*
PI-62.	Flame propagation of highly reactive combustible mixtures in closed pipe with L/D of 51 (305) *S. Sulaiman, R. MdKasmani, A. Mustafa, M. Hassim, R. Rasit Ali, N. Ibrahim, K. Kidam*
PI-63.	Investigation on shock wave focusing in 2-stage PDE (309) *Z. Hao*

8:50 – Plenary lecture 1

Non linear theory for the dynamics of shock fronts and cellular detonations in gases, *P. Clavin* The multidimensional dynamics of shock waves and gaseous detonations are discussed on the basis of analytical studies by comparison with experiments and numerical simulations. The basic mechanism of cellular detonations is the coupling between the longitudinal oscillatory behaviour of the exothermal reaction zone (galloping detonation) and the transverse propagation of disturbances along the lead shock. Analytical studies of both mechanisms will be revisited separately in two limiting cases. Strong shock waves and strongly overdriven regimes in the Newtonian approximation will be considered as well as Chapman-Jouguet regimes with small heat release (reactive transonic flow). Recent experiments and DNS will be reported showing that the fish-skeleton, left by the markings of cellular detonations on the wall, can be reproduced by inert shock fronts that are initially wrinkled in a smooth sinusoidal form. A nonlinear study of the dynamics of such inert shock fronts will be presented showing the spontaneous formation of triple points (Mach stems) that propagate in the transverse direction. The coupling of this phenomenon with heat release then deciphers the pattern structure of cellular detonations. The above-mentioned theoretical results concerning inert shock fronts lead also to simple models for shock-vortex and shock-turbulence interaction. Some recent results will be presented and compared with DNS. The topology of the patterns on the shock front propagating in a turbulent flow is then compared to the structure of the turbulence. It will be shown that the characteristic cell size is much larger than the integral scale and has a tendency to increase with time. An analogy with the formation of large structures in the Universe will be given.

10:00 - Deflagration to detonation transition 1

184- **Engine hot spots: decay, deflagration, auto-ignitive propagation, or detonation?** *L. Bates, D. Bradley, G. Paczko, N. Peters* DNS studies of autoignition at reactive hot spots indicate how an auto-ignition velocity can arise. The rate of change of the heat release rate determines the associated amplitude of the generated pressure pulse and if the auto-ignition velocity is high enough to be close to the acoustic speed, this pulse can be coupled with the heat release in a detonation wave. The DNS studies indicate a peninsula could be constructed, within which detonations could develop. The boundaries were defined by dimensionless groups involving the ratio of acoustic to autoignitive velocity, and the number of heat release rate excitation times occurring during acoustic wave transit through the hot spot. This approach is employed to study benign auto-ignition, knock and super-knock in gasoline engines. Super-knock arises from pre-ignition at hot spots, followed by flame propagation which increases the pressure and thereby the temperature in the unburned part of the combustion chamber, such that a secondary hot spot may subsequently occur, which may lead to a detonation. The paper focuses on the secondary hot spots and the parameter range within which a detonation can develop.

266- **On Chapman-Jouguet deflagrations,** *M.I. Radulescu, W. Wang, M. Saif Al Islam, L. Maley, M. Levin, A. Pekalski* While the Chapman-Jouguet (CJ) criterion for predicting the detonation speed is well established, the same criterion also predicts CJ deflagrations. From purely thermodynamic and gasdynamic considerations, one can also define a CJ deflagration speed, with a corresponding limiting characteristic. The speed of deflagration waves observed in practice, however, is significantly lower than this value, and is dictated by the rate at which heat and species diffuse across the reaction front. In the presence of turbulence, however, the flame speed may be significantly enhanced. We isolate experimentally such CJ deflagrations following the interaction methane-oxygen detonation interaction with a column of cylinders. A self-similar multiple discontinuity model similar to previously proposed models by Chao and Chue et al. with an embedded CJ deflagration is formulated, and the results are found in excellent agreement with the experiments. Detailed flow visualization of the dynamics of these high-speed deflagrations illustrate that they undergo a continuous amplification process. The front organizes into fewer modes and culminates with one of them being sufficiently strong to trigger a detonation.

279- **Investigation of quasi-detonation propagation using simultaneous soot foil and Schlieren photography**, *M. Kellenberger, G. Ciccarelli* Using a method of simultaneous high-speed Schlieren photograph and soot foil, supersonic combustion waves in the quasi-detonation regime were investigated. Experiments were performed in a 2.54 cm wide by 7.62 cm tall channel with equally spaced 1.91 cm tall fence-type obstacles mounted on the top and bottom surfaces. Stoichiometric mixtures of hydrogen-oxygen were ignited by an automotive spark plug at initial pressures of 9-30 kPa. A single-pass Schlieren system was used to take both side-view and top-view videos of the combustion wave propagating down the channel. For side-view tests a thin sheet of glass was used as a soot foil and placed inside the optical section of the channel to obtain a physical record of the quasi-detonation propagation. A very fine cell, associated with the hotspot originating at the reflection of obstacle face, indicates an overdriven detonation. A retonation wave propagates upstream and is bound by the arrival of the flame. Top view tests indicate that a detonation may form along a line at the center of the channel or at a point at the location of a hot spot along the wall. Streaks on the soot foil were observed due to large carbon particles from the sooting process, but did not appear in the path of a detonation wave. Intense light is generated by the passage of the flame across a soot-covered surface. The heated soot particles radiate light in the visible spectrum.

10:00 Rapid compression machines

226- **A RCM study on DME-methane-mixtures under stoichiometric to fuel-rich conditions,** *M. Werler, R. Schießl, U. Maas* In this study auto-ignition in DME-air-mixtures and the influence of DME on the auto-ignition of methane-air mixtures is investigated in a rapid compression machine (RCM). The results are compared to two reaction mechanisms for DME-air-mixtures, developed by LLNL and by Zhao et al. An existing study by Tang et al., who investigated a wide range of mixture compositions at stoichiometric conditions and high temperatures is extended with this study to lower temperatures and fuel-rich mixtures. Furthermore, the investigation of this study is complementary to the recently published RCM study on DME-methane-mixtures from Burke et al. The presented study deals with lower additivation of DME to methane, namely mixtures with 5%, 10% and 20% DME in methane as well as with pure DME-air-mixtures. Equivalence ratios of 1 and 2 were investigated at a pressure of 10 and 20 bar and in a temperature range from 600-1000 K. The ignition delay times for the DME-air-mixtures simulated with the two reaction mechanisms match the experiments well. Although the mechanisms were originally designed for pure DME only, they are applied also to mixtures of DME and methane. For the overall ignition delay times, both mechanisms match the experimental results reasonably well; the Zhao mechanism matches better at lower DME-additivation levels, while the LLNL mechanism matches better at higher additivation. For the first stage ignition, both mechanisms overpredict the ignition delay times compared to the measurements for lower additivation. In addition to the ignition

delay time measurements, the post-ignition exhaust gas composition was analyzed using a micro gas-chromatograph. For stoichiometric mixtures, an almost complete conversion to CO_2/H_2O takes place. In the exhaust gas of the mixtures with an equivalence ratio of 2, a considerable amounts of syngas is observed, showing potential of the RCM as a means of studying processes relevant for co-generation devices.

50- M**ild ignition phenomena in rapid compression machine**, *K. Grogan, S.S. Goldsborough, M. Ihme* A rapid compression machine is an experimental apparatus used to study ignition chemistry at conditions that are relevant to internal combustion engines and gas turbines. However, due to the operating characteristics of these devices, mild ignition events can be encountered, which can obfuscate the interpretation of reaction kinetics measurements. Hence, this paper develops demarcations for mild ignition phenomena to indicate ignition regimes. These demarcations employ familiar Damkohler number and Reynolds number scaling and are compared to experimental data. Favorable agreement between the demarcations and experimental data was found.

194- I**nterpretation of auto-ignition delay times measured in different rapid compression machine**, *D. Bradley, M. Lawes, M. Materego* An international collaboration was initiated by thirteen different research groups to understand and explain the differences in auto-ignition delay times, measured on different rapid compression machines, RCMs, of different design and size. The Consortium measured delay times for iso-octane under the same conditions: fixed oxygen content of 21%, pressure at the end of compression, Po= 2.0 MPa, and compression temperatures, To, in the range 650-950K. The experimental auto-ignition delay times measured from seven different RCMs show significant scatter particularly at the intermediate and low temperatures. Reasons for these differences include (i) heat loss after compression, (ii) reaction during non-instantaneous compression (iii) possible piston bounce and non-uniform ignition, among others. The diversity of the different RCMs was advantageously utilised to increase our understanding of the departures of the RCMs from their ideal performance. Livengood-Wu integrals were computed to show the effects of reaction during the compression, the time for which varied with the machines. The experimental delay times from different RCMs were plotted for different temperatures against the Livengood Wu integral. Extrapolation of the delay times to the zero Livengood-Wu integral condition gave corrected values of the delay time. In addition, the temporal mean temperature and pressure were corrected to allow for the effect of heat loss during the delay time. At the higher temperatures, stronger auto-ignition occurs at reactive hotspots, reducing the overall Livengood-Wu integral. Considerations of these factors have made it possible to derive values of auto-ignition delay times that are probably more accurate.

10:00 Flames: electro-magnetic effects 1

88- **Experimental study on free jet flow with applied electric fields**, *K. GyeongTaek, W. Lee, J. Park, O. Kwon, S. Keel, J. Yun, M. Kim, S. Lee* The characteristics of gaseous laminar free-jet flow with having applied electric fields have been investigated experimentally. A single electrode configuration was adopted such that electric fields were applied directly to the nozzle and thus the surroundings could be an infinite ground. Applying DC electric fields does not modify the jet flow so much. At a certain axial distance, the laminar fuel stem was broken down and subsequently it was separated into three parts when AC electric fields with frequencies less than 120 Hz were applied. Over 120 Hz related to a collision response time, the jet flow did not respond to applied electric fields. The breakdown point was identified by varying applied AC voltage and frequency. The jet width increased and then decreased with applied frequency after showing a maximum around 43 Hz. The breakdown height decreased with voltage at a fixed frequency. Such effects of applying electric fields to laminar free jet flow were discussed in detail.

145- **A study of flame enhancement by microwave induced plasma: the role of dilution inert**, *H. Li, P. Huang, Y.-C. Chao* In this research, a novel centralized microwave jet burner system is proposed that can be used as a test platform to enable direct studies of PAC under various operation conditions and combustible mixtures. Spectroscopic characterizations of the burner have been conducted using digital imaging and optical emission spectrum. PAC of premixed methane/O2/N2 and methane/O_2/Ar mixtures have been investigated at different fuel equivalence ratios and various microwave power. The continuous microwave plasma jets are generated successfully by the design of centralized microwave burner with a sharp-tip electrode as an antenna. The optical emission spectrum results show that with the initiation of a plasma flame by microwave, emission intensity peaks of the OH radicals can be observed both in the methane/O_2/N_2 and methane/O_2/Ar mixtures. A comparison of the OH emission intensity profile shows that the intensity of OH radical in methane/O_2/Ar mixtures is three orders of magnitude larger than that in methane/O_2/N_2 mixture. Namely, the flame enhancement by applying an non-equilibrium plasma is more efficient when the dilution inert N_2 in the oxidizer stream (air) is replaced by Ar. The coupling efficiency of the dilution inert in the oxidizer stream plays an important role in the flame enhancement mechanism for the PAC system.

33- **Experimental study on spreading flame over inclined electrical wire with AC electric fields**, *S. Lim, M. Kim, J. Park, O. Fujita, S. Chung* An experimental study on downwardly and upwardly spreading flames over slanted electrical wire, which is insulated by Polyethylene(PE), was conducted with applied AC electric fields. Inclination angle of the electrical wire varied in range of ~90°;(Downwardly spreading flame) ~70°;(Upwardly spreading flame). The result showed that downwardly and upwardly spreading flames with angle of inclination leaned toward burnt side and unburned side, respectively. With applied AC electric fields, size of downwardly spreading flame decreased slightly and that of upwardly spreading flame increased significantly. Flame spread rate of downwardly spreading flame decreased from 0 to -20°, and then became nearly constant with inclination angle up -90°. In increase of applied voltage and frequency, downwardly spreading flame decreased. In case of upwardly spreading flame, the spread rate showed various trends with applied electric fields. With inclination angle, that increased significantly. Such variation of flame-spread rate could be explained by thermal balance mechanism.

10:00 Diffusion flames 1

44- **A study on self-excitations in laminar lifted coflow-jet flames,** *K. Van, W. Lee, J. Park, J. Yun, S. Keel, I. Lim, M. Kim, S. Lee* The comprehensive study have been widely studied about Laminar non-premixed lifted free and coflow-jet flames, because the fundamental characteristics are useful in extended laminar stretched flamelet modeling and also in designing industrial burners. Laminar lifted flame in free- and coflow-jet configurations propagates along a stoichiometric contour due to the intrinsic nature of tribrachial structure such that the edge flame displacement velocity is the balance of the vectorial sum of the edge flame velocity and the local flow velocity. However, such lifted flames are occasionally destabilized in the case of that the tribrachial flame velocity varies due to various factors such as Lewis number larger than unity, the repetitive interaction of burning rate and buoyancy-driven convection, buoyancy due to a flame flicker, and conductive heat loss from premixed wings to

trailing diffusion flame. Experimtental study on self-excitations in laminar coflow-jet flames diluted with nitrogen was conducted to research differences between Lewis-number-induced self-excitation and buoyancy-driven self-excitation. From former times research, our research group proved that Lewis-number-induced self-excitation coupled with buoyancy-induced self-excitation nearby lower fuel mole fraction than buoyancy-induced self-excitation regime (close to extinction limit) in 9.4mm nozzle diameter. In order to reduce buoyancy effect, 0.95mm nozzle diameter was used to deplete thermal accumulation of partially premixed mixture in front of edge flame and obtain higher exit nozzle velocity. The experimental result that Lewis-number-induced self-excitation and buoyancy-driven self-excitation were appeared largely divide two regime. The flame stability map was represented as a function of nozzle exit velocity and fuel mole fraction for propane in coflow diluted with Helium 10% and 20%. The results was shown that Lewis-number-induced self-excitation was existed in $0.28<X_{f,o}<0.35$, $U_o<40$. in this self-excitation, the edge flame move to upstream and downstream in flat flame before extinguished via blow-out. While buoyancy-driven self-excitation was shown in comparatively higher fuel mole fraction and exit nozzle velocity in $0.28<X_{f,o}<0.35$, $U_o<40$. Regime 1: Lewis-number-induced self excitation, Regime 2: Lewis-number-induced self-excitation coupled with bouyancy-driven self-excitation, Regime 3: buoyancy driven self-excitation. in case of dillution with He 20%, regime 1 and 3 were expanded to $0.28<X_{f,o}<0.35$, $U_o<40$ and $0.28<X_{f,o}<0.35$, $Uo < 40$ respectively. According to this outcome, our research group conducted that helium 25% was diluted in coflow. The results also show that same to former times research, Lewis-number-induced self-excitation coupled with buoyancy-induced self-excitation was represented in $0.28 <X_{f,o} < 0.35$, $U_o < 40$. To investigate the behavior of self excitation, Various flame dimensions of LCB at $0.28 < X_{f,o} < 0.35$, $U_o < 40$ and $V_{co} = 8$cm/s were showed by diagram. The phase of tip was unmatched to flame base, this means that coupled self-excitation behavior was different with other self-excitation.

67- On blow-out of jet spray diffusion flames, *B. Greenberg, N. Weinberg* A laminar jet spray diffusion flame is analysed mathematically for the first time using an extension of classical similarity solutions for gas flames. The analysis enables a comparison to be drawn between conditions for flame stability or flame blow out for purely gaseous flames and for spray flames. It is found that, in contrast to the Schmidt number criteria relevant to gas flames, spray related parameters also play a critical role in determining the potential flame scenarios.

100- Experimental study on micro diffusion flame of liquid fuels from a micro tube, *J. Li, Z. Qiu, R. Yao, N. Wang* In order to understand diffusion flame characteristics of liquid fuels in a micro-tube, four types of liquid fuels are chosen, i.e. isooctane, ethanol, n-heptane and kerosene. Experimental study was conducted in a micro-tube with inner diameter of 0.2mm. In the experiments, micro tubes made of quartz and stainless steel are used, and their effects on flame are obtained. Effects of fuel types and fuel flow rate on laminar flame are also investigated. It is found that high wall conductivity is advantageous for liquid fuel evaporation, and the micro-flame is longer in the stainless steel tube. Furthermore, fuel flow rates have great effects on flame length and wall temperature. With fuel flow rate increasing, the flame length first increases and then does not change. At a large flow rate, liquid fuel cannot be completely evaporated and small droplets are ejected with fuel vapour from the tube, resulting in a long plume flame. Due to the effects of buoyancy, flame length of the horizontal jet is much shorter than the length predicted by the empirical equation. Furthermore, fuel types have great effects on flame stability and flame length. Flammable limits of ethanol are much narrow due to a relative lower combustion heat. But kerosene flame is the brightest in four fuels due to high C/H.

11:45 Deflagration to detonation transition 2

313- Experimental study of 2D-instabilities of hydrogen flames in flat layer, *M. Kuznetsov, J. Grune, S. Tengah, J. Yanez* To date, very limited knowledge is available on how hydrogen behaves in two-dimensional planar geometry as much focus were given towards hydrogen flame behaviour in one dimensional tube and three dimensional spherical geometry. The focus of this work is to investigate how flame behaves in a planar 2D-geometry and particularly, how the intrinsic instabilities of hydrogen flame affects its propagation in such geometry. A series of experiments in 2D-geometry with hydrogen air and hydrogen oxygen mixtures were conducted in between two transparent glass plates at ambient conditions. Different configurations with respect to hydrogen concentration and layer thickness were implemented. Shadowgraph method, with the help of a high speed camera, was used to visualize the flame dynamics. Flame instabilities give rise to the development of a cellular structure on the surface of the flame. The cellular structure results in an increase of flame surface area and hence, promotes higher rate of fuel consumption. This results in flame acceleration (FA), which in turn could lead to the transition from deflagration to detonation (DDT). Formation of the cellular structure was analyzed and the stretched-free laminar burning velocity was determined. Thermo-diffusion and Landau Darrieus instabilities were leading to formation of double-modes cellular structure of the flame surface. A theoretical analysis using the Sivashinski-Michelson equation was performed in order to describe the experimental results and its dynamic development in terms of the basic physical properties of combustible mixtures. It was found the same the burning velocity amplification by the factor of Ξ = 1.2-1.5 due to the flame instability. The characteristic time of flame development with a cellular structure due to Landau-Darrieus instability was found to be much longer than the corresponding one for thermo-diffusion instability for lean mixtures. Also, we correlated the time required for instability development as a function of the mixture reactivity.

1- Deflagration-to-detonation transition in narrow channels: Hydraulic resistance vs. flame folding, *L. Kagan, G. Sivashinsky* This study is concerned with identification of the key interactions controlling deflagration-to-detonation transition (DDT) in narrow smooth-walled channels. Two agencies contributing to the transition are discussed: hydraulic resistance for very thin channels (thick flames) and flame folding for wider channels (moderately thick flames). The dual nature of the DDT mechanism is reflected in the non-monotinicity of the dependency of the run-up time/distance on the channel width.

174- Large eddy simulation of flame acceleration and transition from deflagration to detonation, *C. Wang, Y. Zhao* The 5-th order weighted essentially non-oscillatory (WENO) finite difference scheme is combined with a large eddy simulation (LES) methodology to simulate flame acceleration and transition from deflagration to detonation. The numerical simulations on flame acceleration and DDT of ethylene-air mixture in a tube with no-slip and adiabatic walls are performed at different tube widths and mesh sizes. In the microscale tube, since transverse mode is restrained in the tube with small width, single head detonation forms after DDT and the single triple point collides constantly with the top and bottom wall and renders the detonation self-sustained. The cellular structure of the detonation recorded takes on a very regular quasi-periodic cellular structure. However, in the wider tube multi-head detonation can be formed and the cell is with many modes interacting nonlinearly. It is interesting that the cell nearby the

wall is relatively irregular, while the cell in the middle is regular. This shows that the viscous effect in boundary layer has obviously influence on the track of triple point in the transverse scale, but this seldom can be observed in the case of neglecting the viscous from the wall.

11:45 Ignition modeling

65- **Effects of mixture distribution on localised forced ignition of stratified mixtures: a numerical investigation**, *D. Patel, N. Chakraborty* The influences of initial mixture distribution on localised forced ignition of globally fuel-lean (i.e. phi=0.8) and stoichiometric (phi=1.0) stratified mixtures are analysed using three-dimensional compressible Direct Numerical Simulations (DNS). The globally fuel-lean (phi=0.8) and stoichiometric mixtures for different root-mean-square (rms) values of equivalence ratio (phi=0.2, 0.4 and 0.6) and the Taylor micro-scale of phi variation (i.e. phi=2.1, 5.5 and 8.3 with being the Zel'dovich flame thickness of stoichiometric mixture have been analysed for different initial values of rms turbulent velocity u'. The equivalence ratio variation is initialised following both Gaussian and bi-modal distributions for prescribed values of phi' and phi in order to analyse the effects of initial mixture distribution. The localised forced ignition is accounted by a source term in the energy transport equation that deposits energy for a stipulated time interval. It has been demonstrated that the initial equivalence ratio distribution has significant effects on the extent of burning of stratified mixtures following successful localised forced ignition. It has been found that an increase in u'(phi') has adverse effects on the burned gas mass, whereas the effect of phi on the extent of burning are non-monotonic and dependent on phi' for the initial bi-modal mixture distribution. The initial Gaussian mixture distribution exhibits an increase in burned gas mass with decreasing phi but these cases are more prone to flame extinction for high values of u'(phi=1) than the corresponding bi-modal distribution cases. For a given value of phi, an increase in phi' leads to a reduction of burned gas mass for both Gaussian and bi-modal distributions. The increase in heat transfer rate from hot gas kernel with an increase in u'(phi=1) leads to a decrease in the extent of burning. The above findings demonstrate that favourable conditions in terms of initial distribution of phi, phi^, phi and u'(phi=1)} are required for self-sustained combustion following successful ignition of stratified mixtures. Detailed physical explanations have been provided for observed phi, mixture distribution, phi', u' and phi dependences of the burned gas mass in localised forced ignition of stratified mixtures.

244- **Non-equilibrium reaction rates in hydrogen combustion**, *S. Voelkel, V. Raman, P. Varghese* A non-equilibrium reaction rate model for hydrogen-air combustion that utilizes a vibrational temperature for each chemical species is presented. Developing this new model requires non-averaged, state-specific reaction rates, which are calculated using a quasi-classical trajectory (QCT) technique. Reaction rates attained by state-specific cross-sections of the chain branching reaction H+O2→O+OH are presented. The rates are compared to Park's two-temperature model, which shows that Park's model overestimates the effect of thermodynamic non-equilibrium or temperature below 5,000 K.

248- **Simplifying ignition delay prediction of chemical kinetic models by means of ignition correlations**, *A. Zhou, T. Dong, B. Akih Kumgeh* Sustained research activities in combustion chemistry have yielded multi-component chemical kinetic models for various combustion analysis. These models are often very large, with over a thousand chemical species and thousands of elementary chemical kinetic reactions. Although model reduction can be used to obtain smaller versions to lower the computational cost, the resulting skeletal schemes are still too large to permit direct implementation in some transport-dominated combustion analysis. For predictions of ignition delay times, it would be useful to develop analytic expressions, which summarize the performance of given detailed chemical kinetic models. In this work, an approach is demonstrated for ignition delay correlation developments from chemical kinetic models. Ignition delay times are simulated using literature models over a range of temperatures and pressures. The data set is used to develop ignition delay time correlations, which enable the prediction of simulated ignition delay times at a wide range of conditions. The correlation consists of three sub correlations covering the low-temperature, high-temperature, and Negative Temperature Coefficient (NTC) regions, with switch functions, which capture the pressure-temperature dependence of the boundaries of the NTC region. This approach can also be applied to experimental data, providing a means of rigorously constraining and comparing the performance of kinetic models with respect to experimental observations.

11:45 Flames: electro-magnetic effects 2

149- **Non-premixed impinging flames and CO release under the influence of an electric field,** *Y. Chien, D. Escofet-Martin, D. Dunn-Rankin* This research examines the use of electric fields as one mechanism for controlling combustion. In particular, it studies the use of the electrical properties of the flame to determine the combustion behavior and it then explores the use of the electric field driven ion wind to improve the burning in real time. The current work follows from a related study of carbon monoxide (CO) release from flames near a quenching surface by Weinberg, et al. [1]. That paper provided measurements of CO released from a small diffusion flame as a quenching surface was brought into its proximity. By relating surface proximity to CO release, the study showed that electrical detection of the flame-to-surface distance could be used to predict incipient quenching and CO release. The research focused on sensing and so mainly supplied the flame with low DC voltage from batteries (37 and 56 Volts) and probed with an electrode around a partially premixed flame to observe the first ion current appearance. This prior research revealed the possibility of using a low voltage source and different probe materials as a flame proximity sensor, and by inference then incipient CO release. The study also suggested another potential investigation active electric field control of CO release. Reference [1] also postulated that the source of CO release from impinging diffusion flames is the high concentration of partially oxidized fuel inside the flame envelope that avoids the final oxidation step. Hence, by exploiting the flame shaping capability of an ion-driven wind [2], it may be possible to control CO release from flames near a quenching surface. In particular for the current work, we measure CO emission changes when a quenching surface gradually moves close to a small diffusion flame. Then, by using strong electric fields as a mechanism for controlling combustion, we examine the changes in CO release. The research comprises primarily experimental measurements of flame shape, hydroxyl radical (OH) location, and global carbon monoxide emission Experimental measurement have already demonstrated that CO emission is changing under electric field influence [3], [4]. The present work helps elucidate some of the processes that might account for these CO emission results by including OH* chemiluminescence and OH planar laser induced fluorescence (PLIF) imaging [5] results, as OH is a key reactant for diffusion flames. The use of OH and OH* together has been described as marking the heat release zone and reaction zone in several publications (e.g., [6], [7]). These two pieces of information make OH PLIF and OH* chemiluminescence a complementary combination that can provide useful information regarding the physical extent and progress of combustion processes. The thermal and flow characteristics of

electrically actuated impinging flames are not easily assessed because any particles or probes strongly influence the electric field. The spatially resolved non-intrusive measurement of CO is also a challenge, as it requires multi-photon approaches [5], [8], or laser absorption by tunable diode laser [9] followed by tomographic reconstruction. Consequently, in order to determine the relationship between carbon monoxide release and the electrical potential applied to a diffusion flame near surfaces, we use PLIF of OH to provide qualitative information of the two-dimensional distribution of this important reactive intermediate. We also identify the highly reactive zone using tomographic reconstructions from the chemiluminescence of excited-state OH. These two techniques help describe the relationships between the quenching surface, electric field effects, OH distribution, and CO emission from impinging diffusion flames. In addition, the research explores the possibility of detecting and changing the flame behaviour electrically. The ultimate goal is to control the emission of carbon monoxide from flames near surfaces.

227- **The effect of pulse electric discharge on the stabilization of turbulent lifted jet flames,** *C. Tzu-Wei, T. Cheng, Y. Chao, G. Chen* In the present study, the effect of pulse electric discharges on the stabilization characteristics of turbulent lifted propane-jet diffusion flames are investigated experimentally by applying repetitive high-voltage pulsed discharges. The mean liftoff heights have been measured by using a High-speed video camera to record the instanteous images of lifted flame base with varying the pulse repetition frequency. Meanwhile, the typical discharged voltage and current profile measurements are also presented to determine the type of electric discharge. The results show that the enhancement stabilization can be obtained by increasing pulse repetition frequency in terms of mean liftoff height and reattachment velocity. Furthermore, the pulsed corona discharges probably occurred at electrode tip with a increase in located height of electrode. Therefore, the lifted jet flames stabilize close to the electrode powered by pulse high-voltage.

215- **Magnetic effects on flickering laminar methane/air diffusion flames,** *P. Gillon, W. Badat, V. Gilard & B. Sarh* We investigate the responses of buoyant jet diffusion flames to the application of magnetic field gradients. In a magnetic gradient, the paramagnetic oxygen is submitted to a magnetic force of attraction directed to the center of the magnet. Positive and negative magnetic gradients effects were compared to the case with no magnetic field applied. Measurements in methane/air flames from a coaxial injector show that over a range of air coflow velocity, the magnetic gradients affect both the oxygen supply at the flame edge and the displacement of the vortices in the air side of the high temperature reaction zone. Upward increasing magnetic field attracts paramagnetic oxygen upwards leading to variations of the lift height and the flame length and counteracts the gravity convective motion attested by a noticeable decrease of the flickering frequency whereas the upward decreasing magnetic field generates a downward magnetic force on oxygen, depriving the flame edge of oxygen (hence a higher lift height) and enhancing the gravity convection in air along the flame evidenced by an increase of the flickering frequency. The magnetic field gradient impacts the soot production through modifications of local temperature, stoichiometry and residence time, effect that is shown by the variation of flame visible luminosity.

11:45 Diffusion flames 2

138- **Effects of oxy-enriched oxidizer and nitrous oxide addition on characteristics of laminar methane jet diffusion flame,** *H. Lin, G. Chen, T. Cheng, Y. Li, Y. Chao* Effective control of flame configurations will help to improve combustion efficiency and reduce pollution emissions on new energy conversion devices. In order to avoid the combustion instability during lean operation for low fuel consumption, the strong oxidizer concept, such as employing oxy-enriched conditions and nitrous oxide (N2O) to enhance combustion, is proposed in this study. The objective of this work is to theoretically and experimentally investigate the flame behaviours of oxidizer addition to methane diffusion flames by varying the ratio of oxidizer jet velocity to that of the fuel jet (R=V1/V2), carried out on a triple port burner. The theoretical results show that the stream velocities, fuel and oxidizer concentrations and stream temperatures affect the flame structures. The experimental results reveal that the formation of the double flame structures, an inner inverse diffusion flame (IDF) and an outer normal diffusion flame (NDF), occurs only when Ω = 35% and using N2O as an oxidizer. It is conjectured that the increase of oxygen content enhances the local heat release rate to induce the partially premixed flame that propagates rapidly upstream to form the inner IDF. The increased soot formation could also due to the changes of local velocity and temperature. Furthermore, before the formation of IDF, N2O addition to the flame strongly favours soot formation as compared to the oxy-enriched conditions. Besides, when N2O is used as the oxidizer, the critical values of R for IDF formation are equivalent to the condition of Ω=70%.

218- **Global linear instability analysis of diffusion-flame flickering,** *D. Moreno-Boza, W. Coenen, A. Sevilla, J. Carpio Huertas, A. Liñan, A. Sanchez* This work investigates the global stability of axisymmetric laminar jet diffusion flames at moderately large Reynolds numbers, including effects of buoyancy, temperature increase due to chemical reaction, and fuel dilution. The ultimate objective is to clarify the instability mechanism responsible for the phenomenon of diffusion-flame flickering. Quasi-isobaric conditions corresponding to low-Mach-number jets are considered. The limit of infinitely fast chemical reaction is used in the development, enabling a simplified description of the temperature and composition fields in terms of the modified mixture fraction and the excess-enthalpy variables. A finite-element method is implemented to integrate the steady equations of continuity, momentum, mixture fraction, and excess-enthalpy that determine the basic steady flame structure. To study the global stability of the flame, a normal-mode decomposition is used, where the wave packet structures are temporal eigenmodes of the linearized equations of motion in a 2D domain. The growth rate of the most unstable eigenvalue dictates whether the flow is globally stable. The resulting spectra show that the leading eigenvalue varies with the control parameters, such as the Reynolds and Froude numbers, permitting to calculate the onset of global instability as a function of these. The spatial structure of the associated eigenfunction, together with the low value of the frequency, indicates that this global mode can be identified with the self-sustained oscillations found in flickering flames.

58- **Flame propagation in the stratified mixing layer between CH_4 and CO_2/O_2 stream**, *C. Wu, K. Chen, W. Yu* The propagation phenomena of methane laminar flame in a well confined quartz tube with O_2/CO_2 are numerically and experimentally studied. Based on the distribution of the isopleths of the mixture fractions and the chemical reactions, this paper characterizes the flame base structure, and the propagation phenomena of the jet flame base.

14:20 Deflagration to detonation transition 3

217- **Numerical simulation of flame acceleration and fast deflagrations using artificial thickening flame approach**, *S. Emami, K. Mazaheri, A. Shamooni, Y. Mahmoudi* A large eddy simulation is performed to study the deflagration to detonation

transition phenomenon in an obstructed channel containing premixed stoichiometric hydrogen-air mixture. Two-dimensional filtered reactive Navier-Stokes equations are solved utilising artificially thickened flame approach for modeling of the sub-grid scale combustion. To include the effect of induction time a 27-step detailed chemistry is utilized along with an in situ adaptive tabulation (ISAT) method to reduce the computational cost due to the detailed chemistry. The results show that in the slow flame propagation regime, the flame-vortex interaction and, the resulting flame folding and wrinkling are the main mechanisms for the increase of the flame surface and consequently acceleration of the flow. Furthermore, at high speed, the major mechanisms responsible for flame propagation are repeated reflected shock-flame interactions and the resulting Richtmyer Meshkov instability. These interactions intensify the rate of heat release and maintain the turbulence and flame speed at high level. During the flame acceleration the turbulent flame enters the thickened reaction zones regime. Therefore, it is necessary to utilise the chemistry base combustion model with detailed chemical kinetic to capture properly the salient features of the fast deflagration propagation.

176- **Visualization of deflagration-to-detonation transitions in a channel with repeated obstacles**, *S. Maeda, S. Minami, D. Okamoto, T. Obara* In the present study, a hydrogen/oxygen premixed gas with an initial pressure of 70 kPa was ignited, and behaviors of a deflagration-to-detonation transition phenomenon above repeated obstacles were visualized using a high-speed camera. The rectangular obstacles with 5 mm width were attached at regular intervals of 60 mm in the bottom wall of the detonation tube, which had the rectangular cross-section channel with 85 mm height and 100 mm depth. The obstacle height was varied as 5 or 15 mm. The flow field was visualized from two orthogonal directions using a Schlieren system. They are the transverse view and underside view looking the obstacles from a lateral view and from underneath, respectively. Detonation transition occurred at a short distance from the ignition at the end wall of the detonation tube. The location of the transition was the third or fourth obstacle for the obstacle height of the 5 mm or 15 mm, respectively. Because of the very reactive experimental conditions, the detonation transition occurred without a strong leading shock or its reflection with obstacles, which was pointed out by Gamezo et al. (2007) as the one of mechanisms for a DDT phenomenon. In this study, this was also confirmed by removing the obstacles that were installed downstream the obstacle where the DDT was occurred. Visualization from the transverse view showed the local explosion and following detonation transition occurred downstream the obstacle where the flame front was convoluted. Mixing of the unreacted and reacted gas in the convoluted turbulent flame front would be the dominant contributing factor for the detonation transition, as indicated in studies of a jet initiation. The visualization from the underside view showed that a rapid reaction was progressed along the obstacle depth where the unreacted gas remained downstream the obstacle. Accordingly, detonation transition occurred at the corner surrounded by the obstacle, the side and bottom wall of the detonation tube. The new observation from the underside view demonstrated the three dimensional evolution of the detonation transition phenomenon behind the obstacle.

289- **Shock wave - boundary layer interaction driven auto-ignition and DDT**, *E. Dzieminska, J. Misawa, A. Hayashi* Detonation studies are very important in many aspects of science. One on the most important feature in a development of any new technology are basics. Once we can understand how does detonation, auto-ignition or deflagration-to-detonation transition (DDT) take place, we are able to create sophisticated, new, efficient mechanisms. The purpose of this research is to investigate a chapter of detonation, namely shock wave boundary layer interaction (SWBLI) triggered DDT and show that weak waves, which seems to be insignificant can promote uncontrolled explosions. Numerical and experimental researched were performed. Numerical research was done using 2-D compressible Navier-Stokes equations for highly viscous and diffusive flow field in its early stage of deflagration. Stanford model with nine chemical species. The experimental tube is a 40 x 40 mm square 3.5-meter long tube. Near the closed end a Shchelkin wire is installed to enhance DDT. We could recognize the existence of boundary layer and the upstream-direction moving of ignition point.

14:20 Flame dynamics 1

222- **Acceleration and extinction of flames in channels with cold walls,** *C. Dion, B. Demirgok, V. Akkerman, D. Valiev, V. Bychkov* The present work considers the problem of premixed flame front acceleration in micro-channels with smooth cold non-slip walls in the context of the deflagration-to-detonation transition; the flame accelerates from the closed channel end to the open one. Recently, a number of theoretical and computational papers have demonstrated the possibility of powerful flame acceleration for micro-channels with adiabatic walls. In contrast to the previous studies, here we investigate the case of flame propagation in channels with isothermal cold walls. The problem is solved by using direct numerical simulations of the complete set of the Navier-Stokes combustion equations. We obtain flame extinction for narrow channels due to heat loss to the walls. However, for sufficiently wide channels, flame acceleration is found even for the conditions of cold walls in spite of the heat loss. Specifically, the flame accelerates in the linear regime in that case. While this acceleration regime is quite different from the exponential acceleration predicted theoretically and obtained computationally for the adiabatic channels, it is consistent with the previous experimental observations, which inevitably involve thermal losses to the walls. In this particular work, we focus on the effect of the Reynolds number of the flow on the manner of the flame acceleration.

258- **Flame propagation in narrow channels at varying Lewis number**, *J. Wongwiwat, J. Gross, P. D. Ronney* The propagation of quasi-2D premixed-gas flames in H2-O2-inert mixtures having various Lewis numbers from fuel-lean to fuel-rich conditions were studied using a Hele-Shaw cell. Various instabilities were observed including those attributed to thermal expansion of the burned gas (Darrieus-Landau, DL), buoyancy (Rayleigh-Taylor, RT), viscosity contrast across the flame (Saffman-Taylor, ST), and diffusive-thermal (DT) effects. By varying the concentrations of hydrogen, oxygen, and nitrogen, a range of equivalence ratios and Lewis numbers were obtained at fixed adiabatic flame temperature. The direction of propagation relative to the gravity vector was also varied. It was found that the flame front shapes and propagation rates were strongly affected by all 4 of the aforementioned instability mechanisms but in many cases the contributions of each mechanism were identifiable and nearly independent of each other.

268- **The effect of mixture fraction on edge flame propagation speed,** *P. Wang, H. Song, R. Boles, H. Prahanphap, J. Piotrowicz, W. Li, P. Ronney* Flames in strongly turbulent flows are subject to local extinction and re-ignition that may affect their heat release rates, extinction conditions, and unburned hydrocarbon emissions. The interaction of flames with turbulence is an extremely complicated problem hence simpler, tractable model systems are needed to develop a fundamental understanding of these local extinction and re-ignition events. As a consequence, so-called œedge flames separating regions of burning and non-

burning portions of a flame surface has been studied by many researchers. The most important property of edge flames is the speed (Uedge) it moves relative to the unburned gases in the direction parallel to the flame sheet. Uedge can be positive, negative or zero depending on the mixture strength and global strain rate. While some experimental studies of non-premixed edge flames have been conducted, one aspect that has not received attention in prior literature is the effect of the stoichiometric mixture fraction (Z_{st}). With the growing popularity of unconventional combustion systems such as oxy-fuel combustion, massive exhaust gas recirculation, etc., values of Z_{st} may be very different from those of conventional fuel-air mixtures.With this motivation, the effect of Z_{st} and strain rate; on U_{edge} was measured for several fuel/oxidant/diluent combinations using a counter-flow slot-jet burner. It was found that for conditions with fuel Lewis number (Le_{fuel}) approximately = 1 and oxidant Lewis number (Le_{O2}) approximately = 1 (e.g. CH_4-O_2-N_2 mixtures) with fixed Z_{st}, U_{edge} is negative for sufficiently large or small strain rate and positive at intermediate strain rate, and that U_{edge} increases monotonically with increasing Zst for both positive and negative values of Uedge. In contrast, for $Le_{fuel}<1$ and Le_{O2} is approximately = 1 with fixed strain rate, Uedge exhibits a minimum at Z_{st} approximately = 0.3. These results indicate that varying Z_{st} has both chemical and Lewis number effects on non-premixed edge flame speeds. For Le_{fuel} and Le_{O2} both approaches unity, chemical effects dominate over the whole range of Z_{st} whereas for $Le_{fuel}<1$ and Le_{O2} approximately = 1, Lewis number effects become important at low Z_st. Consequently, the near-extinction behavior of highly turbulent non-premixed flames may depend critically on (1) the fuel type (i.e. Lewis number), (2) the extent of dilution of both fuel and air, and (3) the local strain rate at the flame front.

14:20 Detonations in propulsion 1

304- **Invited review**: **present status of pulse and rotating detonation engine research**, *J. Kasahara, S. Frolov* Self sustained detonation wave propagates at speed of 2-3 km/s and it completes the exothermic chemical reaction in a tube filled with a premixed gas. An engine using a detonation wave intermittently generates in a straight tube is called a pulse detonation engine (PDE) and that is using a detonation wave generated continuously in annular tubes is called a rotating detonation engine (RDE). In this paper, present status of pulse and rotating detonation engine researches are reviewed for the special session of propulsion application of detonation.

19- **Design and testing of a rotating detonation engine for open-loop gas turbine integration**, *A. Naples, M. Fotia, T. Scott, J. Hoke, F. Schauer* A rotating detonation engine is developed for implementation into a gas turbine environment. A modular ejector is designed and built to dilute RDE exhaust flow to admissible turbine inlet temperatures. Operability of the RDE is explored, and degree of exhaust stream mixing is determined. Multiple operating modes are demonstrated within the target testing space, with uniform outlet temperature distribution. A separate RDE is tested with high temperature walls. Testing shows hot walls absorb 60% less heat than cold, reducing final design cooling load. Preliminary testing lessons are applied to design an air-cooled RDE with diluted exhaust flow. Final testing shows an RDE operating at thermal equilibrium throughout the target testing space. The outlet flow is measured to be within turbine temperature limits, while the unsteady pressure generated by the RDE is still present to determine turbine response, once implemented.

26- **Analysis of experimental research of continuous detonation of fuel-air mixtures**, *F. Bykovskii, S. Zhdan* Application of a thermodynamic detonation cycle in air-breathing engines is of interest for modern jet-driven vehicles. In particular, the development of the scientific basis for detonation engines where the fuel is continuously burned in the detonation wave running across the annular combustor (pattern proposed by B. V. Voitsekhovskii) is important. Of interest for practice is continuous spin detonation (CSD) of fuel-air mixtures (FAMs) in flow-type combustors. CSD regimes were first obtained in acetylene-air (2005), hydrogen-air (2006), and syngas-air (2013) FAMs. The structure of transverse detonation waves (TDWs) and the flow in their vicinity, as well as conditions, properties, and domains of CSD existence in these FAMs were considered. The goal of this work is to find the key parameters responsible for the geometric similarity of continuous detonation by varying the geometric parameters of the annular combustor and to determine the influence of additional injection of air on continuous spin detonation occurrence and on the values of the specific impulses in hydrogen-air and syngas-air mixtures. Multi-wave CSD regimes in syngas-air mixtures are obtained for the first time in flow-type annular cylindrical combustors with diameters dc1 = 306 mm and dc2 = 503 mm. It is found that the CSD is a high-frequency process with a frequency of 1 - 6 kHz; it exists in a wide range of the governing parameters and possesses an effect of scalability. The structure of transverse detonation waves and the wave front heights for syngas-air TDWs are close to those previously found by our team for hydrogen-air mixtures. Owing to injection of additional air into the annular combustor, the CSD admits a four-fold decrease in the fuel concentration as compared to the stoichiometric mixture, simultaneously providing a decrease in the temperature of the CSD products and an increase in the specific impulse.

14:20 Reaction dynamics 1

108- **On the combustion characteristics of a novel biofuel: heat of combustion and vaporization rate**, *M. Birouk, I. Chowdhury, L. David, M. Sailer, J. Sorensen* The main objective of the present research was to develop and test a novel bio-based liquid substance as an additive for improving cold flow performance of biodiesel, or as stand-alone fuel. We chose to use 1,3-dimethoxyoctane as a novel fuel/fuel additive, which was prepared from methyl 3-hydroxyoctanoate. Some combustion properties such as the vaporization rate and heat of combustion were measured and compared with established fuels to assess the merit of the newly developed biofuel/fuel additive.

163- **The effects of carbon dioxide in oxy-fuel atmosphere on catalyst reaction in a small-scale channel**, *Y. Li, G. Chen, Y. Chao* In this study, the effect of carbon dioxide on catalyst reaction in a small-scale channel in oxy-fuel atmosphere is experimentally investigated. In the oxy-combustion, carbon dioxide in the flue gas is usually recirculated to dilute the oxidizer stream in order to reduce the flame temperature. However, the specific heat of carbon dioxide is relatively higher than that of nitrogen, and it causes significant reduction on flame temperature and combustion stability. Furthermore, carbon dioxide in flames does not only act as an inert diluent, but also involves in flame reactions and modifies flame behaviours and combustion characteristics. During the miniaturization, the surface-to-volume ratio of the combustion chamber will be increased, and the mixing and reaction residence time will be decreased. It causes flame quenching, such as thermal quenching and radical quenching. Segmented catalyst with cavity in a micro-channel is expected to induce gas reaction and surface reaction simultaneously, and enhance fuel conversion. The experimental results of the segmented catalyst with cavities show the improvement of oxy-combustion behaviours in a micro channel by reducing the requirement of excessive oxygen concentration in the oxidizer stream for flame stability. When the flow rate is 10 m/sec and corresponding equivalence ratio of 0.6, oxy-hydrogen combustion in a channel

can be stabilized in a condition of 23% oxygen concentration in the oxidizer stream. Besides, the gas analysis shows that carbon monoxide is yielded in oxy-hydrogen combustion, and it speculates that gas reaction and surface reaction somehow induce the inverse reaction of carbon dioxide. However, the producing carbon monoxide can be consumed in downstream-segmented catalyst.

101- **A comprehensive and compact mechanism for the oxidation of methyl-decanoate,** *X. Wang, L. Seidel, T. Zeuch, F. Mauss* In this work a detailed oxidation scheme for methyl-decanoate was developed and further reduced to a skeletal size of 248 species. The detailed model was developed by using a semi automatic mechanism generator and applying 25 reaction classes for low and high temperature chemistry. A well validated C1-C4 chemistry is used to model the combustion chemistry of smaller species and sub models for NOx and PAH formation are added. The prediction of the detailed scheme is compared against published data for ignition delay time, laminar flame speeds and speciation in jet stirred reactors and flames. The mechanism was reduced to a skeletal size by applying the Chemistry Guided Reduction technique were horizontal lumping is performed and species are removed on the basis of species necessity values calculated from an combined reaction flow and sensitivity analysis. The predictions of the skeletal model are largely unchanged and a two stage flow analysis and sensitivity coefficients are calculated to underline that the main reaction pathways were kept. Due to its compact size and good predictions the skeletal mechanism is suitable for application in engine simulations were methyl-deaconate is used as reference fuel for biodiesel.

16:05 Deflagration to detonation transition 4

192- **Front tracking of DDT from ultra-high speed video films**, *D. Bjerketvedt, A. Gaathaug, K. Vaagsaether, G.O. Thomas* The main objective of this study is to observe and extract detailed information of the deflagration to detonation (DDT) process in hydrogen-air by using an ultra-high speed camera, Schlieren technique and image processing. Since the ultra-high speed camera has the capability of frame rates up to 5 million frames per sec it gives us a unique tool for observation of the DDT process. The experimental set-up consists of a 3 m long channel with 10 x 10 cm2 cross section. The channel was closed in the ignition end and an obstacle was placed 1 m from ignition. The side walls of the channel were made of transparent polycarbonate. The obstruction was a baffle type obstacle creating an open slit with a blockage ratio of 0.85. The gas mixture was stoichiometric hydrogen-air at atmospheric pressure. The gas was ignited by a weak spark. The image processing was done in Matlab. We used background subtraction similar to our previous work on shock tracking. The front was detected by thresholding the 1-order gradient of the image intensity level. When the position of the front in x-direction xf(y,t), is established, the normal velocity of the front. The experiments demonstrate that it is possible with an ultra-high speed camera, Schlieren technique and image processing to observe and extract detail information of the deflagration to detonation (DDT) process. We have been able to follow the shock wave and the transition process in atmospheric hydrogen at 500 000 fps and 924 x 768 pixels resolution. From the images we can find the front velocity and estimate the pressure behind the front wave. For the same experimental conditions two different modes of DDT was observed; i) Overdriven transverse wave, ii) Mach-stem leading up to DDT. In case i) we observe the transvers front propagates at 2700 m/s while the leading detonation propagates at near CJ velocity. In case ii) a triple point propagates close to CJ velocity in both cases the Mach-reflection appears to be of major importance. We believe that present experimental results in combination with CFD simulation can further improve the understanding of DDT mechanism(s) and modes of DDT.

116- **X-Ray radiographic studies of the deflagration to detonation transition in porous beds of explosives**, *L. Smilowitz, B. Henson, M. Holmes, L. Vaughan, G. Parker* The deflagration to detonation transition in explosives is an important phenomenon impacting the safety and performance of explosives. Deflagration refers to the sub-sonic burning of explosives and detonation to the supersonic energy release. Deflagration can be started by thermal or mechanical means and with appropriate conditions of material and case confinement, can propagate to a detonation. The transition between the sub- and super-sonic regimes is referred to as the DDT transition. Mechanisms for the transition have been posited to include conductive and convective burning of porous beds leading to pressurization of the bed ahead of the burn front and formation of a compacted plug of material which initiates an SDT event. Indirect observations of these steps have been made1-4. However, no direct observation of the compacted plug has been made to date. It is a goal of this work using continuous x-ray transmission imaging to observe the compacted plug mechanism. In this paper, we describe work developing x-ray radiographic diagnostics to follow the transition between sub-sonic deflagration and super-sonic detonation. Work to date on porous beds of HMX will be described and future directions outlined.

159- **Application of high-speed OH-PLIF to DDT experiments**, *L. Boeck, T. Fiala, J. Hasslberger, T. Sattelmayer* OH-PLIF (Planar Laser-Induced Fluorescence) allows for capturing two-dimensional images of flame fronts by visualizing OH radicals. While it is widely used for diagnostics of scientific and technical flames, its application to explosion experiments is more uncommon and has been mostly limited to single-shot PLIF so far. Low speed PLIF systems (around 10 Hz repetition rate) deliver pulse energies of several mJ (pumped dye lasers) or even a few 100 mJ (excimer lasers). Resolving explosion processes and in particular the fast deflagration regime in time requires repetition rates in the kHz range. Pulse energies thereby reduce to about 0.100 mJ for typical commercially available dye laser systems. This work presents, to the best of our knowledge , the first application of HS (High Speed) OH-PLIF to an explosion experiment with fast deflagrations. Our intention is to particularly discuss the potential and limitations of HS OH-PLIF and thereby provide practical guidance.

16:05 Shock tube ignition 1

260- **Invited review: Advances in shock tube techniques for fundamental studies of combustion kinetics**, *R. Hanson, D. Davidson* Shock tubes can provide well-defined temperatures and pressures for combustion kinetics investigations that cover broad regimes of engineering and scientific interest. Shock tube experiments can be performed at temperatures of 500-5000 K (and higher) and pressures from sub-atmospheric to 500 atm (and higher). Measurements performed behind reflected shock waves have near-instantaneous heating times, spatially uniform mixtures, and occur in near-stationary (stagnant) flows. However, advances in the understanding of combustion kinetics have led to the need for even higher quality experimental data for model validation and refinement. This need for higher quality experimental data has provided new challenges for shock tube experimenters. Shock tube performance and models must be improved; shock tube operating regimes must be extended; real fuels must be studied; and sensitive species-specific diagnostics must be implemented. And good progress towards these goals is taking place. In this presentation, we overview work in several of these areas.

20- Development of hot spots and ignition behind reflected shocks in $2H_2+O_2$, *A. Khokhlov* The goal of this work is a numerical study of the hot spots leading to mild and strong ignition behind reflected shocks in reactive gases. To this end we carry out three-dimensional reactive flow Navier-Stokes (NS) direct numerical simulations (DNS) of the shock reflection in stoichiometric $2H_2+O_2$ mixture. We find that the formation of hot spots responsible for the transition between strong and mild ignition regimes may be related to the generation of acoustic (pressure) waves in the recirculation region of the bifurcated reflected shock. The subsequent modulation of the reflected shock by the pressure waves creates secondary entropy perturbations in the shocked matter, which serve as initial sites for the hot spot development. The shock Mach number, M, determines the average temperature of the shocked matter and controls whether the ignition leads directly to a detonation (strong ignition) or to a number of growing flame kernels and a mild ignition.

191- Ignition delay-time study of fuel-rich CH4/air and CH4/additive/air mixtures over a wide temperature range at high pressure, *J. Herzler* Flexibility between the conversion and storage of energy will be an important aspect in future energy systems, especially when considering the fluctuating availability of renewable energies. In times of low demand but high availability of renewable energy, an interesting concept is its use as external mechanical or electrical energy in internal combustion engines (ICEs) to convert cheap chemicals (e.g., natural gas) into higher-value chemicals (syngas, unsaturated and oxygenated species) so that most of the exergy of the cheap fuels is stored. This production of chemicals typically proceeds at fuel-rich conditions, far away from current operating regimes of ICEs. A fundamental understanding of the chemical kinetics under these conditions and the availability of validated chemical kinetics mechanisms for these fuel-rich conditions are essential for the successful implementation of such concepts. However, most of the reaction mechanisms published in the literature are validated preferentially for lean and stoichiometric mixtures, because these conditions are important in ICEs and gas turbines. To test the performance of existing chemical kinetics mechanisms under fuel-rich conditions, we measured the ignition delay times of CH_4/air and CH_4/additive/air mixtures at fuel-rich (phi=2) and engine-relevant conditions (20 and 30 bar, temperature range 700-1620 K) and compared the results with the predictions of literature mechanisms. The experiments were performed in a high-pressure shock-tube with driver gas tailoring that enabled the determination of ignition delay times up to 16 ms. Small amounts of additives (5 mol% ethanol, dimethyl ether (DME), n-heptane) were used to reduce the ignition delay times of CH_4 (i.e., to increase its reactivity) so that engines can be used in the HCCI mode without the need to preheat the reactants. Additional measurements with CH_4/DME mixtures (20 mol% DME, phi=2) at p = 20 bar show a very good agreement with shock-tube and RCM experiments of Burke et al.. Good agreement of the simulations with the experiments was found using the mechanism of Herzler and Naumann [1] for CH_4 and CH_4/ethanol, Yasunaga et al and Burke et al. [4] for CH_4, CH_4/ethanol and CH_4/DME and Mehl et al. [5] for CH_4 and CH_4/n-heptane. Future work will be focused on validation of chemical kinetic mechanisms for product formation. Time-resolved formation of individual species (e.g., CO) will be measured with mid-IR CO laser absorption and high-repetition-rate time-of-flight mass spectrometry (HRR-TOF-MS) during partial oxidation of CH_4/additive mixtures in shock tubes

16:05 Detonations in propulsion 2

132- 3D Numerical simulation on rotating detonation engine: effects of converging-diverging-nozzle on thrust performance, *S. Eto, N. Tsuboi, Y. Watanabe, T. Kojima, A. Hayashi* The effect of the converging-diverging(CD) nozzle on the thrust performance of the rotating detonation engine(RDE) was estimated using three-dimensional numerical simulations with the detailed chemical reaction model. The nozzle geometry is designed based on the reference of Brent et al. The nozzle is composed of the long constant cross section, the short converging section, and the diverging section. The periodic exhaust oscillation due to the rotating detonation is considerably reduced by the present CD nozzle. The variation of the time-averaged pressure is approximately 0.01 MPa and the ratio to the time-averaged value (approximately 0.34 MPa) is 3%. The variation of the time-averaged Mach number is approximately 0.02 and the ratio to the time-averaged value (approximately 2) is 1%. The increment of Isp using the CD nozzle is approximately 90 sec. (33%) more that Isp without nozzle. Additionally, Isp of RDE with the CD nozzle increases 35 sec. larger than that of the chemical equilibrium state under a vacuum environment.

49- Numerical investigations of tail Laval nozzle effects on rotating detonation engines, *D. Wu, R. Zhou, S.-J. Zhang, J.-P. Wang* Based on three-dimensional simulations, the effects of the tail Laval nozzle on the flow field and flow properties of rotating detonation engines (RDE) are investigated in detail. It is found that the chamber length has almost no effects on either the flow distribution or the flow properties of RDE. Without tail nozzles, only a small part of flow is supersonic nearby the exit of RDE. When a tail Laval nozzle is connected, the flow inside the tail Laval nozzle speeds up. At the exit of the tail Laval nozzle, the flow is all supersonic and the average pressure matches the environmental pressure. However, in terms of the propulsive performance, the RDE with tail Laval nozzle shows no obvious advantages.

157- Numerical investigation on the airbreathing continuous rotating detonation engine, *S. Liu, W. Liu, L. Jiang, Z. Lin* Three dimensional numerical simulations on the airbreathing CRDE were carried out. The computational results showed that the influence of the detonation wave expanded along both upstream and downstream, and a shock wave is formed in the upstream inflow. The influence of the air total temperature were studied and is shown to had little influence on the propagation velocity of the detonation wave. However, a lower temperature resulted in a higher pressure ratio of the detonation wave and average pressure in the combustor. Moreover, the location of the upstream shock wave was closer to the inlet. The effect of the area ratio of the divergence section were studied and it was shown that the inflow was affected by the continuous detonation combustion more severely with a lower area ratio.

16:05 Fires

51- Interaction between crosswind and aviation-fuel fire engulfing an aircraft: numerical study, *H. Wang, G. Wang* Aviation liquid fuel is volatilise to form a cloud of combustible mixture, with subsequent gas-phase ignition and establishment of a vapour cloud fire. Large fully turbulent fires, which result as a consequence of an aircraft accident, pose a severe hazard to the occupants and cargo. In large-scale hydrocarbon fires, higher soot levels result in radiation blockage effects around the perimeter of large fire plumes: this yields a drastic reduction in the radiative loss fraction. There are other complications deriving from the intermittency of the behaviour, with luminous regions of efficient combustion appearing randomly in the outer surface of the fire according the turbulent fluctuations in the fire plume. The burnthrough time of a metallic fuselage depends strongly on external heat flux from a post crash fire, to the fuselage with multilayer including skin, thermo-acoustic insulation, air layer and cabin wall. Moreover, fire resistance of

aircraft structure elements depends on the radiation heat transfer from the flames to aircraft skin, which is greatly affected by soot production. We have attempted to provide an entirely tractable solution for engineering calculations such as aircraft fires. The availability of such simulation can provide cost-effective alternatives by reducing the number of large-scale tests necessary to develop fire protection requirements or standards. Large Eddy Simulation (LES) for the fluid dynamic equations of three-dimensional elliptic flow is coupled with an Eddy Dissipation Concept, allowing to the simulation of turbulent flame. The basis of the analysis is the conservation equations of mass, momentum, energy and species, a set of three-dimensional elliptic, time-dependent Navier-Stokes equations. A dynamic modelling method is applied to obtain appropriate value of the EDC coefficient, allowing taking into account the mass transfer rate between the fine structures and the bulk of the fluid.

144- **Dynamic behaviour and structure of wind-blown flames,** *M. Gollner, W. Tang, D. Gorham, M. Finney, S. McAllister, J. Cohen, J. Forthofer* Experiments were performed using stationary gas burners to study features of fundamental wildland fire behaviour, particularly unsteady flame heating. These experiments were motivated by observations of instabilities in spreading fire experiments that suggest they play a critical role in fire spread. Stationary fire experiments in forced flow exhibited instabilities similar to those observed in spreading fires but allowed for more detailed analysis of the mechanisms responsible. Forced flow experiments were performed on a small scale gas burner at wind speeds from 0.5 to 3 m/s. Study of the downstream extension of the flame yielded reasonable scaling between the Strouhal and Froude number, similar to correlations for puffing pool fires. The downstream extension of the flame was also found to follow a normal distribution, with extension of the flame further downstream becoming more likely for fires with a larger heat-release rate. Further study is necessary, but the fact that similar scaling to purely buoyant phenomena describes features of these fires points to the importance of buoyant instabilities in the description of wildland fire spread.

122- **Modeling optical emissions from HE fireballs**, *D. Grote, A. Kuhl, J. Bell, V. Beckner* We investigate the optical emission from TNT fireballs. We model the expansion of the detonation products, mixing and turbulent combustion with air with our AMR code. The flow-field is assumed to obey the gasdynamic conservation laws, while combustion is modeled in the high-Damköhler limit appropriate to gasdynamics (i.e., fast-chemistry limit). The equations are integrated with our high-order Godunov scheme. Adaptive mesh refinement is used to capture the turbulent mixing on the computational grid (iLES approach). We assume a 1-kg spherical TNT charge, detonated at the center. We initialize the mesh with the similarity solution for a constant-velocity Chapman-Jouguet detonation wave at the breakout time of 7 μs thereby establishing an initial value problem. Our 3D ray-tracing code: LUX was used to compute optical emissions from the fireball, based on the temperature, density and species composition of the flow field. Carbon soot was the dominant radiator (43 mole percent of the species). We predict the spectral radiance histories at seven wavelengths: 0.35264μm-0.84638μm. Two peaks are found. The first is from the initial expansion of the fireball; emissions come primarily from soot in the shock-heated air layer near the detonation products-air interface. The second comes from a re-heating of the fireball by the implosion shock. By comparing the results at grid levels 5, 4 and 3, we show convergence of the spectral radiance at different wavelengths. Turbulent combustion structures in the simulation are similar to those seen in field tests.

10:00 (all day) Posters 1

2 - The combustion process of ADN-based liquid propellant in attitude control engine, *L. Jing, J. Huo, X. You, M. Zhu, Yao* The ammonium dinitramide (ADN) based liquid propellant is a kind of green propellants and can be used in small rocket. In this paper, the combustion process of ADN-based liquid propellant in attitude control engine is investigated experimentally and numerically. In the experiment, the pressure, the temperature and the characteristic species concentrations of CO and NO in the combustion chamber are measured to estimate the performance of thruster. In the simulation work, the non-equilibrium model for porous media is used to describe the heat transfer in catalyst bed and interaction between liquid droplet and porous media is also considered. A simplified chemical mechanism is used to model the reactions between ADN and CH_3OH in gas phase. The numerical results are in agreement with the experimental results. The results show that there are two stages of temperature increasing in the ADN-CH_3OH combustion process. In the thruster, the decomposition of ADN and the oxidization of methanol do not happen synchronously. Since the combustion is non-adiabatic, the transformation from N_2O to N_2 and the oxidization of CH_3OH cannot be completed in the combustion chamber.

3 - **Minimum ignition temperature of hybrid mixtures of burnable dusts and gases**, *A. Emmanuel, D. Gabel, U. Krause* Investigation of the ignition behaviour (minimum ignition temperature (MIT)) of hybrid mixtures of dusts and gases has been undertaken. This was achieved by performing series of test in the modified Godbert-Greenwold furnace. The materials used are, gases (methane, propane and hydrogen) and dust (starch, lycopodium, toner, wood and CN4). The test protocol for testing the MIT for dust was according to ASTM (E1491-06) while in the case of gas and hybrid mixture the same standard was used but with slight modification. The experimental results demonstrate the significant decrease of the MIT of either gas or dust and increase in explosion likelihood when small amount dust which is either below the minimum explosion concentration or not ignitable itself are admixture with gas and vice versa. For example the MIT of methane decreases from 600°C to 530°C when small amount of toner which is not ignitable at the MIT of methane was added to it. The same effect was noticed when a small amount of gas was added to dust for example, wood with MIT of 460°C decreases to 420°C when a small amount of methane which is not ignitable at the MIT of wood was added. The result also confirm that, an ignition is possible for a process or a system where hybrid mixtures are generated even if the temperature is below the MIT of a single substance and hence the MIT of hybrid mixtures cannot be predicted by simply overlapping the effects of the single dust or gas. These results also confirm the work done by Shaikh Zunaid [9] of which he concluded that, some dust generate sparks below the MIT and if the spark energy produced are strong enough could ignite a gas. This was seen in starch, wood and CN4 of which ignition were obtained below the MIT when small amount of methane, propane and hydrogen which were not ignitable even at the MIT of the various dust were added.

5 - **Simulation of suspended mixed RDX and Al dust in one dimension with the CESE method**, *W. Zan, T. Hong, H. Dong* This paper studied the two-phase detonation of AL and RDX in air used by CE/SE (conservation-element and solution-element) method. It simulates the detonation of the RDX and aluminum separately in air and found the result is well correspond to the other researchers. Also it studied the problem of different diameter of AL and RDX with the definite density when the two dusts are in air together. It was found that the diameter of the Al can affect the structure and the parameter of detonation wave. It compares the construction of the detonation wave in condition that the two dusts detonation and the one dust detonation.

When the radius of Al reach the limit, the wave speed will keep const that the maximum wave speed of the Al only at the same density.

12 - Superadiabatic temperatures in processes of homogeneous combustion of gases, *V. Babkin* It is concluded then that taking account of SAT properties is rather promising for academic and practical applications due to a number of circumstances. First, many important combustion processes, e.g., laminar flame, propagation limits, flame ignition and extinction, etc., are determined, on the one hand, by the rate of Arrhenius reactions and, on the other hand, by maximal temperature, for our case, by $T_{b,max}$ rather than by $T_{b,eq}$. In this case, $T_{b,max}$ depends on both the thermodynamic and the kinetic data of elementary, chemical reactions, most of which are to be determined. On the other hand, the value of $T_{b,max}$ may be considered as a new parameter to control combustion processes. Thus, the kinetic phenomenon of superadiabatic temperatures should be taken as one of the actual problems of the up-to-date chemical physics.

8 - Reactive flow modeling of density effect on diverging JB-9014 detonation impelling, *X. Yu* Difference of original density has a remarkable effect on detonation performance of IHE (Insensitive High Explosive), which attracts much interesting of researchers. A serious of typical experiments were designed and the results were represented in this paper, in which the cooper shells with 2mm thickness were impacted by explosives named JB-9014 with different densities and the surface velocities of the OFHC shells were measured. The comparison of experimental data shows the free surface velocity of the OFHC shell increase with the IHE density clearly. Numerical modeling, which combined phenomenological reactive flow rate model using the two-dimensional Lagrange hydrodynamic code, were carried out in this paper to simulate the above experiments, empirical adjustments on detonation velocity and pressure and Pier Tangs adjustments on EOS of detonation products were both introduced in our numerical simulation work. The agreement between our computational results and that of experiment is excellent, and the numerical results with original parameters and the adjusted ones of JB-9014 could describe the density effect distinctly. Both the experimental results and the numerical modeling are significative to the investigators who deal with the detonation impact systems.

11 - The influence of magnetic field on RM instability of circular heavy gas eruption, *Z. Lin, Z. Chen* Richtmyer-Meshkov (RM) instability arises when a material interface is accelerated impulsively by shock waves. In this paper, initially, we study the RM instability of circular heavy gas cloud explosion, then we add magnetic field and conduct numerical simulations of circular heavy gas cloud explosion by using CTU + CT algorithm. The numerical results show that magnetic magnetic field have an impact on pressure in the flow field, thereby restrain the formation of spike and bubble caused by RM instability. We also find that these phenomena become more and more obvious with the increase of magnetic field intensity.

18 - Experiments and mechanisms of gas explosion suppression with foam ceramics, *B. Nie, L. Yang* Gas and coal dust explosion accidents especially continuous and multiple gas explosions is the chief disaster that cause group injuries and death, which bring much threat to safety production. The traditional water and rock powder shed could not work after the first explosion and the effect is limited, which leave rescuers into dangerous conditions. A steel square duct with a length of 18m was built in order to test capacity of foam ceramic to suppress gas explosion. The tested samples were made from Al_2O_3 and SiC with different thicknesses and porosities. Foam ceramics made of two materials (Al_2O_3, SiC) with different thickness and different porosity are studied experimentally. The results show that the foam ceramic has a significant attenuation of overpressure of gas explosion. Foam ceramics is porous material made of the pores and struts with good interconnectivity. During the explosion process, free radicals are reduced and heat cannot increase because pores of foam ceramic are small. So the quenching of flame is achieved.

21 - Explosion behavior of methane - dimethyl ether /air mixtures, *B. Zhang, H.D. Ng* In this study, the effect of dimethyl ether (DME) addition in promoting the ignition of methane/air mixture is investigated. In particular, the explosion and deflagration parameters of various CH_4-DME/air mixtures are systematically studied. Those parameters include flammability limits, maximum explosion pressure, pmax, maximum rate of pressure rise $(dp/dt)_{max}$, and laminar burning velocity S_L. In general, the experimental results indicate that both p_{max} and $(dp/dt)_{max}$ increase with increasing DME content in the total fuel. Simple correlations to evaluate the dimensionless pressure (p) of CH_4-air and DME-air mixtures with an initial pressure of 100 kPa are developed and given respectively by $p=1/[2.81839+(0.22424x_{CH4})-2.14347\ln x_{CH4})]$ and $p = 1/[1.04153+0.12637x_{DME}- 0.94532\ln(x_{DME})]$ where x is the volume fraction of the fuel. The experimental results also indicate that for lean CH_4 mixtures, the relationship between p_{max} and DME concentration exhibits an inversely U-shaped curve. In contrast, an exponential decay of p_{max} with increasing DME concentration is observed for rich CH_4 mixtures. By adding DME into the CH_4-air mixture, both the lower and upper flammability limits go down. The maximum amount of the total fuel (CH_4 plus DME) below which the mixture can be initiated is approximately 16%. Lastly, a good agreement is found in the determination of the laminar burning velocity S_L using both a theoretical model and the CHEMKIN-PREMIX simulation. For CH_4-DME/air mixtures, the S_L near the stoichiometric equivalence ratio $\varphi= 1$ is larger than the fuel lean or rich side. It is found that with a slight amount of DME adding into the lean CH4 mixture, making φ_{total} closer to stoichiometry, the value of S_L increases. However, with further addition of DME into lean CH_4 mixture, or DME adding into rich CH_4 mixture, only a decreasing behavior of S_L is observed.

25 - Numerical simulation of detonations in suspensions of RDX particles, *H. Dong, T. Hong, X. Zhang* Detonations of suspended RDX particles in air were simulated with two-phase flow model by using the CESE method. Formation, propagation and the parameters of detonations were obtained. The effects of particle diameter and concentration on the detonation character were examined. The run distance to detonation increases along with the rise of particle diameter or the fall of the dust concentration. By reducing the dust concentration, the lower limit of explosion was determined. The detonation process in a wavy tube was simulated. A cellular-like structure was observed.

27 - Numerical simulation for the thermal response of the pbx-2 explosive with confinement on fire, *X. Zhang, T. Hong, H. Dong, J. Lou, J. Li* Thermal explosion of the explosive is an uncontrolled self-heating effect of the exothermic reaction system. Under certain conditions (temperature, physical properties, dimensions and heat transfer conditions), smooth reaction can rapidly change to acute luminous or detonable phenomenon. This paper is intended to study the thermal stability of the PBX explosive under the abnormal circumstance of fire. The numerical simulation of the thermal response of the bomb, PBX-2 explosive with confinement on fire were carried out by means of FLUENT program, in which the charge sizes are 25mmx50mm and 50mmx100mm. The calculating condition of fire was proofread by the experiment. The time to ignition, the location of the ignition and the ignition temperature are obtained. The law of the thermal ignition of the explosive was

analysed. The results of the simulation show good agreement with that of the experiments.

32 - Dynamics of secondary breakup of emulsified fuel drop, *O. Girin* We consider a fuel drop of macroemulsion consisting of spherical fuel layer (SFL), which bounds the water vapor bubble. Behaviour of this system, which we called fuel globule, differs both from behavior of a liquid drop and of a gas bubble in an infinite liquid. In this regard the differential equation of a fuel globule radial motion is derived and key estimations are obtained. The latter show that SFL is affected by huge inertia forces, caused by acceleration of order. At such accelerations of SFL mass is affected by inertia force of. The question regarding hydrodynamic instability of SFL of Rayleigh – Taylor type arises, and this allows us to formulate a hypothesis of the possible SFL breakup by the instability mechanism. The justification is carried out via the analysis of feasibility of necessary conditions for the instability realization. It is done on the basis of regularities of SFL motion, which are obtained numerically. Calculations show that in the DE combustion chamber the fuel globule makes damped oscillations with the period. The analysis confirms that the external SFL surface is unstable and the necessary conditions are satisfied. The obtained relations give the opportunity to estimate the induction time of instability, the sizes and quantity of droplets, which are formed as a result of a fuel globule microexplosion. The value is small, so that it gives the possibility of the -fold growth of the disturbance amplitude. Therefore it is obvious that the instability has high probability of realization at external SFL surface at the moment of a fuel globule maximal expansion when the acceleration and related inertia forces are maximal. For water concentrations and at large ratio of vapour – to combustion chamber pressures there exists a possibility of the internal SFL surface instability. At the stage of breakup the inertia forces are pulling out the liquid from SFL in the form of thin stems in outward radial direction, making up a hedgehog form, and are blowing out thin films at penetration of air through SFL in inward counter-direction. All the surface of a fuel globule is divided thus by the two-dimensional unstable disturbances into the system of claviform cells, each of which consists of a stem and the surrounding air troughs. These cell elements form the droplets of different sizes at breakup. The total amount of droplets of secondary dispersion of EF is defined also by number of cells (is SFL radius at , is disturbance wavelength). The stem generates droplets, which have diameter (is SFL thickness at). There are also droplets of diameter formed by the film. Thus, the total number of the droplets formed at a fuel globule microexplosion equals to , where. These sizes are the key ones for calculation of further processes of preparation of homogeneous gas mixture in the diesel engine combustion chamber.

39 - Energies of prechamber initiation of detonation in propane-butane-oxygen and acetylene-oxygen mixtures, *V. Golub* A process of deflagration-to-detonation transition in propane-butane-oxygen and acetylene-oxygen mixtures, in an open channel with a circular cross section with a diameter of 3 mm, was investigated experimentally. Detonation initiation was carried out by burning the mixture in the prechamber connected to the channel. The prechamber was considered as an extended source for the initiation of the detonation of a finite volume. To measure the velocity of a flame front, photodiodes, installed along the axis of the channel, were used. To determine the boundary conditions at the entrance to the channel, a piezoelectric pressure transducer was used. The influence of the dimensions of the prechamber, equivalence ratio and fuel on the pressure profile, and evolution of the flame front along the axis of the channel are presented. It was shown that, the dynamics of the flame front and shock waves in the channel can occur in different scenarios depending on the geometry of the prechamber and equivalence ratio. Two limit effects of the prechamber detonation initiation in the channel have been analysed. The pre-detonation distances and the minimal energy of direct initiation of the detonation were determined.

40- The effect of oxygen concentration on the burning characteristics of kerosene droplets using spark ignition, *S. Yang, M. Wu* This study used experimental methods to investigate the combustion characteristics of kerosene at different oxygen concentrations. The droplets were spark ignited at an ignition energy of 0.1J and initial droplet diameter was 0.4~0.5mm. Combustion at different oxygen concentrations were observed, including droplet burning rate and flame standoff ratio (FSR). The results indicated that ignition delay of kerosene was longer under the conditions of 21%O_2/79%N_2 and resulting in a conical diffusion flame shape and the light was also less obvious. When the oxygen concentration was adjusted to 30%, the time required for ignition was significantly shortened and the light was centered on the top. At 100% O_2, the light-emission region apparently covered the droplet after ignition. The flame was apparently higher (FSR>6) and was more distant from the droplet when the droplet is burning under the condition of 21%O_2/79%N_2. However, the flame became closer to the droplet (FSR>5) and reduced in diameter when the oxygen concentration was increased to 30%O_2/70%N_2 and 100%O_2/0%N_2. When the flame was approaching the droplet surface, the evaporation rate increased alongside the heat transfer inside the droplet. The burning rate at different oxygen concentrations was K100%O_2> K30%O_2> K21%O_2. The results suggested during the process of droplet combustion, mass diffusivity affects diffusion of fuel vapor and oxidizer, which results in change of the mass burning rate.

42- Flame disturbance growth induced by a radial flow, *T. Tsuruda* The turbulence at the flame front of a propagating premixed flame induces its acceleration. Many studies have been performed on the growth of the flame front turbulence at premixed flame fronts. Most of these studies are based on the concepts of the flame induced turbulence and/or flame-turbulent flow interaction. There are two mechanisms for the intrinsic instability of premixed flame, hydrodynamic and thermodiffusive ones. The effect of hydrodynamic instability is counter-balanced by thermodiffusive instability that have a stabilizing effect that becomes stronger as the wave length of the disturbances is small. To understand the initial turbulence inception, the flow field turbulence in premixed mixture needs to be examined. If the intensities of diverging flow were made very large as accelerated by a pressure wave in experiments, gas flow turbulence would appear due to the viscous stress of the fluid. In this study, a simple simulation of viscous flow was carried out to determine the flow field observed in experimental studies. The flow in premixed mixture is laminar along smooth flame front. Due to thermal expansion of burned gas, the laminar flow becomes a radial flow. The combined flow of this radial flow and the flow caused by pressure wave is another radial flow with large velocity and a small flow angle. This combined flow is not purely expanding flow at large velocity. A periodic flow appears in premixed mixture normal to the flame front. The viscous stress determines the appearance of these periodic flows.

46- Towards second-order algorithm for the pulsating detonation wave modeling in the shock-attached frame, *A. Lopato, P. Utkin* Numerous theoretical computational studies are devoted to the investigation of the mechanism of pulsating one-dimensional detonation wave propagation using shock-capturing schemes which cause the leading shock smearing. The essentially different formulation includes the transition to the shock-attached frame. In this case the leading shock wave becomes one of the boundaries of the fixed computational

domain and so the problem of the leading shock smearing is solved. However in the shock-attached frame one should introduce the shock speed evolution equation to define new unknown. We proposed the second approximation order algorithm for the shock speed evolution equation integration for the pulsating detonation wave investigation in the shock-attached frame. The algorithm is based on the method of characteristics. The whole mathematical model is a set of Euler equations with one-step Arrhenius kinetics written in the shock-attached frame. The whole computational algorithm is based on the physical processes splitting technique. The key point in gas dynamics equations integration procedure is the combination of ENO-reconstruction approach, monotone Courant-Isaacson-Rees numerical scheme in conservative formulation and Runge-Kutta time stepping. The local quadratic approximation for the characteristics curve, quadratic space interpolation procedure and three-point one-sided approximation for the derivatives along the characteristics are used in the algorithm for shock speed evolution equation integration. The algorithm is verified on shock overtaking another shock test as it is the model of the interaction of the internal shock with the leading wave in the unstable detonations. The numerical investigations of pulsating detonation wave propagation in four cases stable, weakly unstable, irregular and strongly unstable detonations are carried out. For the stable case the estimated approximation order of the numerical algorithm is 1.76. The algorithm is robust for the cases of irregular and strongly unstable detonations.

59- Al/CuO nanothermite shell assembled via depositing aluminum nanoparticles onto CuO nanowire array on a copper wire, *M. Wu, Y. Chiang* A novel method for assembling Al/CuO thermite on a copper wire has been successfully developed. The method is based on electrophoretic deposition of aluminum nanoparticles onto CuO nanowire array on the surface of a copper wire. The copper wire act as both the base material for growing CuO nanowires through thermal oxidation, and as the carrier of the nanothermite shell. It has been found that the density and length of CuO nanowire array obtained by oxidizing copper wires in a box furnace at 550 ºC for 3 hours was suitable for the assembly with 90 nm aluminium nano spheres. Aluminium nanoparticles were first dispersed in ethanol water solution, and then driven into the gaps of CuO NWs under the influence of electric field between the side wall of the copper tube containing the dispersion medium and the copper wire itself. Various EPD electric field gradients have been applied for the assembly. Ignition temperature of the nanothermite shell formed through the electrophoretic deposition process was found to be around 575 oC. The first stage of the thermite reaction peaked at ~ 630 oC. The ignition temperature was lower than the melting temperature of aluminum indicating that the reaction was solid-solid reactions between aluminum and copper oxide. Beyond the melting temperature of aluminum, a second stage reaction between the liquid aluminium and remaining copper oxides was also found.

61- Some aspects of rotated detonation waves, *A. Vasil'ev* Some important aspects of rotated detonation waves are discussed in this report: correlation of acoustic characteristics of reaction products with rotation velocity of transverse waves; velocity deficit and energy-release; multifront system of rotated transverse waves; streak-records trajectory of rotated transverse wave on moving film

70- Influence of a dispersed ignition in the explosion of two-phase mixtures, *J. Pascaud* The aim of this work is to study the effects of a multi-source ignition in a wide energy range on a two-phase mixture explosion composed of agricultural dusts with a gaseous fuel (methane or propane) and more particularly the pressure history inside a partitioned vessel. The initiation is introduced in the form of an increase of internal energy and a calculation methodology, particularly interesting in the field of the risk assessment is used to simulate the transmission of the explosion from one compartment to another adjacent compartment by the means of the hot flow through the shared orifice and finally to generalise this methodology to a complex multi-partitioned structure. The basic characteristics of the model have been developed for the ignition and the combustion of dust suspensions and adapted to hybrid mixtures with appropriate parameters linked to simplified kinetics. A simple representation of the combustion phenomena based on energy transfers and the action of specific molecular species is presented. The model allows the study of the influence of various parameters such as the dust or the gas concentration, the different ignition energies and their locations, the size of the inner openings or the vent areas. The theoretical results have been compared with many data available in the literature and indicate correct preliminary tendencies.

71 - Modes of chocked flame instability and transition to detonation defined by the peculiarities of combustion kinetics at rising pressure, *A. Kiverin, I. Yakovenko* The aim of the paper was to analyze the structure and the stability of the chocked flames to understand the origins of different possible combustion modes, including quasi-stable supersonic flames and deflagration-to-detonation transition. By means of numerical analysis it is shown that the chocked flame structure and its stability are defined by two basic mechanisms: compression of the fresh mixture ahead of the flame front and compression of the reacting mixture inside it. The first mechanism provides burning velocity increase, the second one can either accelerate or decelerate reaction depending on the pressure-dependent reaction behaviour in the observed pressure range and depending on the rate of compression. In case of reaction intensification with rising pressure a detonation forms on the leading edge of the flame front. Otherwise the flame propagates in a quasi-stable supersonic regime consisting of consequential stages of deceleration and re-acceleration. On the deceleration stage the compressed fresh mixture chocked by the supersonic flow in the vicinity of the flame tip flows downstream generating the compression wave ahead. The new contact surface between this packet of compressed mixture and the fresh mixture ahead of the flame front can become the kernel of the exothermal reaction, evolving in a deflagration wave or even detonation. Depending on the conditions of prior flow evolution the new kernel of auto-ignition can be formed at different distance out from the flame surface: directly ahead of the flame front, between the flame front and the leading shock, directly behind the leading shock. The obtained interpretation agrees well with the available experimental data.

72- Development of the constant volume spray combustion chamber for ignition quality testing of diesel-like fuel , *C. Wu, K. Chen, T. Hsu* In the present study, a constant volume spray combustion testing device was fabricated to measure the ignition quality for diesel-like or low volatility liquid fuel. The testing chamber has been well verified using blended n-Hexadecane and 2, 2, 4, 4, 6, 8, 8- Heptamethylnonane with variant cetane number. According to the preliminary results, the device can be used to measure cetane number for low volatility fuels and to calculate the heat release rate based on measured pressure.

265- A re-evaluation of lamppost deflection data in the Buncefield Explosion, *R. Rogers, J. Venart* Subsequent to the devastating Buncefield unconfined vapour cloud explosion (UCVE) there have been at least three further very large UCVEs involving evaporating gasoline type hydrocarbons each that formed very large clouds with lateral dimensions of several hundreds of meters, under essentially non existing wind conditions. These four events had devastating repercussions. The first occurred at Buncefield in December 2005 in the UK. There

soon followed three more; IOC, Jaipur India 2009, Gulf Oil in San Juan Puerto Rico 2009, and Amuay, Venezuela 2012. The direction of blas was inferred in most cases by directional indicators such as scouring, bendinding or collapse of light posts and the tearing off of small branches and their displacement. This paper presents some finite element deformation studies of lampposts and their comparison to photographs. The analyses reveal discrepancies in the assumed blast directions which if true should cause a revaluation of ignition and and blast formation.

8:30 – Plenary lecture 2

Extreme states of matter and rarefaction, generated by the explosive driven shock waves, *V. E. Fortov* The behaviour of matter at extremely high densities is of high interest for understanding the structure and evolution of astrophysical objects and many modern energy technologies. Dynamic methods of generation of warm dense matter at extremely high pressures, based on the compression and heating of matter in intensive shock waves, adiabatic expansion of preliminary compressed matter and quasi-isentropic compression are considered. To generate shock waves in the terapascal pressure range the cylindrical and spherical condensed high explosives, laser and corpuscular beams, high velocity impacts, and soft X-rays were used. The highly time-resolved diagnostics of the extreme states of plasma were carried out with differential laser indicators of velocity, fast acting electron-optical transducers, pyrometers, and high-speed spectrometers equipped with the electron-optical transmission lines. The experimental data obtained and the physical models of behaviour of plasma at extremely high pressures, temperatures and deformation rates are discussed. These are the metallization and dielectrization of strongly compressed matter, high energy density thermodynamics and phase transitions, including plasma phase transitions. Shear viscosity of matter as an indicator of particles correlations in a wide region of parameters from Plank's scale to laboratory conditions is analyzed. Wide-range semi-empirical equations of state and models are constructed, which were used for multidimensional numerical simulation of pulsed high-energy processes and description of solar plasma.

9:40 Astrophysical and terrestrial combustion 1

276- Invited Review: Astrophysical combustion: from a laboratory flame to a thermonuclear supernova, *A. Poludnenko* Despite seemingly vast differences, burning in astrophysical plasmas and chemical systems on Earth bears many similarities both in terms of the underlying physical model and the key open challenges. Thus, it is well warranted to ask the following two questions. 1) Can theoretical, numerical, and experimental advances in terrestrial combustion help address open problems in astrophysical combustion? 2) Conversely, can astrophysical systems provide a unique and complementary (in terms of extreme spatial and temporal scales, physical conditions, etc.) test bed for our understanding of the dynamics of flames and detonations? The goal of the special session on astrophysical combustion at the ICDERS 2015 meeting is to promote the dialog between the astrophysical and chemical combustion communities with the aim of answering these two questions. In this talk, I will give an overview of both the similarities and differences in terms of the underlying physical model between chemical and astrophysical combustion, as well as of the open challenges facing both communities. The goal of this talk is to provide an introduction for the subsequent presentations in this special session.

103- Understanding Ignition in Type Ia supernovae (Invited), *M. Zingale, A. Jacobs, A. Almgren, J. Bell, A. Nonaka, C. Malone, S. Woosley* Type Ia supernovae (SNe Ia) share many similarities with chemical reacting systems. We describe the details of the ignition phase of SNe Ia by performing detailed simulations of the convective flow leading up to the formation of the burning front in two different progenitor models.

197- Shock and adiabatic compression ignitions of inhomogeneous gas and two-phase flows (Invited), *O. Penyazkov* Experimental modeling of energy release deposition and reaction behaviour associated with a problem of combustion and detonation initiation in reaction systems is important for theory and applications. At real conditions, the traditional assumption on homogeneous distribution of local flow parameters is never fulfilled. For this reasons mainly all combustion and detonations initiation events are local and dependent on specific features of primary hot spots formation, which predetermine subsequent propagation scenarios in reaction flows. In this sense the ability of reactive system to generate hot spots (or exited states) any ways determines the sensitivity to explosions. Several mechanisms can be responsible for hot spot formation in standard gasdynamic environment. These are the local velocity fluctuations across the flow field resulting in occurrence of stagnant zone with higher temperature and pressure, interaction of shock-compression waves each other, with boundaries and local flow gradients, local remote temperature and radical excitations, and the presence of ultrafine or catalytic particles in the flow with higher reactivity. Several experimental means of hot spot formation and their influence on auto-ignitions of inhomogeneous gas and two-phase flow are considered here. We investigated the influence of 2D and 3D shock-wave collisions on auto-ignitions in hydrogen/propane/air mixtures behind reflected shock waves. Different collisions and, subsequently, reactive hot spots were produced at interaction of the incident shock wave (ISW) with wedge and conical walls. Induction times and auto-ignition modes of the mixture (strong, transient and weak) were measured by means of pressure, ion current, emission observations and high-speed imaging. The results were compared with a reference data obtained behind normally reflected shock waves. The kinetic consideration of necessity of hot spot formation for steady state detonation propagation is made on the basis of time-resolved induction and reaction time measurements. Low-temperature auto-ignitions of hybrid particle/methane/hydrogen/air mixtures at conditions of rapid compression were also studied in RCM machine. It was found that at temperatures lower 1000 K methane and hydrogen ignitions occur only when some amount of reactive particles are presented in the test volume. It was shown that auto-ignition of ultrafine particles starts to be earlier and control subsequent initiation of gas phase combustion at lower temperatures. The results are compared with shock tube data obtained at the same temperature and pressures and, finally, different scenarios of the deflagration to detonation transition (DDT) in stationary and turbulent reacting flow are considered. Dynamic gasdynamic peculiarities of a combustion-driven shock wave complex are measured. It is shown that transmissions of a shock wave followed by deflagration into a semi-confined area could essentially facilitate the following detonation re-ignition and reduces the sensitivity and requirement for driver tube mixtures. Such transmission could produce the successful detonation initiation in a large volume, at least, at five times lower initial pressure than for the classical direct detonation transmission case. Different local detonation initiation events are captured and visualized by different high-speed imaging techniques.

9:40 Detonation dynamics 1

204- Research on detonation propagation in a 90-degree bifurcated tube, *L. Li, C. Teo, J. Li, P. Chang, V. Nguyen, B. Khoo* Study on deflagration/detonation propagation in a bifurcated tube is very important since it can be useful in energy and chemical industries about pipe or tunnel design for explosive hazard prevention. In this study, experiments using Schlieren technique were performed to provide direct visualization results regarding detonation reflected re-initiation and DDT phenomenon in a specially designed testing channel. For detonation re-initiation process, the generation of the Mach stem and the multiple reflections are the key factors for detonation successful re-initiation. For DDT process, two different transition modes classified by the initial wave velocity were identified. Future work will be conducted to further address some details and mechanisms using a longer optical

accessible tube and other optical measurement techniques such as PLIF

288- Modeling of Rayleigh scattering imaging of detonation waves, *G. Bechon, R. Mevel, D. Davidenko, J. Shepherd* A detailed Rayleigh scattering model has been implemented and used to postprocess detonation wave numerical simulation results to allow for a direct comparison with previous experimental visualizations of detonations in hydrogen-based mixtures. A quantum chemistry approach has been employed to obtain realistic Rayleigh scattering cross-sections. A database of Rayleigh cross-sections for relevant species was created and validated against available experimental data. Steady one dimensional as well as unsteady two-dimensional simulations of detonation were used for comparison with experimental Rayleigh profiles and images. We demonstrate that both realistic Rayleigh scattering cross-sections and the characteristics of the imaging system have to be taken into account to accurately reproduce the experimental results. We show how this approach can be applied to estimate the performance and design improved Rayleigh imaging systems.

14- Experimental measurement of cell size at high pressure, *C. Stevens, J. Hoke, F. Schauer* In this research, the cell size of hydrogen-air and ethylene-air mixtures at 1 and 10 atm was measured using a focusing Schlieren technique. Measurements at 1 atm agreed well with existing data, and measurements at 10 atm are a first for both fuels.

9:40 Detonations in propulsion 3

81- Development of a liquid-purge method for valveless pulse detonation combustor using liquid fuel and oxidizer, K. *Matsuoka, K. Muto, J. Kasahara, H. Watanabe, A. Matsuo, T. Endo* Toward the practical use of a pulse detonation combustor (PDC), both long-time and high-frequency operation are required. We developed a novel method of operation for a valveless PDC in which burned gas is purged by injecting liquid droplets into the PDC and gaseous fuel and oxidizer are supplied to the PDC in the valveless mode. The newly developed purge method is called the liquid-purge method (LIP method). In the present study, a liquid fuel (ethylene) and liquid oxidizer (nitrous oxide) were applied to the purging material instead of liquid water to apply a PDC to aerospace propulsion engine. Measured propagation speeds were in the range of 109 ± 5 % (ethylene) and 102 ± 6 % (nitrous oxide) of the CJ detonation speed of the undiluted stoichiometric ethylene-oxygen mixture at the ambient conditions, so demonstrated the valveless PDC operation at 100 Hz. It was found that the quantity of injected liquid droplet per unit cross-sectional area of the PDC is an important parameter governing the stable operation of the PDC with the LIP method even if ethylene or nitrous oxide was used as a liquid droplet instead of liquid water.

165- Heating and acceleration of particles by high-frequency pulsed detonations, *T. Endo, R. Obayashi, T. Tajiri, K. Kimura, Y. Morohashi, T. Johzaki, K. Matsuoka* It is important for the operation of a pulse-detonation combustor (PDC) that the residual hot burned gas is purged before refilling the PDC with fresh detonable gas. The authors developed two high-frequency operation modes of PDCs which we call the inert-gas-purge (GAP) mode and the liquid-purge (LIP) mode. The GAP-mode operation of a PDC is very stable and durable because it is moving-component free, although pure fuel-oxygen combustion is impossible because the detonable gas is unavoidably diluted by the inert gas for the purge process in principle. Contrary, almost pure fuel-oxygen combustion is possible in the LIP-mode operation because the liquid-gas phase transition of the injected liquid droplets is not so fast, although the liquid-droplet injector has to be actuated every cycle. The authors intend to apply the developed technologies for the high-frequency operation of PDCs in the field of thermal spray. In order to examine the ability of the developed PDCs to heat and accelerate spray particles, we carried out experiments on heating and acceleration of the particles of CoNiCrAlY, which is a material often used for thermal barrier coating. In the experiments, we operated two kinds of PDCs in the GAP and LIP modes at 150 Hz. CoNiCrAlY particles were heated and accelerated by injecting them into a PDC, and the temperature and speed of the in-flight particles were measured at 0.1 m from the PDC exit. The highest particle temperature observed in the LIP-mode operation was higher than that in the GAP-mode operation by about 1000 K. On the particle speed, the highest particle speed measured for the LIP-mode operation was higher than that for the GAP-mode operation by only about 50 m/s. The differences in the measured particle temperature and speed between two operation modes were qualitatively what we expected, but quantitatively not, considering the difference in the CJ detonation parameters between two operation modes. For the quantitative analysis, we carried out simple model calculations. The calculation results well reproduced the experimental results. Analyzing the calculation results, the following was found out. The increase of the particle speed due to the acceleration by the burned-gas jet outside the PDC intensively reflected the difference in the gas-flow speed at the CJ surface of detonation. However, the difference in the increase of the particle speed due to the acceleration by the flow of the fresh detonable gas inside the PDC reduced the difference in the particle speed to only 27% of the difference in the gas-flow speed at the CJ surface of detonation. The large difference in the particle temperature between two operation modes was due to the difference in the thermal conductivity of gas between two operation modes. That is, the thermal conductivity of gas for the GAP-mode operation was smaller than that for the LIP-mode operation because the mole fraction of argon, which was used as the purging gas and a monatomic molecule with a large molar mass, was large (54%) in the burned gas for the GAP-mode operation.

292- Gas dynamics in the inlets of a valveless micro pulse detonation engine, *Z. Chen, M. Wu* Gas dynamics in the inlets of a valveless micro PDE operating without the purging stage was studied using high-speed shadowgraph in this research. A transparent pulsed detonation engine was built for the high-speed visualization. Detonation channel, mixing section, and inlet channels were fabricated on a 1 mm thick stainless steel plate. Mean width of the 79 mm long detonation channel with zig-zag side walls was 3 mm, and the width of the 17 mm long straight mixing section as well as the inlet channels were 2 mm. The fuel channels intersect the oxygen channel from the sides at 30 degrees. It has been found that back flow of burned gas mixture into the inlet channels is crucial for the interruption of the reaction, and thereby stable pulsed detonation. Reaction may be stabilized at the intersection of fuel and oxidizer inlets if the mixing planes of fuel and oxidzer were not properly isolated from high temperature burned gas. Under lower supply pressures, small amount of unburned mixture was squeezed into the inlet channels that allowed the reaction to propagate further backwards into the inlets. At higher ethylene/oxygen pressures above 436/520 kPa, no reaction front was observed in the fuel and oxygen manifolds due to the faster reaction front velocity that largely reduce the length of the unburned gas section between the shock and the reaction front, and all unburned mixture was consumed at the intersection. However, the back flowing burned gas would eventually filled the intersection and part of the inlet channels that interrupted mixing between fuel and oxidizer at the intersection in all cases. Refill stage of the pulsed detonation cycle was initiated by reflow of oxygen into the inlet channel. Cooling by the oxygen flow as well as the enhanced heat loss of the miniature channel reduce the temperature of the mixture near the intersection. Thus, pre-

ignition would not occur as ethylene also began to flow into the intersection, and the mixing plane was re-established.

9:40 Flame acoustic interactions 1

114- Direct and indirect combustion noise in an idealised combustor, *Y. Mahmoudi, A. Dowling, S. Stow* We examine travelling of acoustic, entropy and vorticity perturbations created by a flame zone through a thin annular choked nozzle, where a normal shock wave is present in the divergent section of the nozzle. The nozzle is assumed to be acoustically compact. Exact solutions are developed for the acoustic, entropy and vorticity waves at the outlet of the nozzle. For simplicity a low Mach number approximation is made upstream and downstream of the nozzle. It is found that the pressure and entropy perturbations at the nozzle outlet can be obtained directly from the density perturbation at the nozzle inlet. Thus, there is no need to model either the linear waves or the mean flow within the nozzle including the supersonic region. For an idealised combustor model, compared to the direct acoustic noise, the entropy indirect noise is found to be the main source of noise at the combustor outlet, while the indirect vorticity noise has negligible contribution.

57- Finite amplitude disturbance interaction with premixed laminar flames, *M. Aslani, J. Regele* Flame-disturbance interactions are primarily studied with either acoustic or strong shock waves with little information about the behaviours that may exist between them. In this work the interaction of a premixed laminar flame with a finite amplitude compression wave is studied numerically using 2-D simulations. The interaction is characterized based on the properties of an idealized compression wave that is modeled as a shock followed by an expansion fan of some prescribed length. Compression waves that have wavelengths on the order of or an order of magnitude larger than the flame thickness show a more rapid increase in flame surface area than in shocks or very short compression waves. On the other hand, the average burning speed increases linearly in the shock interaction while it fluctuates slightly for the compression wave cases.

99- Methane/Hydrogen/Air flame oscillations in open ended tubes, *C. Ebieto, N. Amaludin, R. Woolley* Experimental investigation to determine the laminar flame speed of methane-air mixture and methane hydrogen-air mixtures has been carried out using a 20 mm internal diameter quartz tube opened at both ends. The flame was ignited using flame ignition and the flame propagation captured. The following observations/findings were drawn from the experimental measurements: (1)Three types of behaviour were observed, the flame propagated down the tube steadily (= 0); II, the flame propagates down the tube steadily and is then subjected to violent acoustic oscillations resulting in an increase in the burn rate (= 0.1 to 0.3); III, the flame propagates down the tube steadily and is then subjected to acoustic oscillations that result in a decrease in the burn rate (= 0.4 to 0.5). (2) The frequency of the acoustic oscillations was similar for all flames (~ 240 Hz) and is thought to be a characteristic of the tube. (3)The flame area (here approximated by the number of grey/white pixels) appeared to have some influence on the underlying flame speed. The larger area flames were observed tended to travel faster.

11:25 Astrophysical and terrestrial combustion 2

24- Turbulent combustion in astrophysical systems (Invited), *F. Roepke* Combustion processes drive the evolution of many astrophysical systems. Although some details differ from terrestrial combustion due to the extreme conditions in stellar systems, many of the concepts still apply and have been successfully employed to astrophysical simulations. I will review the particular problem of modeling the interaction of deflagration fronts with turbulence, an effect that is eminent in thermonuclear explosions of white dwarf stars that are thought to explain the astronomical phenomenon of Type Ia supernovae. Recent progress in combustion modeling and super-computational power led to a breakthrough in multidimensional simulations of these events. This facilitates the prediction of observables and the validation of the models based on direct comparison with astronomical data.

170- Expanding statistically spherical premixed turbulent flames and astrophysical combustion (Invited), *A. Lipatnikov* While certain basic features of astrophysical nuclear combustion, e.g. extremely wide range of scales, huge Reynolds and Lewis numbers, moderate density ratios, strong gravitation, etc., are very peculiar when compared to terrestrial chemical premixed turbulent flames, modeling of the astrophysical burning is still strongly based on knowledge gained by investigating the chemical flames. Among various premixed turbulent flames studied in terrestrial laboratories, expanding statistically spherical flames appear to be most similar to deflagration waves associated with the astrophysical combustion. Moreover, the global features of the spherical flames are thoroughly investigated by many research groups in a wide range of substantially different conditions, with many important physical mechanisms of premixed turbulent burning manifesting themselves well in experiments with such flames. Accordingly, the goals of the present work are (i) to overview key effects documented in experiments with expanding statistically spherical premixed turbulent flames, with particular emphasis being placed on effects disregarded often in astrophysical applications, (ii) to discuss capabilities of available numerical models for predicting these effects, (iii) to highlight unresolved basic issue, and (iv) to contribute to bridging a gap between chemical and astrophysical combustion communities. In particular, first, dependencies of turbulent burning velocity on rms turbulent velocity, laminar flame speed, Lewis number, and pressure will be discussed, as well as physical mechanisms that control these dependencies for different combustion regimes and capabilities of contemporary models for yielding qualitatively similar dependencies. Basic limitations of the widely used linear relation between turbulent burning and rms velocities will be stressed, and alternative expressions that well reproduce experimentally documented trends will be considered. Second, based on a strong effect of the Lewis number on the turbulent burning velocity, an important role played eventually by so-called leading points in premixed turbulent combustion will be emphasized, followed by discussion of whether the propagation of premixed turbulent flame is governed by creation of flame surface area by turbulent eddies within the mean flame brush or the flame brush is pulled forward by its leading point. At high Lewis numbers, this issue appears to be straightforwardly relevant to an issue regarding a range of turbulent eddy scales (small-scale eddies unresolved in LES or resolved large-scale eddies) that controls the flame expansion. Third, the growth of turbulent flame speed and mean flame brush thickness will be addressed, as well as the influence of the Darrieus-Landau mechanism on the dynamics of large-scale turbulent flame kernels. Importance of properly predicting the thickness will be emphasized and limitations of available models will be shown. Fourth, a role played by the density ratio in premixed turbulent combustion will be considered and physical mechanisms and phenomena that are particularly sensitive to the density ratio will be discussed.

224- Rayleigh-Taylor unstable flames: speed and structure, *E. Hicks* Type Ia supernovae are extremely bright stellar explosions whose light curves can be calibrated for use as standard candles in cosmology. Researchers simulating these explosions have a problem: the driver of the explosion, a flame less than 1cm wide,

is so much smaller than the size of star that it can't be resolved in the simulations. So, full-star simulations of Type Ia supernovae must include a subgrid model that sets the flame speed below a certain scale. These subgrid models take into account the complex small-scale effects of the gravitationally-driven Rayleigh-Taylor (RT) instability, turbulence generated by the RT instability, and burning on the flame speed. Two main types of subgrid models are currently in use: turbulence-based models and RT-based models. The choice of subgrid model drastically affects the full-star simulation outcome, yet there is no agreement about which models are most accurate. In this paper, we discuss DNS simulations of RT unstable flames and compare measurements from these simulations to the predictions of different turbulent flame speed models. Our main focus is on whether or not RT unstable flames behave like traditional turbulent flames.

11:25 Detonation dynamics 2

300- Ethylene-air detonation in water spray, *G. Jarsale, F. Virot, A. Chinnayya* Detonation experiments were conducted in a 52mm square tube with C_2H_4/Air/H_2O(L) mixtures. Equivalent ratio ranges from 0.9 to 1.1. An ultrasonic atomizer generated a liquid water spray with droplets of 8.5-12 μm diameter, for liquid water mass fraction varying from 0 to 7 % Cellular structure was recorded on soot plates and detonation velocities were measured by 7 pressure gauges. Results show detonation propagation regime very close to theoretical CJ velocity. The Detonation behaviour is similar to those in gaseous detonation. Investigations highlight the influence of small amount of water on a detonation, for, a dramatic cell size increase has been observed, from a multi-cell to a half-cell regime. The detonation velocity, on the contrary, slightly decreases. No large velocity deficits were observed before detonation failure.

53- Influence of mechanoactivation on detonation parameters of perchlorate based mixtures, *A. Dolgoborodov, V. Kirilenko, A. Shevchenko, M. Brazhnikov, V. Teselkin* The influence of mechanical activation on the detonation process of mixtures based on ammonium perchlorate with aluminum was investigated. The optimal conditions were found for mechanical activation of these mixtures in a planetary ball mill to obtain compositions with the highest reactivity. The analysis by X-ray diffraction and electron microscopy showed that during mechanical treatment the crushing of particles and there intermixing occur without chemical interaction between components. Mechanical sensitivity, dependences of burning rate and detonation velocity on activation time and charge densities were investigated. The obtained results showed that, compared with conventional mixtures the velocities of combustion and detonation of the activated compositions can be essentially increased due to increased reactivity.

311- Impact of nitromethane addition on the detonation properties of n-heptane / oxygen mixtures, *N. Chaumeix, B. Imbert, S. Abid, L. Catoire, C. Paillard* The experimental study is aimed at the analysis of the promoting effect of nitromethane as an additive to n-heptane/oxygen mixtures. The detonation properties of different amounts of nitromethane added to n-heptane are determined using a detonation tube. The possible transition from shock to detonation is also analyzed based on a the simulation of ignition delay times behind the leading shock. For this, a mechanism for the oxidation of nitromethane / n-heptane / oxygen mixtures has built-up based on the literature and our previous work.

11:25 Detonations in propulsion 4

15- Experimental testing of a rotating detonation engine coupled to nozzles at conditions approaching flight, *M. Fotia, F. Schauer, J. Hoke* Experimental testing is conducted on laboratory scale rotating detonation engines that are coupled to various nozzle concepts. The goal of the testing is to better understand the interactions between the detonating combustor and the nozzle, while noting the implications that the various configuration have on attained performance. Testing is conducted over a limited range of inlet condition. The corresponding flight enthalpies, the experimental trends in the behavior of the rotating detonation engines and the current work to expand this understanding is discussed.

69- Influence of gradual expanding channel cutoff on propagation of the toroidal detonation wave, *M. Wakita, T. Himono, K. Kikuchi, S. Kameyama, T. Totani, H. Nagata* We have proposed a PDE initiator, which consists of a predetonator and a reflector to achieve reliable transmission of detonation wave to a pulse detonation engine (PDE) combustor. A series of experiments was performed to find out the path width at which the conical part can be cut down without performance decrement, and to confirm our hypothesis that the path width at which the conical part can be cut down is 4 times of the cell size λ. The obtained results are as follows: Even if the cone part was cut at the position which L'/λ; is larger than 4, the cutoff reflector has same effect as the traditional cone reflector and leads also to weight reduction. Due to existence of the transition region of cell size during the wave expansion, it is mostly in agreement with a hypothesis, through the marginal case is observed near the threshold values

22- Modeling of non-stationary gas flow in annular nozzle, *V. A. Levin, N. E. Afonina, V. G. Gromov, I. S. Manuylovich, G. D. Smekhov, A. N. Khmelevsky, V. V. Markov* Search for new nozzle devices that can compete in jet engines with traditional Laval nozzles, is one of the promising directions on a way of improvement of their overall-mass and specific characteristics. In this respect the certain interest are represent annular and dual-slotted nozzles with deflector in the form of a spherical segment. As have shown experiments , there are various modes of gas flow in such nozzle devices. In steady-state operation, they belong to the class of nozzles with the central body. In non-stationary periodic pulsing operating modes specified nozzles represent high-frequency pulsed outlet devices. Such devices are considered to be promising for realization of pulsed detonation regime of fuels combustion. In this paper, based on the Navier-Stokes equations, it is carried numerical parametric study of the influence of various factors on the development over time of the initial perturbations caused by the device start, blown by air, under a laminar flow model. In the calculations parameters of the numerical scheme and determinative conditions of problem were varied. As a result, in the calculation first discovered the flow regimes in which the starting perturbation accompanying the start of the annular nozzle, do not decay, and pass into the quasi-periodic regime. Determined the Fourier frequency spectrum of the pressure fluctuations in the center of the deflector thrust wall and the value of nozzle thrust. Showed typical pulsed pressure signals obtained in the computational model and registered in the experiments that are performed in an pulsed aerodynamic setup using as a working gas air and combustion products of stoichiometric air-acetylene mixture.

11:25 Flame acoustic interactions 2

153- Effects of variation of the flame area and natural damping on primary acoustic instability of downward propagating flames in a tube, *Y. Sung Hwan, O. Fujita* This paper provides experimental evidence regarding the effect of the flame area and natural damping on primary acoustic instability of downward propagating flames in a tube. The conclusions are as follows: 1) Depending on the thermal diffusivity and kinematic viscosity of the mixture, two different cases, one with no acoustic vibration and the other with acoustic vibration, are

found even for the same laminar burning velocity. 2) When laminar burning velocities and the activation energy are very low, primary acoustic instability does not appear. This might arise because the energy input to the vibration system is too small in comparison with the natural damping effect. 3) Although it is expected that the increase of the flame surface area causes primary acoustic sound, the sustained growth of flame area on laser irradiation did not contribute to the onset of acoustic instability in the present experiments. 4) The restabilization of the secondary acoustic instability was observed under certain conditions.

36- Effects of gas compressibility on the dynamics of premixed flames in long narrow channels, *V. Kurdyumov, M. Matalon* Effects of gas compressibility on the dynamics of premixed flames in long narrow adiabatic channels open at both ends are studied. A fast traveling flame generates pressure waves in the unburned gas ahead that tend to preheat the fresh mixture, adding to the heat transferred by conduction that is mainly responsible for its propagation. The pressure waves are generally weak and the question is whether they could, in long enough channels, lead to a significant increase in the flame propagation speed.

206- Interaction between thermoacoustic oscillation and vortical motions in turbulent swirling premixed flame, *K. Aoki, M. Shimura, Y. Naka, M. Tanahashi* Combustion oscillations caused by thermoacoustic instabilities are critical for operations of practical gasturbine combustors. Though a lot of investigations about thermoacoustic instability have been conducted, interactions between thermoacoustic oscillation and vortical motions have not been elucidated sufficiently despite their importance of combustion instabilities. To investigate dominant oscillation modes of pressure and heat release rate and interaction between their oscillations and vortical motions, dynamic mode decomposition (DMD) and thermoacoustic instability analyses are conducted for the results of direct numerical simulations (DNS) of hydrogen-air turbulent swirling premixed flame. The DNS in this study is conducted for two swirl number cases of S = 0.6 and 1.2, considering detailed kinetic mechanism of hydrogen-air mixture and temperature dependence of transport and thermal properties. The DNS results for S = 0.6 show that large-scale helical and ring shaped vortical structures appear in the upstream region of the combustor, whereas a lot of fine-scale eddies emerge in the downstream region. As for S = 1.2, large- and fine-scale eddies emerge in relatively upstream region compared to low swirl number case and combustion process is almost completed in the upstream region. Heat release rate is distributed along the large- and fine-scale vortices and shows complex distribution in the downstream region since flame front is distorted by a lot of fine-scale eddies. Pressure distributions on the walls show different regular patterns depending on the swirl number. It implys that dominant natural acoustic mode in the combustor strongly depends not only on the shape of the combustor, but also on the swirl number. Spectral analysis of vortical motions shows that the periodic motions of large-scale ring and helical shaped vortices have large energy. The DMD results of pressure field for S = 0.6 show that the most dominant mode of pressure is the longitudinal quarter wave mode of the combustor and a transverse acoustic mode induced by the large-scale ring shaped vortical motion is also strong. As for high swirl number case, it is shown that the longitudinal quarter wave mode is not dominant and much shorter-term mode induced by large-scale vortical motions is most dominant. The DMD results of heat release rate fields reveal that the oscillations of heat release rate interact mainly with transverse acoustic modes and large-scale vortical motions for both cases. Moreover, thermoacoustic instability analysis in terms of acoustic energy transfer shows that the frequencies where acoustic energy is actively transferred agree well with those of large-scale vortical motions. Moreover, the regions where acoustic energy is supplied corresponds to those where large-scale ring shaped vortices break down and a lot of fine scale eddies emerge for low swirl number case. As for high swirl number case, acoustic energy is supplied in the inner and outer shear layers where large-scale vortical structures are generated. These results suggest the importance of interactions between pressure, heat release rate and vortical motions to thermoacoustic instability.

14:00 Astrophysical and terrestrial combustion 3

301- Mechanisms of DDT in terrestrial systems (Invited), *V. Gamezo, A. Poludnenko* Deflagration-to-detonation transition (DDT) is one of the key unsolved problems in the theory of Type Ia supernovae (SNIa), and is still not completely understood for terrestrial chemical systems. It is rather paradoxical that while DDT in terrestrial systems is routinely observed in laboratory experiments, the actual detonation initiation was never observed with enough detail to clearly identify the mechanism of this initiation. This is related to a wide range of length and time scales involved at different stages of DDT, and a stochastic nature of DDT. As a result, it is difficult to predict the time and location where the detonation will appear, and then apply experimental diagnostics at this location with enough resolution. Nevertheless, at least two distinct mechanisms for the detonation initiation at the second stage of DDT were analyzed theoretically an identified in numerical simulations. These include the gradient mechanism and the spontaneous runaway of fast flames. Here we analyze existing evidence for these mechanisms in terrestrial systems and discuss their applicability to SNIa explosion models.

310-Distributed burning in chemical and themonuclear flames (Invited), *A. Aspden* There has been much recent interest in distributed flames, where turbulent mixing drives flame propagation in place of species of thermal diffusion, both in the context of thermonuclear astrophysical and terrestrial chemical flames. In the thermonuclear context, the Zel'dovich gradient mechanism provides a potential route for deflagration to detonation transition (DDT) in type Ia supernovae (SNeIa), and distributed flames are thought to provide suitable conditions for transition to take place. In the chemical flame context, a number of recent experiments and numerical simulations have reported burning in the distributed regime, where this mode of burning has potential for lowering emissions. In this paper, a review of these recent works on distributed flames will be presented, discussing conditions necessary for burning in the distributed regime and how they may occur in both contexts, properties of distributed flames, scaling laws, and consequences of distributed burning, including potential for DDT in SNeIa.

14:00 Explosions 1

291- Observation of flame propagation and knock in a constant volume vessel, *Y. Nagano, T. Kitagawa* Flame propagation, consequent onset of knock were investigated at various mixture temperatures from 420 to 520K using a constant volume tube-shaped vessel. The flame initiated by the spark ignition at one end of the chamber propagated towards the opposite end. The behaviors of the propagating flame and the end gas were observed with Schlieren and direct photography using the high speed camera and the pressure history in the chamber was recorded. Knock occurred at the mixture temperatures at 480K and higher than it. It was most intense at 480K than other higher temperatures. Prior to the knock, the hesitation of the flame propagation, onset of bluish white zone in the vicinity of the propagating flame and its rapid displacement were observed.

229- Suppression of a propane-air explosion using a powdered suppressant, *J. Chao* Suppression experiments using sodium bicarbonate on propane-air explosions were conducted in 2.5 and 25 m^3 vessels. The effect of different parameters (such as system-activation pressure, suppressant-injection location, suppressant concentration, and number of injection locations) on the reduced overpressure was investigated. It was found that, in general, lower system-activation pressures and higher suppressant concentrations resulted in lower reduced overpressures. As well, multiple injection locations were more effective in reducing the overpressure compared to a single injection location (for the same total amount of suppressant); however, direct suppressant injection from a single location onto the growing flame ball was shown to be just as effective. From the experimental results, there was no clear indication how the results should be scaled to full-volume systems.

232- Turbulent explosions in H_2 enriched CO and CH_4 mixtures, *T. Li, F. Hampp, P. Lindstedt* The use of hydrogen enriched fuel streams has come to the fore due to the use of syngas and/or biogas related feedstocks in gas engine or gas turbine based power generation applications. The associated safety implications are, however, not well established. The current work presents a systematic study of over-pressures generated in an obstructed explosion tube. The conditions were chosen to generate strongly turbulent explosions with resulting flame speeds in the range 200 to 300 m/s. The use of hydrogen enrichment also facilities the use of fuel lean to ultra-fuel lean blends due to overall improved combustion characteristics. Accordingly, the current focus is on such mixtures with CH_4/H_2 and CO/H_2 systems investigated for hydrogen enrichment levels between 0 and 100% and for stoichiometries of 0.40, 0.60 and 0.80. The results highlight the differences in behaviour between the two blending components, with CO mixtures providing substantially higher over pressures than the corresponding CH_4 blend. The results suggest that methane has a mitigating effect up to comparatively high hydrogen blending fractions and that synergistic effects between fuel components need to be taken into account.

14:00 Detonations in propulsion 5

75- Towards exhaust gas emissions from rotating detonation engines, *K. Kailasanath* Rotating detonation-wave engines (RDE) are a form of continuous detonation-wave engine. They potentially provide further gains than an intermittent or pulsed detonation-wave engine (PDE). However, significantly less work has been on this concept when compared to the PDE. An area that has received very little attention is the exhaust flow field and the potential impact of the detonation on the exhaust gas emissions. In this talk, we present the detailed flow field in an idealized RDE, primarily consisting of two concentric cylinders. A premixed detonable mixture is injected into the annulus between the two concentric cylinders. Once a detonation is initiated, it keeps travelling around in the annulus as long as there is fresh detonable mixture ahead of it. The main focus of this work is not on specific nozzle shape or design, but more on characterizing the effect of a large exhaust plenum on the combustion chamber flow and RDE exhaust characteristics. In addition, the chemistry model is modified so that the late-time recombination kinetics and its impact on exhaust gas emissions can be estimated.

152- Visualization study on the flowfield of rotating detonation, *W. Lin, J. Zhou, S. Liu, Z. Lin* Basic flowfield structure of rotating detonation and its propagation mechanism has yet to be fully interpreted. Some technical methods are confined by the annular shape, such as Schlieren photography and other laser diagnostic techniques (e.g., PLIF) are difficult to be utilized. Consequently, visualized experimental results on rotating detonation flowfield structure are scarce. Moreover, the simulation results are hard to cover all the real physics of a detonation, e.g., pre-ignition and involving a real injection process. In present study we presented the experimental physics of the rotating detonation wave in two mixtures of H_2/air and CH_4/O_2. Distinct momentary photographs were illustrated for understanding the flowfield structure. The high-speed photography provides an excellent method to help to explain the propagation and detail structures of continuously rotating detonation waves in mixtures of H_2/air and CH_4/O_2. Therefore from the frames, momentary velocity and specific structure, such as approximately height of detonation wave, oblique shock wave and its deflection angle, and even the injection velocity could be estimated.

154- Propagation characteristics of continuous rotating detonation wave under different temperature air, *C. Wang, W. Liu, S. Liu, L. Jiang, Z. Lin* Experiments on continuous rotating detonation (CRD) were carried out using air with different total temperature, namely 300K and 860K. Dynamic piezoelectric pressure sensors (PCB 113B24) are mounted on the outer wall of the detonation combustor and the air slot channel to capture high-frequency pressure oscillation caused by the continuous rotating detonation wave (CRDW). The propagation velocity and frequency of the CRDW were analyzed, based on which the relative standard deviation was obtained to describe the propagation stability. The effect of the total temperature on the propagation characteristics was studied and the results showed that the CRDW propagates with a higher frequency and more stably when the total temperature of air was 300K. Moreover, both high-frequency pressure fluctuations with the same period of CRDW and pressure rise in the air slot were excited during CRDW, while they did not exist when the total temperature of the air is 860K.

14:00 Flame dynamics 2

315- Towards identifying flame patterns in multiple injection schemes on a single cylinder optical diesel engine, *C. Hong, D. Touloupis, C. Keramiotis, G. Ramaswamy, N. Soulopoulos, G. Vourliotakis, M. Founti, Y. Hardalupas, A. Taylor* Increasing global concern over air quality and security of energy supply poses momentous challenges on engine research and manufacturing. Despite improvements in conventional engine design, many alternatives are winning their place in order to further reduce engine-out emissions. Rather sophisticated operating modes, which incorporate multiple pre- and post-injection strategies, are developed, in order to regulate soot emission levels. However, complex flow-chemistry interactions are inherently difficult to identify. Flame structures may significantly vary resulting in return in fuel concentration and temperature discrepancies, which could significantly affect the ignition and combustion processes as well as NOx and smoke emissions. The present work investigates flame patterns, which originate through a combination of multi-injection schemes. Flame structures are visualized using appropriate flame markers on a single cylinder optical engine. The results identify the prevailing patterns for each case studied, leading towards understanding the governing mechanism of the aforementioned interactions.

78- Flame extinction in buoyancy suppressed methane-air non-premixed counter triple co-flow burner, *J. Park J. Park, O. Kwon, J. Yun, S. Keel* A Experimental study on flame extinction behaviour was investigated using He curtain flow with counter triple co-flow burner. Buoyancy force was suppressed up to a microgravity level of 10-2-10-3g by using He curtain flow. The stability maps were provided with a functional dependency of diluent mole fraction and global strain rate to clarify the differences in flame extinction behaviour. The flame extinction

curves had C-shapes at various global strain rates. The oscillation and extinction modes were different each other in terms of the global strain rate, and the flames extinction modes could be classified into five modes. These oscillation and extinction modes could be identified well to the behaviour of edge flame. The result also showed that the edge flame was influenced significantly by the conductive heat losses to the flame center or ambient He curtain flow.

213- Reduced order modeling of self-igniting reaction-diffusion system based on POD technique and k-means clustering, *K. Bizon, S. Lombardi, G. Continillo* In this work, the method of POD is applied to a problem of a self-ignition of a coal stockpile, described by one-dimensional reaction-diffusion equations. POD has been widely employed for model order reduction in many fields, however there are still a number of issues that need further investigation. Among the others, the policy of the collection of the representative set of experimental or simulation data is considered to be crucial for generating a global basis suitable for the determination of accurate reduced order model (ROM). At present, there exists no unequivocal procedure for optimal snapshot selection. It is well known that a potentially representative ensemble of data can be obtained by combining data from different simulations, conducted for different values of key parameters or characterized by high spatiotemporal complexity. However, while the exploration of the parameter space is a well-established policy, there is no clear indication in the literature about the influence of the total number of snapshots and their temporal distribution on the ROM performance. In an attempt of improving the performance of POD-based reduced order models (ROMs) of a reaction-diffusion system, the influence of two different sampling strategies on the solution was investigated. First, POD modes were determined from databases that consisted of various number of samples collected at constant frequency. Then, an innovative approach, based on the clustering of samples, was introduced and evaluated. It appears that, for low values of the total number of observations, the new approach ensures more stable and more accurate ROMs, with one third of the CPU time with respect to the full order model. The results obtained confirm that a proper choice of the sampling strategy can not only improve the performance of the ROM, but can also reduce significantly the size of the eigenvalue problem to be solved when building the POD modes, and, by designing an appropriate clustering procedure, reduce the amount of data to be computed and stored.

15:45 Astrophysical and terrestrial combustion 4

297- Incomplete detonation in Type Ia supernovae (Invited), *A. Khokhlov, I. Dominguez* All the currently proposed SNIa explosion models involve carbon-oxygen (CO) detonation at low densities. Below approximately 1E+6 g/cc the detonation may proceed only through the first stage of carbon burning referred to as an incomplete C-detonation. The incomplete detonation explains the presence of intermediate mass elements in the outer layers of SNIa in agreement with early spectroscopic observations. We present results of one, two, and three-dimensional numerical simulations of low-density carbon-oxygen detonations and discuss their stability, structure, and propagation through a constant low-density background. The simulations were carried out using a realistic equation of state of partially degenerate matter and nuclear kinetics described by the alpha-network including nuclei from helium to nickel, and with the numerical resolution up to fifty computational cells per the half-length of a one-dimensional ZND detonation wave. The incomplete detonations are highly unstable and the simulations in 1D, 2D and 3D give qualitatively different results. Three-dimensional detonations develop a robust small-scale cellular structure and propagate without decay, as compared to galloping marginal propagation of one and two-dimensional detonations. The detonation stability, cell size, and whether carbon burning in a three-dimensional detonation wave is followed by the subsequent oxygen burning is sensitive to the background density, to the detonation overdrive, and, significantly, to the initial carbon to oxygen mass ratio ahead of the detonation wave. Implications of the results for Type Ia supernova modelling will be discussed.

225- Reaction rate closure for turbulent detonation propagation through CLEM-LES, *B. Maxwell, M. Radulescu, S. Falle, G. Sharpe* Turbulent and unstable detonation propagation is modelled using the Compressible-Linear Eddy Model for Large Eddy Simulation (CLEM-LES); a novel combustion modelling strategy which treats highly compressible and reactive flows involving very rapid transients in pressure and energy. A major challenge of modelling unstable detonation propagation is to provide adequate closure to the reaction rate of the governing Navier-Stokes equations. This is often difficult as highly unstable detonation fronts give rise to unburned pockets of fuel in its wake. These pockets then burn out, relatively quickly, through molecular diffusion enhanced by turbulent mixing. Direct Numerical Simulation of the Navier-Stokes equations address this problem by resolving the full spectrum of scales present, but are limited to providing insight only on single-isolated events, such as triple point collisions. Therefore, a reasonable compromise between accuracy of solution and resolvability of larger-scale flow fields is to employ LES. Recent studies have shown that LES can be used to provide insight on the sub-grid effects that contribute to the unstable detonation reaction rate. Closure to the reaction rate, however, remains difficult to resolve as it is typically obtained by assuming either instantaneous mixing or reaction at the subgrid scale. The LES strategy adopted here does not rely on such assumptions regarding the mixing or reaction rates. Instead, the subgrid is treated as a 1-D sample of a diffusion-reaction system within each LES cell. This is intended to reduce the expense of solving a complete multi-dimensional problem through DNS while preserving micro-scale hot spots and their physical effects on ignition. Thus, the model provides high resolution closure for the unresolved chemical reaction terms in the governing, LES-filtered, reactive Navier-Stokes equations. In this paper, the CLEM-LES approach is applied to simulate two-dimensional, unobstructed, detonation propagation in a narrow channel at low pressures. The parameters of the model are chosen to mimic the premixed methane-oxygen mixture of experiments conducted at the University of Ottawa. Additional closure for the unresolved turbulent viscosity is provided by a one-equation Localized subgrid Kinetic energy Model (LKM). The results of the CLEM-LES have shown that qualitative features of a detonation triple point collision process are captured when compared to experiments. Also, the CLEM-LES was found to converge to, and capture, the correct approximate burning rates in the presence of Kelvin-Helmholtz and Richtmyer-Meshkov instabilities. Finally, the simulated hydrodynamic thickness is found to be comparable to experimental observation.

15:45 Explosions 2

66- Flame propagation of pulverised biomass crop residues and their explosion characteristics, *M. Saeed, G. Andrews, H. Phylaktou, D. Slatter, H. Medina, B. Gibbs* Pulverised agricultural crop residues were investigated using the ISO 1 m3 turbulent explosion vessel. This was modified to enable the spherical flame propagation flame speed and the heat release rate in MW/m^2 to be determined. From the turbulent flame speed, the laminar flame speed and laminar burning velocity and global heat release, MW/m^2, were determined. In addition the

equipment was used to determine the biomass explosibility, K_{st} (= $dP/dt_{max}V^{1/3}$), and the minimum explosion concentration (MEC). Two Pakistani crop residues bagasse (B) and wheat straw (WS) were investigated. Particle size distribution, elemental and proximate analysis and surface morphology for the raw powders and for their post explosion residues were carried out. It was found that these crop residues have explosibility characteristics comparable to wood biomass powders. MEC values as low as equivalence ratios of 0.18 to 0.3 were found which were lower than for gaseous hydrocarbons, but similar to other measurements for biomass using the Hartmann explosibility equipment. Peak turbulent flame speeds were measured at 3-4 m/s. There was a significant post explosion residue of unburned material which was shown to have an increase in char content relative to the raw biomass, while the volatile content was reduced. The BET surface area of the post explosion residue of bagasse was higher than that of the wheat straw residue, showing a higher release of volatiles for bagasse with a more porous char residue in the burnout indicating higher reactivity. These crop residues are a viable renewable fuel for existing coal power plants or as a basis for a new generation of small scale steam power generators in Pakistan.

97- **The suppression effect of ultra-fine water mist on methane/air explosion in the closed Vessel**, *J. Ren, P. Zhang, Y. Zhou, M. Bi* Fine water mist has got the concern of more and more researchers for its applications on suppressing combustions and explosions of gas, dust, and explosives such as trinitrotoluene (TNT) and Destex. Compared to other mathods, the disturbance caused by the ultrasonic atomization to the flow field inside the container is much smaller, and the ultra-fine water mist has characteristics similar to gases. The research of the suppresion mechanism of it on gas explosions would provide a basis for understand the action mechanisms of water mists on explosions. In this paper, experimental investigation of the suppression effect of ultra-fine water mist on methane/air explosion was carried out in a closed vessel. The suppression of the gas explosions by the ultra-fine water mist can be attributed to the physical mechanism of cooling and blocking the radiative heat transfer, as well as the chemical mechanism of inhibiting and terminating the chain reaction. Under this mechanism, the suppression effect would improve with the increase of the mist amount. But affected by the saturation effect, it would improve no more when the mist amount increased to a certain extent.

15:45 Detonation in propulsion 6

73- Numerical study of propulsive performance of different injection patterns in rotating detonation engine, *S. Yao, Y. Liu, J. Wang* Rotating detonation engine (RDE) is one of the propulsion systems utilizing detonation waves for combustion. In this paper, the propulsive performances of RDE with four specific injection patterns are numerically studied, including the radial strip injection, oblique strip injection, side-slit injection and mid-slit injection patterns. Our simulations show that the propulsive parameters vary with different injection patterns. The specific impulse, however, is not distinctly affected by the fuel injection on the head wall of the chamber. The phenomenon of total pressure loss in RDE is also discussed in our study.

17- **OH* chemiluminescence images of detonations propagating through the annular channel of a nonpremixed rotating detonation engine**, *B. Rankin, D. Richardson, A. Caswell, A. Naples, J. Hoke, F. Schauer* The detonation propagating through the annular channel of an optically accessible nonpremixed rotating detonation engine (RDE) is visualized in this work using OH* chemiluminescence imaging. The fuel and air are injected from separate streams and partially premix in the channel in front of the detonation wave. The OH* chemiluminescence images allow observation of the size and shape of the detonation structure, trailing edge oblique shock wave, and possible presence of deflagration between the fuel fill region and expansion region containing detonated products. The OH* chemiluminescence images are useful for evaluating the effects of the air mass flow rate, equivalence ratio, air injection area, and fuel injection scheme on the detonation structure and its corresponding impact on RDE operation and performance. The detonation increases in height as the air mass flow rate is increased for low flow rates, experiences subtle changes in size and shape for intermediate flow rates, and transitions from one-wave to two-waves as the flow rate is further increased. For fuel lean conditions, the high OH* emissions from the detonation are distributed more broadly in space. For stoichiometric and fuel rich conditions, the high OH* emissions typically are confined to a more narrow region near the detonation wave front. The wave front is more concave with respect to the fuel fill region in front of the detonation as the air injection slot is increased from low to intermediate values. The angle between the wave front and fuel injection surface in front of the detonation becomes more acute as the air injection slot is further increased. Reducing the number of fuel injection holes has significant effects on the detonation structure including transition from one-wave to two-waves. The waves typically co-rotate with the detonations propagating in the same azimuthal direction for most conditions in which two-waves are established in the channel. Counter-rotating waves with the detonations propagating in the opposite azimuthal direction are observed for some conditions. The observation of two counter-rotating detonation waves demonstrates one occasional effect of non-ideal mixing between the fuel and air in a nonpremixed RDE. The OH* chemiluminescence images are useful for evaluating RDE models and simulations, improving fundamental understanding of the detonation structure in nonpremixed RDEs, and identifying critical design parameters that influence RDE operation and performance.

15:45 Combustion dynamics 1

48- Nonlinear two-time-scale perturbation theory for transverse combustion dynamics, *W. Sirignano.* Nonlinear, transverse-mode, combustion instability is examined via a two-time-variable amplitude-perturbation expansion. Following an established process, a two-dimensional, unsteady chamber-wave-dynamics model by Sirignano and Popov is used where the three-dimensional equations are integrated over the axial direction. Nonlinear, transverse-wave oscillations in the circular combustion chamber are examined with the primary flow in the axial direction. The analysis is first generalized to match a variety of relevant injection and combustion mechanisms. Then, a specific example with liquid-propellant-rocket-motor co-axial injectors is used to demonstrate the matching process between wave dynamics and the injection and combustion mechanisms. Turbulent mixing of gaseous propellants with co-axial injection and a multi-orifice, short thrust nozzle are considered, producing a characteristic time for mixing and a time lag in the energy release rate relative to pressure. The coupled combustion process and wave dynamics are calculated for a multi-injector chamber. In particular, the first-tangential mode is examined. Two coupled first-order ordinary differential equations (ODEs) are developed and solved to predict amplitude and phase-angle variations in the slow time for the major eigenfunction component of the waveform. Limit cycles and transient behaviors are resolved. Nonlinear triggering can occur in certain operational domains; above a critical initial amplitude, the amplitude grows; otherwise, it decays with time. The reduction to ODEs provides a foundation for future work on active controls.

236- REDIM based reduced modeling of transient premixed combustion regimes, *A. Neagos, V. Bykov, U. Maas* Study of the transient dynamics of combustion systems has become crucial for applications because of the importance of critical regimes of combustion systems. This is due to the fact that for the increase of the efficiency (economy) and robustness of control of pollutants of the combustion facilities lean mixture compositions and extreme regimes have to be in the use. Therefore, recently unstable (with different types of flame instabilities) and highly turbulent regimes are often in the focus of the study. At the same time, most combustion models (mechanisms of chemical kinetics, transport models etc.) have been developed to address the stationary dynamics of the flame. It is clear that experimental and numerical investigations of reacting flows in stationary regimes are more simple. But for developing reliable models dealing with transient combustion regimes, especially in the context of model reduction, it is very important to develop the method to compare and validate the reduced model in the transient regimes. In the present work, we consider the transient dynamics of the premixed flame in the context of the REDIM. The method to validate the reduced model in the transient regime is suggested. The transient solutions of 1D and 2D REDIM based reduced models are compared to the detailed transient solutions. A stoichiometric syngas-air system whose behavior is studied very well is considered for illustration of the methodology developed. Investigations focus on transient regimes of flame propagation which have as initial profiles states situated along the mixing line in state space. Mixing line states are only of theoretical nature, since they are associated to an infinitely high mixing rate. Nevertheless such scenarios represent a useful base for model testing. It is studied whether the application of the manifold based model reduction concept incorporates the properties of the transient combustion processes towards stationary state. The exact reproduction of such transient processes represents a key challenge for model reduction methodologies. It is shown in the present work that the 1D and 2D REDIM based reduced calculations are able to capture the crucial mechanisms of transition towards stationary state. Detailed and reduced transient system solution profiles in physical and state space show good agreement after a short time period of transition. The analysis of the time scale of transition reveals that the reduced transition time scales are in the same order of magnitude as the detailed transition time scales. Additionally, the 2D reduced model is able to reproduce the time scale of the detailed transient processes to a higher extent compared to the 1D model.

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8:30 Plenary lecture 3

Approaching detonation dynamics as an ensemble of interacting waves, *A. J. Higgins* Despite significant advances in understanding of detonation wave propagation in recent years, a theoretical description of the transient, multidimensional propagation of detonation waves remains a challenging problem. Detonation waves in liquids and highly heterogeneous solid explosives are similarly challenging. Presently, significant advances originate from computational simulations of the reactive Euler and Navier-Stokes equations. Theoretical treatments, however, remain focused on CJ and ZND-based quasi-one-dimensional models. This talk will suggest an approach base on the randomize, geometric structure of unstable detonation waves, in essence, viewing them as a collective of interacting blast waves. Historical predecessors to this approach, advanced by Leiber, Stewart and Asay, and others, will be reviewed. Analogs and models of a heuristic nature will be considered, as opposed to those that derive rigorously from the governing conservation laws. As a prototypical example, detonation in a system consisting of discrete, point-like sources of energy will be considered, and the existence of super-CJ waves will be demonstrated both theoretically and computationally. Multidimensional models, drawing upon concepts in percolation theory, will be explored that might be able to explain experimental results of anomalous scaling in the dynamics of gaseous and condensed-phase detonation.

9:40 Detonations with losses

128- **High explosive detonation propagation in slab and rate-stick geometries near the Chapman-Jouguet velocity**, *M. Short, S. Jackson, C. Chiquete* There has been significant recent work on understanding the variation of high explosive detonation phase velocity (D_0) in a two-dimensional slab geometric relative to that in an axisymmetric cylindrical (rate-stick) geometry having the same confinement as the slab. The ratio $R(D_0)/T(D_0)$ has been termed the *steady propagation scale factor by Jackson and Short*, where R is the radius of a rate-stick that results in a given detonation phase velocity D_0, while T is the corresponding thickness of a slab that result in the same detonation phase velocity. The ratio $R(D_0)/T(D_0)$ varies as a function of D_0. In the cylindrical rate-stick geometry, the detonation shock has two curvature components; the slab component which is the two-dimensional curvature along a diameter of the rate-stick, and the corresponding axisymmetric component. Petel et. al, Silvestrov et al. and Higgins have found a propagation scale factor $R(D_0)/T(D_0)>1$ for the explosives studied. In contrast, Jackson and Short $R(D_0)/T(D_0)<1$ for three explosives nominally characteristic of ideal (PBX 9501), insensitive (PBX 9502) and non-ideal (ANFO) explosives. The purpose of the current work is to use a Detonation Shock Dynamics (DSD) model to give detailed insight into the dynamics behind the variation in the propagation scale factor R/T when the detonation phase velocity D0 approaches the Chapman-Jouguet velocity D_{CJ} for different degrees of confinement. In particular, we will extend the analysis in Jackson and Short for larger variations in the difference between D_0 and D_{CJ}.

245- **Numerical simulations of mildly unstable gaseous detonations in small channels**, *A. Sow, A. Chinnayya, A. Hadjadj* Detonation has issues in many engineering sciences such as safety and explosion, aerospace propulsion systems. Detonation wave propagating in a narrow channel filled with a reactive mixture exhibits different flow features and hydrodynamics instabilities with boundary layers effects. The flow resistance can lead to a detonation velocity deficit compared to the ideal Chapman-Jouguet detonation velocity. Detonation are unstable for most known gaseous combustible mixtures. These multidimensional instabilities provide an essential mechanism for detonation propagation. Different mechanisms were proposed to explain the velocity deficit. In the Fay model, the detonation propagation is only sustained by the chemical energy released in the core of the channel. For Fay The boundary-layer development behind the shock wave leads to a mass diffusion from the core of the channel to the wall, which leads in turn to the velocity deficit of the detonation front. The goals of the present work are to investigate the structure of gaseous detonation waves propagating in a thin rectangular channel and to characterize the sonic surface and the viscous boundary layer growing downstream the detonation front.

223- **Velocity deficits in thin channels for a cylindrically expanding detonation**, *H. Ng, J. Wang, J. Lee* In this paper, the propagation of a diverging cellular detonation in thin cylindrical channels is investigated. Two unstable mixtures, stoichiometric acetylene-oxygen and acetylene-nitrous oxide, are tested. The velocity deficit behavior, as the limit is approached by decreasing the initial pressure, is reported. Although the necessity of transverse wave generation as the surface area along the circumference increases is crucial in maintaining the steady, self-sustained propagation of a diverging detonation, in the present work the effect of channel width is found to be the dominant mechanism for the velocity deficit leading to the limit. The observed velocity deficit exhibits a similar trend as those previously reported in small circular tubes and thin annular channels. Using available cell size data for the acetylene-oxygen mixture and hence w/λ for the scaling, all the velocity deficit data of this mixture can be gathered into a single curve and the limiting w/λ is found to be about 1.0. In this configuration where a single-headed spin detonation is not possible, at least one cell at the detonation front is necessary for the steady propagation of the detonation.

9:40 Explosions 3

251- **Numerical investigation of constant volume propane-air explosions in a 3.6-metre flame acceleration tube**, *T. Skjold, H. Hisken* The work presented in the paper explores the use of a correlation for turbulent burning velocity that incorporates the effect of the strain rate Markstein number on the turbulent burning velocity. The results from computational fluid dynamics (CFD) simulations with FLACS, for two different correlations for turbulent burning velocity, are compared with results from experiments in a 3.6-m flame acceleration tube. The comparison shows that the new correlation represents a significant improvement for fuel-rich propane-air mixtures. Future work should include experiments in other geometries, and preferably include measurements of turbulence parameters.

306- **Numerical investigation and comparison of hydrogen/air and propane/air explosion by hot jets**, *A. Ghorbani, S. Fischer, G. Steinhilber, D. Markus, U. Maas* In this paper we investigate numerically the initiation of an explosion in a premixed propane/air mixture which is caused by hot exhaust gas jets (of its own combustion products). Ignition by hot turbulent jets is found in many areas including pulsed engines, pulsed detonation engines and safety relevant applications. The primary motivation of this study is the prevention of an accidental explosion of a combustible mixture in the field of explosion protection. In order to perform the simulation we use the PDF-PM algorithm which has been developed based on a Lagrangian PDF (probability density function) method, in conjunction with a projection method to calculate mean pressure for transient flows. The simulations are performed for hydrogen/air and propane/air cases, in configurations relevant to safety applications. The ignition in hydrogen case and propane case are investigated by comparison of time scales relevant for chemical reactions and mixing processes. Calculations of propane/air case shows that the ignition (as in hydrogen case) first appears at the

jet head. However, in contrast to hydrogen case, it is observed that for propane the initiation of an ignition (if it occurs) appears with considerable larger delay times. This will be explained by comparison of time scales relevant for chemical reactions and mixing processes. The aim of the current study is to investigate qualitatively the conditions and processes that lead to ignition. The results of these investigations will be used as a basis in our following work in order to understand and prevent accidental explosions.

181- **Experimental investigation on micro- and nano-PMMA dust explosion Venting**, *W. Gao, J. Li, X. Zhang, X. Yan, W. Ji, J. Yu* Vented flame configurations and pressure characteristics of micro- and nano-PMMA particles were examined simultaneously using the standard 20 L spherical dust explosion venting apparatus to reveal the differences of venting processes. It was found that the boundary of micro-PMMA vented burned fields almost kept the same width with the vent, emitted yellow light, and exhibited medium and poor under-expanded structures. On the contrary, the venting of burned nano-PMMA flames began earlier and were not the narrow tapered flames but changed from the burned bright field to high under-expanded jet flow. In addition, maximum overpressure of micro-PMMA particles reduced significantly after venting comparing with nano-PMMA particles.

9:40 Reactive systems 1

141- **Fuel reforming using counter-current heat-recirculating,** *S. Trivedi, S. Koli, A. Lawson, C. Chen, H. Pearlman, P. Ronney* The performance of a Swiss Roll heat-recirculating combustor as a self-contained and thermally self-sustaining fuel reformer was tested using very rich propane-air mixtures that cannot support combustion without heat recirculation. This scheme allowed reforming of hydrocarbon fuels into hydrogen and carbon monoxide which could be used in fuel cells. Results showed a hydrogen yield of about 12% for a propane-air mixture for a given flow rate and a monotonically increasing hydrogen yield with increasing flow velocity for a given fuel concentration. It is suggested that such a reformer could be used as part of a portable system using Solid Oxide Fuel Cells to generate electrical power.

135- **A study of methane hydrate combustion phenomenon using a novel porous cylindrical burner**, *F. Wu, G. Chen, Y. Li, Y. Chao* Methane hydrate refers to methane molecules are surrounded by water molecules with crystalline structure and it is formed as an ice-like solid structure (SI structure). Methane hydrate is usually expressed by the chemical formula of CH4*nH2O(s) (CH4(g) +n H2O(s->l) -> CH4*nH2O(s)), where n is the hydrate number and its theoretical value is 5.73. The literature shows that approximate 160 m^3 methane will be released from the decomposition of 1 m^3 methane hydrate. Methane hydrates can be stably stored at the temperature of -15°C under the atmospheric pressure. In contrast, for stable delivery liquefied natural gas must attain the temperature of -160°C at atmospheric pressure. Methane hydrate has higher storage capacity and safety. From these studies, it is obvious and imperative that a device to properly drain water from the dissociated hydrate surface is a very important issue for stable and complete combustion of methane hydrate. The flame phenomenon and pattern of methane hydrate combustion and how to overcome the problem of flame extinction are still not clear. Therefore, we proposed the design of a novel combustor to maintain stable combustion of methane hydrate for the experimental studies of the flame patterns and phenomenon. Theoretical models are also established and used to compare with the experimental results.

160- **Gas turbine burner reactor network construction and application,** *T. Nilsson, C. Perlman, H. Lehtiniemi, D. Lörstad, S. Möller, F. Mauss* To perform quick engineering studies on temperature and fuel effects in gas turbine burners, it is convenient to use one dimensional reactor networks. A reactor network description of the combustion process allows for the incorporation of effects of the flow-field and the application of detailed chemical reaction mechanisms at affordable computational cost. This work reports on a novel network construction methodology using flow-field data from a Reynolds Averaged Navier-Stokes (RANS) Computational Fluid Dynamics (CFD) simulation. Network construction can be performed based on an arbitrary number of field variables, such as species concentrations, reaction progress, temperature etc. It is also possible to include spatial coordinates in the network construction, which helps to ensure geometrically compact zones. The method has been applied to create and analyze homogeneous as well as stochastic reactor networks. Using the solution from a CFD simulation of a methane Siemens SGT-800 burner operated at baseline condition, studies of the effect of flame temperature and hydrogen content on NO emissions were performed for homogeneous networks while sensitivity studies on number of particles and mixing time constant were performed for the stochastic networks. It was found that the homogeneous reactor networks could be used to predict trends resulting from flame temperature while effects on NO emission due to hydrogen enrichment of the fuel stream were more difficult to reproduce. For the stochastic networks, it was found that the number of particles can be kept relatively low without significant loss of accuracy and that the modified Curl mixing time model yielded better results the standard Curl mixing model.

9:40 Combustion dynamics 2

86- **Discrete model of filtrational gas combustion,** *F. Sirotkin, R. Fursenko, S. Minaev* A discrete two-dimensional model of gas combustion in porous media is proposed. The porous media is represented as the set of randomly placed solid grains which are connected through the artificial solid plate. The latter mimics thermal conductivity between grains. The propagation of the combustion wave is simulated in the frame of thermal-diffusion model with the prescribed flow field computed preliminary using Lagrangian particles method. Dependencies of combustion wave velocity on the inlet gas velocity for different equivalence ratios and porosities are obtained and compared with the continuous one-dimensional thermal-diffusion model. Our results imply that the flame propagation in the porous media can be considered as a collective process, when the actual combustion wave can be represented by a set of individual flame fronts propagating in the mutually connected micro-channels of the different diameter. The discrete structure of the combustion wave is most prominent when the inlet velocities are small and the flame propagation is accomplished with pulsations of flame front fragments. When the inlet velocities are high enough, the propagation of the combustion wave is much more regular. Our model describes the flame anchoring phenomena when the combustion wave is stabilized inside of the porous media for a range of inlet velocities.

208- **DMD analysis of experimental PIV data of a swirled jet**, *S. Lombardi, K. Bizon, A. Coghe, F. Cozzi, G. Continillo* This paper concerns the study of high Reynolds and high swirl number flow through the use of PIV measurements and Dynamic Mode Decomposition (DMD) analysis. Principles governing DMD are briefly recalled, then the use of DMD is demonstrated by analysing the acquired PIV data in order to study the dominant dynamics of the system and extracting relevant morphology via DMD modes, focusing the attention on phenomenon known as Precessing Vortex Core (PVC).

295- Methane combustion dynamics in a diabatic PSR with global, reduced and detailed reaction mechanisms, *L. Acampora, F. Marra, E. Martelli* A comparison of the dynamic features of different chemical mechanisms for the methane combustion in a PSR with heat losses is presented. Four different mechanisms have been considered: the GRI Mech. 3.0, a reduced mechanism by Lu and Law and two global mechanisms, a single step one by Westbrook and Dryer and a two-steps mechanism by Bibrzycki and Poinsot. The analysis starts with the comparison of the bifurcations diagrams obtained adopting the residence time as continuation parameter. This analysis highlights the macroscopic differences in the behaviour of the different mechanisms, in terms of ignition and extinction points and temperature and composition reached at equilibrium conditions. Regions with stably oscillating solutions are also detected. Then, several dynamic simulations are performed and illustrated to analyse the dynamic behaviour of the system. The dynamics is investigated considering both conditions where a periodic forcing is required to obtain a non-steady solution and conditions where natural oscillations arise. Similarities and discrepancies are shown assessing the ability to reproduce, with simplified mechanisms, the behaviour obtained with a detailed mechanism.

11:25 Detonations with losses 2

257- Dynamics of detonations with constant mass divergence, *B. Borzou, T. Phenix, B. Maxwell, M. Radulescu* The main loss mechanism in steadily propagating detonations in narrow channels, weakly confined tubes or porous wall tubes is the global mass divergence experienced by gases in the reaction zone structure. In the present study, we study the dynamics of detonation waves in the presence of constant global rate of mass divergence. This is achieved by propagating detonations in a channel for which the cross-sectional area diverges exponentially, such that the source term appearing in the continuity equation, d(lnA)/dr is a constant. Experiments were performed in two mixtures, one displaying characteristic weakly unstable detonations ($2C_2H_2+5O_2+21Ar$), and the other displaying highly unstable detonations ($C_3H_8+5O_2$). The dependence of the velocity deficits and limits on the amount of mass divergence for the two mixtures were compared with a quasi-one-dimensional model. Comparisons were also made with the results of simulations of inviscid cellular detonations and detonations modeled with a newly formulated linear eddy model subgrid scale model for large eddy simulations of compressible reactive flows. The velocity deficits in the weakly unstable mixture were reasonably well predicted by the quasi-1D model, with departures near the limits. Near the limits, the inviscid cellular simulations were found in very good agreement with the experiment, suggesting that cellular instabilities play an increasing role near limits. For the highly unstable detonations, the quasi-one-dimensional significantly over-predicted the effect of mass divergence. Detonations were observed for rates of mass divergence higher than the critical predicted value by 150%, displaying more substantial velocity deficits than predicted. The preliminary results obtained for the cellular dynamics modeled with the linear eddy model were in found in close agreement with the experiment, suggesting the importance of the fine scale turbulent burning mechanism in unstable detonations in controlling the limits, consistent with experimental observations of the reaction zone structures near the limits.

179- The effect of radius of curvature on the detonation propagating to the unconfined space, *T. Hayashi, A. Matsuo, J. Kasahara* In this study, two-dimensional numerical investigation about detonation diffraction along curved surface is conducted in order to reveal the effect of radius of curvature on the propagation behavior of detonation diffraction. Two-dimensional compressible and reactive Euler equations are used as a governing equations and two-step chemical reaction model is used as a chemical reaction model. The ratio of radius of curvature Rc and cell width Rc/λ is varied from 0.06 to 20 to discuss the effect of radius of curvature on the behavior of detonation diffraction. The straight channel width is fixed at ten times the cell width. In the simulation results, two types of propagation behavior are observed depending on the radius of curvature: one is sub-critical regime and the other is super-critical regime. In sub-critical regime, the leading shock front and the reaction front are decoupled and fail to propagate to the unconfined space. As the radius of curvature increases, the range of attenuation becomes small. Therefore, the transverse wave near the channel center is activated, and the cellular pattern expands toward the open area after the channel exit. In super-critical regime, the local explosion occurred near the central axis due to collision of reflected triple points. The transverse detonation wave is generated by local explosion and propagated toward the wall. New triple points were formed after propagation of the transverse detonation wave and succeeded to propagate to the unconfined space.

134- Detonation mode and frequency variation under high loss conditions, *S. Jackson, B. Lee, J. Shepherd* A quantitative analysis of the velocity distribution, velocity probability and galloping frequency versus initial pressure was performed for near-limit detonation propagation in stoichiometric propane-oxygen mixtures confined in polyurethane tubing with the tube diameter on the order of the detonation reaction zone length. The use of extremely long tube lengths (over 7,000 diameters) allowed observation of over 15 galloping cycles. The results showed that two dominant velocity modes exist near 40% and 95% of the Chapman-Jouguet velocity, with the lower velocity mode becoming more prevalent with decreasing mixture initial pressure. The results of multiple experiments were used to generate a probability density function allowing visualization of this behavior. Analysis of the galloping frequency indicated a single peak near 1kHz that was not a strong function of initial pressure.

11:25 Explosions 4

237- Determination of flammability limits of diluted H_2/CO/CH4/air mixtures in spherical bomb, *R. Grosseuvres, A. Comandini, J. Biet, M. Idir, A. Bentaïb, N. Chaumeix* High temperature gas-cooled reactors are graphite moderated and helium cooled. The primary system consists of reactor pressure vessel, steam generator and hot gas duct vessel. The water ingress into the reactor pressure vessel can occur in case of the rupture of a heat transfer tube of the steam generator. The mixture of helium and steam will subsequently enter the reactor and will lead to a graphite corrosion of both fuel elements and graphite structures. This oxidation process can be responsible of the formation of $He-H_2-CO-CO_2-H_2O-CH_4$ mixtures. Subsequently the pressure can increase inside the reactor, which may exceed the design pressure and leads to the opening of safety valves to the reactor hall. Hence, part of the combustible mixture could be released inside the reactor hall leading to a flammable atmosphere. In order to assess the explosion hazard of such complex mixtures, flammability limits are being investigated within the framework of the Archer project. The aim of this study is to determine the flammability limits of 4 different mixtures containing different amount of H_2, CO, and CH_4 at 300K and 1 bar. The effect of the dilution by CO_2 or helium has been investigated over a wide range of fuel/air ratio. These flammability limits have been determined in a spherical vessel using a laser spark induced ignition at the center of the vessel. A high speed imaging is used to monitor the occurrence of the combustion (flame recording) or to assess that the local

ignition does not give rise to a sustainable flame and that the flammability limit is reached. A high frequency pressure transducer is mounted flush with the inner wall to measure any pressure increase due to a successful ignition.

299- **Large eddy simulations of syngas and biogas explosions accounting for high temperature and pressure effects,** *Rao, J. Wen* Hydrogen and hydrogen blended fuels generated from renewable sources such as syngas and biogas are promising potential candidates as future energy carriers. The future wide spread use of these blended fuels requires the knowledge of explosion parameters to help ensure their safe handling. However, there is limited knowledge of these parameters in the literature. In the present study, numerical simulations have been conducted to help filling these knowledge gaps using an in-house version of the open source Computational Fluid Dynamics (CFD) code OpenFOAM. This version uses the Coherent Flame Model (CFM) extended to the Large Eddy Simulation (LES) context by Richards et al. [1] for combustion. It was implemented into the code for flame-wall interaction by the authors [2]. The unstretched laminar flame speed ( ) correlation of Lapalme and Seers [3] for mixture of H_2/CO/CO_2/CH_4 in air is adopted with the correlation further enhanced to include the high pressure effects using power law expression following a similar approach previously proposed by Metghalchi and Keck [4]. The recent experimental results of Ali et al. [5] and Goswami et al. [6] were also taken into account to fit the temperature and baric indexes in a power law expression. The predictions are assessed by simulating the vented explosion experiments of Bauwens et al. [7] in a 4.6x3.0x4.6 (m) test chamber. A hybrid hex-tet computational mesh was used for a computational domain of 30x15x 35 (m) to capture the venting of burned gas, the external explosions and to reduce the effect of boundary conditions on the numerical results. Three mixture compositions are considered, i.e. 1) 18% hydrogen which is approximately 0.53 equivalence ratio; 2) 50% H_2 and 50% CO_2 at equivalence ratio 0.98; and 3) 25% H_2, 25% CO, 25% CH_4 at equivalence ratio 1.1. Comparison will be made with the measurements of Bauwens et al. [7] for hydrogen fuel with the 5.4m^2. It was seen that the peak over pressures are proportional to the reactivity of the mixture i.e. laminar flame speeds with pure hydrogen exhibiting the highest over pressure. The additions of CO_2 and CO were found to result in decreases in the fuel the burning rates.

241- **Detonation hazard classification based on the critical orifice plate diameter for detonation propagation**, *M. Cross, G. Ciccarelli, P. Thibault* Accidental explosions in the chemical and oil and gas industry are a serious problem. The objective of this paper is to establish a new parameter that can be used to categorize the relative detonation explosion hazard of a fuel that can be measured in a smaller, more practical apparatus, independent of detonation cell size. Experiments were carried out in an apparatus consisting of a 6.1 m long (composed of 2 equal length sections), 100 mm inner-diameter tube. A detonation was initiated in the first half of the tube using an acetylene-oxygen driver ignited by a weak spark. The second half of the tube contained orifice plates equally spaced at the tube diameter. Six different orifice plate diameters between 38.1 mm (1.5) and 76.2 mm (3), in increments of 6.4 mm (1/4) were used in the study. The average combustion front velocity was obtained from time-of-arrival measurements deduced from ionization probe signals. The critical (minimum) orifice plate diameter required for successful transmission of a detonation from a smooth tube was measured for different stoichiometric fuel-air mixtures. The ratio of the critical orifice plate diameter and the mixture detonation cell size varies strongly with the orifice plate blockage ratio, with a value approaching unity ($d/\lambda \rightarrow 1$) with decreasing blockage ratio. It is proposed that the critical orifice plate diameter could be used to categorize the detonation hazard potential of single or multi-component fuels. Novel use of soot foils showed that the structure of the detonation wave is very non-uniform and highly unsteady, characterized by local detonation initiation and failure.

11:25 Reactive systems 2

302- **Swirl motion effects on flame dynamic of pulverized olive cake in vertical furnace,** *A. Elorf, N. Mrad-koched, S. Bostyn, B. Sarh, I. Gökalp, B. Izrar, J. Chaoufi* A numerical simulation of pulverized olive cake (OC) combustion in a 3D furnace is presented in this study. The effect of inlet swirl on the flow development and combustion dynamics is carried out. Two cases are studied for the inlet conditions. First, without swirl motion (Ja) and second, with swirl motion (Js). The numerical approach is based on Reynolds Average Navier-Stokses (RANS) equations. The chosen turbulence closure model is the standard k-ε model. For turbulence-chemistry interactions of the non-premixed combustion, a mixture fraction/PDF approach is used. The particles of OC are injected perpendicularly to the central axe of furnace near the lower base. The mean size particle diameter is 100 μm. A comparison was made between (Ja) and (Js) cases for, flow topology, velocity contours, temperature distribution and species concentrations profiles in several location along the burner. The results present that the flame is more stabilized and closer to the inlet for the (Js) case in comparison with (Ja) case, and reaches its maximum value of 1560 K.

303- **Numerical study of a laser-induced ethane pyrolysis in a wall-less reactor using a reduced kinetic scheme,** *J. Yang, O. Matar, O. Stadnichenko, V. Snytnikov* Ethylene, as the most important feedstock, is widely used in chemical industry to produce various rubbers, plastics and synthetics. A recent study found the IR-laser irradiation induced ethane pyrolysis yields 25% higher ethylene production rates compared to the conventional steam cracking method [1]. A schematic for such a reactor is illustrated in Fig. 1 in which a laser beam is used to induce the pyrolysis reaction along the axis of the reactor. Laser induced pyrolysis is initiated by the generation of radicals upon heating of the ethane, then, followed by ethane/ethylene autocatalytic reaction in which ethane is converted into ethylene and other light hydrocarbons. Radicals propagate radially to the edges. The main drawback of convectional steam cracking method includes e.g. significant coking requires regular regeneration procedures, significant amount of high molecular products waste and wastewater containing them, high capital costs associated with the complex process of post-reaction separation of the reaction products. Whereas, the laser-induced the ethane pyrolysis method avoids these problem and have other advantages, e.g. lower wall temperatures, cheaper construction materials, no need of external cooling of products, smaller size reactors allow conversion of stranded gas. The current experimental researches on such kind of reactors are mainly in the laboratory scale. In order to scale up to the pilot and industrial plants, the 3D CFD numerical model is necessary for developing a compact, cost effective reactor for the pyrolysis of light hydrocarbons using lasers. Thereafter, the present work attempts to develop and validate a reduced chemical kinetic to describe ethane pyrolysis process, then implement it into the CFD code and perform a set of 3D CFD simulations on current laboratory scale reactor. Based on the numerical results, the flow field and temperature field and species concentration inside the reactor has been analyzed. The ethane conversion rate has been studied under various conditions, e.g. different laser power, different wall temperatures.

284- **Sooting behavior of ethane in a micro flow reactor with a controlled temperature profile**, *A. Dubey, T. Tezuka, S.*

Hasegawa, H. Nakamura, K. Maruta In the current work sooting behavior of ethane is studied using a micro flow reactor with a controlled temperature profile. Three different kinds of œsoot and flame responses are observed for various equivalence ratio ($1.9 \leq \varphi \leq 2.2$) and mean inlet flow velocity ($10 \leq U_0 \leq 80$) conditions namely, flame, flame + soot and soot. Critical sooting equivalence ratio decreased with increasing mean inlet velocity. Soot is observed only in the flat-temperature region at 1300 K. Computed flame position showed good agreements with observed flame position. At equivalence ratio of 2, sooting region first increases then decreases with increasing mean inlet flow velocity whereas at equivalence ratio of 4, length of sooting region decreases with increasing mean inlet velocity. Similar tendency is shown by computed A4 (Pyrene which is a four ring PAH) mole fractions.

11:25 Spray Combustion

146- Thermodynamic analysis for combustion at high gas densities, *A. Jorda Juanos, W. Sirignano* Combustion of hydrocarbons at high pressure is becoming more common. There are several issues that are not mastered in the combustion literature and must be addressed. (1) The critical pressure of a mixture is commonly substantially higher than the critical pressure of any component. Thus, two phases can easily exist at so-called ``supercritical'' conditions. (2) Since critical pressure varies with composition, a volume (even at uniform pressure and temperature) can have subcritical portions and supercritical portions in space and/ or time. (3) At subcritical mixture conditions, large amounts of ambient gas will dissolve in the fluid and diffuse away from the liquid-gas interface into the liquid interior. Thus, an injected liquid cannot be assumed to have its original composition or any uniform composition; its density, surface tension, specific heat, and transport properties can change with time and space. (4) Consequently, because of density gradients on both sides of the interface, an experimental image showing a fuzzy interface cannot be sufficient proof of single-phase behavior. (5) Even at true supercritical conditions, there can be a pseudo-two-phase behavior. A narrow domain can exist in temperature-pressure space across which sharp changes in density and can occur. Although the changes are not discontinuous like the true two-phase case, there can be similar consequences. (6) Transport rates decrease and chemical rates increase with increasing pressure. Therefore, the rate-controlling mechanism can change. (7) It is known that, at high densities and pressures, fugacity and not partial pressures should appear in the chemical equilibrium laws of mass action. Clearly, one would expect therefore that chemical kinetic laws should be expressed in terms of fugacity; otherwise, they can not drive towards accurate equilibrium at long times.

94- Numerical and theoretical investigation of the scalar dissipation rate in laminar counterflowing spray flames, *H. Olguin, E. Gutheil* The scalar dissipation rate $\chi = 2D(\text{grad}\xi)^2$ of the mixture fraction, ξ, may be considered as the inverse characteristic diffusion time or the residence time in a flow, and it plays a dominant role in the modeling of combustion processes. In laminar counterflows, the scalar dissipation rate depends on the strain rate a, i.e. the velocity gradient of the gas velocity at a boundary of the counterflow configuration. As strain rate is increased in these flames, the residence time of the reactants is reduced and eventually, this continuous increase leads to flame extinction. Thus, this characteristic variable plays an important role, for instance in the flamelet modeling of combustion processes, where the scalar dissipation rate at extinction characterizes the stability of flames. The scalar dissipation rate transport equation is derived and solved with and without considering terms associated with spatial variations of the mean molecular weight of the mixture. Laminar ethanol/air counterflow spray flames in the counterflow configuration at low and high strain rate are considered. The results are compared with the exact value of the scalar dissipation rate obtained by means of the resolution of all chemical species transport equations and use of the definition of ξ. It is found that Fick's diffusion law is appropriate for high strain rate situations and that differences between calculated and expected values of ξ are not due to the negligence of effects associate with the assumption of spatially uniform mean molecular weight but to the inadequacy of the selected diffusion coefficient of the mixture

54- Statistical analysis of the reaction progress variable and mixture fraction gradients in flames propagating into droplet mist: a DNS analysis, *D. Wacks, N. Chakraborty, E. Mastorakos* Turbulent combustion of a droplet-mist has been analyzed here based on three-dimensional Direct Numerical Simulations (DNS) in a canonical configuration under decaying turbulence. Liquid fuel was supplied in the form of mono-disperse droplets, which evaporated providing gaseous fuel for the flame propagation into the droplet-mist. The effects of variations of turbulent velocity fluctuations (u'), droplet equivalence ratios (phi_d) and droplet diameters (a_d) have been investigated. Although the combustion process in the gaseous phase took place predominantly in fuel-lean mode, even for $\text{phi}_d > 1$, nevertheless droplets which were able to penetrate the flame front completed their process of evaporation in the burnt gas region, releasing gaseous fuel which, by means of diffusion, augmented the gaseous equivalence ratio in the region of the flame front. The probability of finding fuel-lean mixture increases with increasing initial droplet diameter due to slower evaporation of larger droplets. The statistical properties of the probability density functions (PDFs) of the mixture fraction, ξ_i, and oxidiser-based reaction progress variable, c, have been analysed at several locations across the flame brush and a β-function distribution has been used to model the PDFs of the DNS data. Furthermore, the PDFs of the gradient of the mixture fraction and the gradient of the reaction progress variable, $\nabla\xi_i$ and ∇c respectively, have been modelled using a log-normal distribution. Finally, the joint PDF of $\nabla\xi_i$ and ∇c, has been compared with (i.e. assuming statistical independence of $\nabla\xi_i$ and ∇c and has been modelled by a presumed bivariate log-normal distribution. The bivariate log-normal distribution has been considered both assuming correlation between $\nabla\xi_i$ and ∇c and assuming no correlation. The accuracy of both β-function distribution and (bivariate) log-normal distribution as models to make both qualitative and quantitative predictions has been discussed in each case.

9:40 (all day) Posters 2

85- The effect of side relief on detonation propagation in a rotating detonation engine, *R. Fievisohn, K. Yu* The effect of side relief on detonation wave propagation in a Rotating Detonation Engine (RDE) is examined analytically. Area divergence through the reaction zone is used to estimate velocity deficits as a possible explanation for experimentally observed wave speeds. Previous work conducted on detonations bounded by inert gases and free jet analyses is extended to provide insight into RDE wave propagation velocities and wave heights. Results are then compared with currently available experimental data to examine the validity of area divergence as an RDE loss mechanism.

98- Kinetic analysis of the mechanisms of ignition and combustion of blended fuels comprising hydrocarbons and hydrogen, *N. Titova, S. Torokhov, I. Chechet, O. Favorskii, A. Starik* Numerical analysis of the features of ignition and chain mechanism development during oxidation of blended fuels

composed of i-octane(n-decane) and H_2 was conducted on the basis of detailed reaction mechanisms involving both high and low temperature channels of i-C_8H_{18} and n-$C_{10}H_{22}$ oxidation. It was shown that both for the i-C_8H_{18}-H_2 and for n-$C_{10}H_{22}$-H_2 blends, there exists the temperature range, where the ignition of the fuel blend occurs faster compared to pure alkanes. The broad of this range has low and high temperature boundaries (Tl and Th, respectively) and depends strongly on the type of primary alkane, H_2 content in the blend and initial pressure of the fuel/air mixture. At $T_0<T_l$, the ignition delay of blended i-C_8H_{18}(n-$C_{10}H_{22}$)-H_2 fuel is longer than that of pure alkane under study. It is remarkable that for the pressure higher atmospheric one, at $T_0>T_l$, the addition of small amount of alkane (2-10%) to H_2 leads to shortening the ignition delay. It was shown that the addition of H_2 both to i-octane and to n-decane increases the flame speed and extends the flammability limits. However, the notable effects achieve at rather high H_2 content (>50% per fuel mass).

104- Two-line OH PLIF temperature measurements of flames near a quenching plate, *D. Escofet-Martin, Y. Chien, D. Dunn-Rankin* The main goal of this work is to understand and focus in two-line OH planar laser induced fluorescence (PLIF) as an experimental tool for making temperature measurements in small non-premixed coflow jet flames interacting with an impingement surface downstream of the jet. In particular, the paper discusses the details used to obtain these temperature measurements as well as identifying the sources of systematic errors. The two-line OH PLIF set up for the impinging coflow flame is discussed, including choosing the appropriate absorption line pair for that specific case. The paper also discusses practical issues related to the image processing of the measurements. Finally some comments are included regarding the potential use of the measurements for this specific case.

105- Methane hydrate Combustion, *J. Santacana Vall, D. Dunn-Rankin* Methane hydrates are ice-like non-stoichiometric crystalline solids composed of water cages that are stabilized by the presence of a guest methane molecule. They occur naturally in the permafrost and in deep ocean sediments. They represent a potential mega-resource of energy and, at the same time, they can have a substantial potential impact on the environment. This project studies experimentally the formation and direct combustion of methane hydrates. Formation of methane hydrates samples is a complex process that needs precise control due to fragile stability of the hydrates at high pressure within narrow time and temperature ranges. Heat from the combustion process dissociates the hydrate into water and methane, which feeds the methane-air diffusion flame. In this thesis, uniform, repeatable and high quality samples were successfully formed with a clathration of 81.82±3.39%. Another achievement was that the samples burned completely and they had three different regimes, an initial one of 1 second based on the propagation of the flame, a second one between 1 and 5 second with a bright and high flame and finally the quasi-steady state regime after 5 seconds until the end of the process. The accomplishment of reaching this quasi-steady state regime permitted the determination of key properties of the combustion behavior. The results show that the burning rate at this regime is 2.5mg/s*cm^2, a flame temperature estimated between 1550 and 2050K and the novelty of determining the water vapor content versus methane in the flame, which is between 0.5 and 1.5 by molar ratio. Finally the energy balance model showed that 25% of the heat is needed for dissociation of the hydrate and the remaining heat produces approximately 470 kW/m^2.

115- The time of effective energy input for direct detonation initiation in spark discharge, *K. Korytchenko, L. Zavada, D. Kudin, S. Rodionov* Effective energy used for direct detonation initiation at high voltage spark discharge is the subject for numerous studies. We have found that the time tef for effective energy input is not equal to ¼ of the period of damped oscillatory discharge, unlike some other studies. It is impossible to obtain an ideal current of clamped discharge at ¼ of discharge period using the electrical circuit consisting of a non-ideal electrical elements. Such ideal interruption results in violation of the law for magnetic field energy conservation. The circuit with the real elements operates only when the switch is closed for the discharge half-cycles. The parameters of the shock waves generated in oxygen environment at atmospheric pressure under various conditions of the spark gap commutation in RLC-circuit were compared. The obtained results show that the spark gap bridging in accordance with the real RLC-circuit at ¼ of the damped oscillatory discharge period led to an increase in the intensity of the shock wave. It is also assumed that the critical time is related to the time of shock wave separation from the conductive spark channel to the width of vibrational relaxation or length of the detonation cell. The developed detonation initiation model can be used for increasing efficiency of the spark detonation initiation.

118- Numerical investigation of shock wave – dense particles cloud interaction, *P. Utkin* The work is dedicated to the problem of shock wave dense particles cloud interaction. Mathematical model is based on the reduced Baer-Nunziato system of equations with algebraic right-hand side source terms that takes into account the interphase friction force. Baer-Nunziato model is well established non-conservative non-strictly hyperbolic set of equations for the two-phase compressible flows. The key point of the numerical algorithm is the Godunov method and the exact solution of the Riemann problem for the Baer-Nunziato system of equations. One of the main advantages of the Godunov approach is the intrinsic coupling between the phases without artificial splitting strategies for the most challenging case when the dispersed phase volume fraction to the left of the discontinuity significantly differs from that to the right. The main features of the shock wave particles bed interaction process are obtained in the calculations namely reflected and transmitted waves as well as the motion of the particles cloud. The calculated quantitative characteristics of the process waves amplitudes and velocities correspond to those in natural experiment.

119- Ignition transient of supercritical oxygen/kerosene combustion system, *D. Kim, K. Lee, J. Koo* During the ignition process of large liquid rocket engine, the thermodynamic state of propellants are changed from subcritical to super critical condition. In the super-critical condition, the distinction between liquid and gas phase would be obscure, and the thermodynamic and fluid-dynamic properties of both a liquid phase and a gas phase coexist. In this study, ignition transient of gaseous oxygen/kerosene spray was observed using subscale liquid rocket combustor, which is operated under supercritical combustion pressure.

127- A study on N2O formation/destruction behavior in sewage sludge combustor, *A. Nakamura, S. Kinoshita, T. Denda, T. Iwasaki, K. Ishii* To study formation and destruction behavior of N_2O, exhaust gas measurement was carried out in fluidized-bed sewage sludge combustors under various conditions, particularly with a focus on temperature and HCN concentration. The measurement results were compared with those of numerical simulation based on chemical kinetic modeling to examine availability of numerical simulation as an analysis tool for improvement of combustion condition and suppressing methods of N2O. The measurement and the calculated results suggest that the exhaust gas residence time of at least 4 seconds in free-board over 850°C is required to achieve N2O emission less than 50 ppm at the combustor exit. In addition, N2O concentration at the combustor exit is strongly

governed by HCN concentration at the lower free-board. The calculated results are found to be only effective in an appropriate temperature range which is dependent on the selected chemical kinetics models. Proper selection of chemical kinetics models plays an important role to use numerical simulation as an analysis tool of combustion condition.

133- Numerical simulations of the diameter effect for nitromethane using ignition and growth model, *Y. Sugiyama, K. Wakabayashi, T. Matsumura, Y. Nakayama* The objective of this study is to develop a numerical model appropriate for predictive simulations of the detonation propagation and failure in order to estimate the hazard assessment of the high explosives. In the present study, we model NM surrounded by the brass and by the air to discuss the diameter effect, and the parameter is the diameter of the explosives. In the case of small diameter of the explosive, radial flows makes curved detonation front, and the post-shock flow divergence weakens the shock wave. This makes unreacted region around the interface and spread to the axis of the cylindrical explosive. In the case that the diameter is smaller than critical diameter, the steady detonation cannot maintain its propagation. The numerical data of diameter effect for NM surrounded by air or by brass are compared with fitted curve with the experimental data. Our study correctly estimates the relation between the detonation velocity and diameter. Critical diameters of the numerical data agree with those of the experimental data within 10 %

136- Numerical study on direct initiation of cylindrical detonation in H_2 /O_2 mixture: influence of higher-order scheme, *T. Niibo, Y. Morii, N. Tsuboi, M. Asahara, A. Hayashi* This study aims to investigate the effect of the grid resolution on the two-dimensional cylindrical detonation by using the recent four higher-order accurate schemes. The scheme investigated in the present study were 2^{nd}-order MUSCL, 3^{rd}, 5^{th} and 7^{th}-order WCNS scheme. The two-dimensional cylindrical detonations by the direct initiation were simulated by a combination of three grid widths and four higher-order schemes. The higher grid resolution can be produced to be the irregurer and larger cellular structure. Further, In the same grid resolution, it is found that the higher-order scheme generates the irregurer and larger cellular structure. In the case of low resolution, Mach stem, incident shock, and unburned gas pockets cannot be observed.

162- Explosion damage in the unit 4 reactor building of fukushima daiichi nuclear power plant, *T. Tsuruda* The unit 4 reactor building of Fukushima Daiichi Nuclear Power Plant experienced a major explosion early in the morning on March 15, 2011. Tokyo Electric Power Company (TEPCO) reported a fire on the fourth floor of its reactor building from 9:30 to 10:00 on March 15, 2011. TEPCO also reported another fire of unit 4 on March 16, 2011. The unit 4 is outage and no fuel rod was in the reactor vessel at the explosion. The Nuclear Regulatory Authority(NRA), Japan set up the Committee on Accident Analysis of Fukushima Daiichi Nuclear Power Station on March 27, 2013. NRA invited fire and explosion investigators to assess the building damage of the unit 4 reactor building. The author as a member of investigators visited the unit 4 reactor building on July 10-12, 2013. NRA released the official intermediate report on the explosion damage of the unit 4 reactor building on October 8, 2014. Nuclear reactor building employs a forced ventilation system, which exhaust air from the highest contaminated area and supply air to the least contaminated area. On the fourth floor of unit 4 reactor building two huge motor driven generators (MG set) locates. To dissipate heat from motor driven generators, ducts were also installed on the fourth floor. If the combustible gas spreads from the exhaust line, the combustible gas concentration decreases from the exhaust duct to the supply duct. In this paper, the damage of the unit 4 nuclear reactor building was examined with the pictures taken in the visit. Non-uniform damages of gas explosion are seen in the reactor building. Several local explosions seem to occurred like dust explosion case. Duct opening areas are heavily damaged on the first floor where the gas explosion damage is minor. Fragments could damage cables and other equipment. Heat damages are seen on plastic materials. This heat damages indicates a gas explosion in the reactor building of unit 4.

164- Influence of the temperature of a heterogeneous mixture on the DDT in a small-size pulsed detonation combustor, *K. Alhussan, M. Assad, O. Penyazkov* As an outcome of the researches carried out for many years, a jet-type pulsed detonation combustor running on a liquid fuel has been developed. Its operating principle is based on the excitation of a detonation wave propagating with a supersonic velocity in a heterogeneous fuel-air mixture diluted with oxygen and causing high temperatures and pressures, thus generating a large thrust pulse. The present work studies the conditions of the combustion wave propagation in a small-size pulsed combustor with regard to the influence of the initial temperature of a heterogeneous mixture on the deflagration-to-detonation transition. It is shown that the heating of the pulsed detonation combustor ensures a partial transition of a liquid fuel into the aggregate state of an oxidant, which is an important factor responsible for the detonation initiation in a small-size tube of length less than 1 m. Analysis of a large number of working cycles in combustion of near-stoichiometric heptane/air/oxygen mixtures ϕ= 0.95-1.05) showed that, when the prechamber is heated from 30 to 60°C, the wave velocity rises from 500 to 2500 m/s. The detonation is generated in this case at distances 140-640 mm from the place of mixture initiation, which amounts to 7-32 tube diameters. This implies that an increase in the thermal activation of a mixture prior to its ignition not only promotes the deflagration-to-detonation transition, but is also decisive for the predetonation distance.

168- Detonations in capillary tubes with nitrous oxide as an oxidizer, *T. Meye, E. Brandes, U. Krause* Microstructured process equipment is more and more used in chemical process engineering. The advantages of such arrangements which use capillary tubes with an internal diameter of less than 1 mm are a better control of the chemical reactions i.e. their process parameters can be influenced more easily. For example a more effective chemical synthesis can be expected which leads to purer reaction products and, thus may, contribute to an increased yield. In addition, it is assumed that the continuous reaction processes, the reduced temporal use of substances associated with them, and the small-scale reaction areas of a microreactor (in which the wall distances may be smaller than 1 mm) will reduce the safety risk. The question, however, is: Which microstructured process design allows it to suppress the propagation of a detonation when gaseous detonative mixtures of substances are used or created? An experimental test arrangement designed to generate stable detonations and to investigate their propagation behavior in capillaries was used to answer this question by drawing conclusions for the diameter of a capillary which is safe due to quenching detonations. Based on theoretical considerations, a detonation should be able to pass through a tube of diameter d only if the following correlation between the detonation cell width λ and d is valid: $d \geq \lambda/\pi \approx \lambda/3$. This theoretical consideration could be proven in former investigations for flammable gas/oxygen mixtures. The investigations reported here have been performed for nitrous oxide as oxidizer. Nitrous oxide is regarded as an oxidant with an oxidation potential between air and oxygen. From the safety engineering point of view, it does not reach the risk potential of oxygen while it has, at the same time, an enhanced oxidizing potential compared to air.

172- Turbulent premixed hydrogen flames at high Karlovitz number: A DNS study, *Y. Chen, K. Luo* There has been increasing interest recently in applying hydrogen or hydrogen-rich fuel to combustors due to the potential for near-zero carbon dioxide emissions. The turbulent velocity fluctuation in realistic combustion devices is reported to be 150 times higher than the lean hydrogen laminar flame speed. However, direct numerical simulation (DNS) of hydrogen flames under such high turbulence intensities is rare as the high hydrogen flame speed requires high resolution to achieve the turbulent Reynolds number for realistic turbulent flames. The aim of this work is to gain detailed understanding of the structure and statistical quantities of premixed turbulent hydrogen/air flames in an unconfined three dimensional domain in the presence of homogenous, high speed turbulence using DNS with detailed chemical mechanisms.

178- Two-dimensional simulation on detonation wave supported by the cylindrical inner wall injecting premixed gas, *J. Fujii, A. Matsuo, J. Kasahara* The aim of this study is to clarify the condition to propagate a detonation wave consuming the injecting premixed gas from the cylindrical inner wall. Stoichiometric H_2-air mixtures are the target fluid. Two computational domains are used; one is rectangular one whose longitudinal chamber length, L, is taken as a parameter, and the other is arc-shaped one whose radius of curvature, rin, is taken as a parameter. The arc-shaped flow field is used after the numerical validation, instead of the whole area around the cylinder. First, L= 50, 60, 75 & 100mm are used to investigate the effect of longitudinal chamber length in the rectangular flow field, which is the method of two-dimensional RDE simulations to get the reference data for comparison. Secondly, rin = 191, 127, 95.5, 79.6 & 63.7 mm (θ= 30°, 45°, 60°, 72°, 90°) at constant L=100mm are used to investigate the effect of the curvature in the arc-shaped flow field. Thirdly, L=75, 100, 150 & 200 mm (θ = 45°, 60θ, 90°, 120°) at constant rin = 95.5 mm are also investigated in the arc-shaped flow field. In the rectangular domain, flow field of L = 60, 75 and 100 mm got stable, but that of the smaller length cases could not show the steady propagation. Here, h is newly defined as the distance from the lower end to the maximum unburned mixtures, which corresponds to the triple point of the detonation front, and hsteady denotes h at steady state. Dsteady also denotes the propagation velocity at steady state. There is a similarity in h_{steady}/L, and D_{steady} also converge to the same value close to the CJ velocity. In the arc-shaped domain at constant L=100 mm, the detonation wave in the cases of rin = 191, 127 and 95.5 mm got stable, but it collapsed in the smaller rin cases. Here, L_h is newly introduced as the length of inner wall at rin + h_{steady}. D_h is also introduced as the propagation velocity at the triple point of the detonation front, and $D_h/2$ denotes the average of Dsteady and Dh. The values of h_{steady}/L_h are close to the rectangular case. The velocities at D_h are more than the CJ velocity, but those at $D_h/2$ are close to it. Therefore, the rin = 95.5 mm would be a critical condition, and the smaller rin cases could not achieve steady propagation. In the arc-shaped domain at constant rin = 95.5 mm, the values of D_h are higher than the CJ velocity due to the effect of curvature, although the velocity near the wall is lower than it. In the case of L = 150 mm, more than 70% of the detonation front is over CJ velocity, and it could be said that it is close to a critical value. Then, the longer L cases could not achieve steady propagation.

182- Study of the morphological properties of ammonium nitrate and decomposition with dextran, *Z. Mansurov* Investigation of the surface of ammonium nitrate granules by optical microscope and scanning electron microscope (SEM) has been conducted for examining their morphological properties to identify the potential depressions and irregularities. The process that increases aquatic resistance of ammonium nitrate (AN) with the addition of carbonaceous materials and the retention capacity of the surface of ammonium nitrate, by the generation of mesopores is described. The generation of the mesaporous structure explains retention the deposition of carbonaceous materials on the surface of the granules. The kinetic parameters of decomposition of ammonium nitrate (NH4NO3) with the addition of dextran $(C_6H_10O_5)n$ was investigated using Differential Scanning Calorimeter (DSC). Each formulation was studied experimentally by different heating rate (5°C/min, 10°C/min, 20°C/min.).

185- Numerical investigation of hydrogen-air mixtures ignition near lean flammability limit, *A. Smygalina, M. Ivanov* The present paper represents an elaboration of the method for lean flammability limit determination. The hydrogen-air mixture was considered. This method implies 1D numerical simulation of combustion with a specific statement of hydrogen concentration gradient. Combustion formed in this statement has a spontaneous manner and propagates in two distinct regimes, what enables to determine insufficient hydrogen concentration, which could be treated as lean flammability limit. This limit was also studied in the framework of 0D simulations. Here it was considered as a hydrogen concentration at crossover. Calculations performed with the use of different kinetics mechanisms led to underestimated value of lean flammability limit, what demonstrated the importance of transport phenomena account and the consistency of 1D approach rather than 0D one. Another aim of this work consisted in the determination of limiting hydrogen concentration, at which the steady flame could not be formed. Results showed that at uniform distribution of hydrogen concentration the steady flame does not exist when initial concentration is less than 10% (vol.). However, at adding the spatial domain with the growing concentration gradient the steady flame exists even if the hydrogen concentration is less than 10% in uniform region.

193- Flame spread along a paper disk in a narrow channel, *T. Daitoku, T. Takahashi, T. Tsuruda* Flame spread along combustible surface is governing growth and extinction in fire hazards. Understanding of the flame spread is practically important to reduce fire risk. Flame spread is controlled by heat and mass transfer, and chemical reaction. Flame spread has been studied in various conditions, for example, flame spread over liquids and solids. In nuclear power plant, to prevent contamination, floor and wall are covered with combustible sheet. Narrow gaps between sheet and wall could be present and fire might spread in these gaps. In the narrow channel, the irregular flame spread called fingering might occur. The conditions of the limit of fingering spread are not well understood. The objective of this study is to determine the flame spread mechanisms in narrow channel. In this research, the flame spread characteristics of solid fuel in a narrow channel is examined, experimentally. Flame spread in narrow channel is categorized into three. It seems the boundary exists among Mode a, c and Mode b. In Mode a, the mean radius of flame spread increased proportionally with time. And flame spread rate of Mode c is clearly slow in comparison with Mode a.

195- Numerical simulations of ignition and combustion of RDX mixed with gaseous additives , *M. Mar, P. Gillard, L. Courty* The effects of different parameters on the combustion of 1,3,5-trinitrohexahydro-s-triazine (RDX) are studied. Different simulations with several initial mass, temperature, pressure, additives and heat transfer coefficient are performed with COMSOL software using a detailed chemical kinetic mechanism. A literature survey has been done on the problem of ignition of propellants for different initial pressures and we found that this parameter and the nature of gaseous additive are of importance. In this work, 0D simulations for initial masses ranging between

0.3 and 1 g (with a 0.1 step) were performed. Initial pressure and temperatures were studied respectively between 1 and 10 bars and between 300 and 1100 K. Different heat transfer coefficients were studied in order to show the influence of convection and radiation near the wall. Simulations were performed using a detailed kinetic mechanism available in the literature. The condensed phase is not included in this study and the gas phase is composed of equivalent RDX vapors, additives and reaction products. We were interested in final temperature, pressure, maximum rate of explosion pressure rise and species concentrations as functions of time. Simulations were carried out thanks to COMSOL Multiphysics® Modeling Software by solving detail kinetic mechanisms, conservation equations of mass, energy and species concentrations. The results show that ignition delays are considerably reduced with increasing temperature and pressure due to the increase of the exothermic reactions. We noticed that initial mass has an effect on the maximal combustion pressure but not on the maximal temperature. At the end of the combustion, major species are H_2, H_2O, N_2, CO. H_2O compounds especially plays an important role on the temperature and pressure profiles. We also showed that it is possible to ignite RDX at ambient temperature and pressure with the artificial addition of OH radicals. Finally, inert gases addition at different initial pressures increases ignition delays. This increase is lower with Ar than with N_2. This last species strongly attenuates the dynamic of combustion whereas synthetic air does not mitigate it so much.

196- Ignition delay times of primary reference fuels , *M. Fikri* Diethyl ether (DEE) can be produced from ethanol by catalytic dehydrogenation and is therefore of interest as a biomass-derived fuel component. It has a surprisingly high cetane number of 125 when compared with alkane with the same molecular size (e.g., 22 for butane and 30 for pentane). DEE is typically used to support cold-start in gasoline and Diesel engines, or as ignition improver for ethanol and is even considered as alternative Diesel fuel. In addition, DEE is used as a model fuel to test safety-relevant ignition processes on hot surfaces. There is a lack of models of diethyl ether at low temperature and high pressure (engine-like conditions). In this study we present ignition delay times of lean and stoichiometric mixture of the primary reference fuel PRF95 doped with DEE (10 and 30 Vol.%) between 650 and 1250 K at pressures of 10 and 40 bar. PRF95 is a gasoline representative. To model these mixtures a new model for DEE (Sakai) with gasoline model (Mehl et al. 2011) was assembled. The model of Sakai contains important low- temperature species such as QOOH. The prediction of the measured ignition delay time data was satisfactory but does still not reproduce the absolute values.

198- Numerical simulations of CNG, LPG & H2 lean premixed deflagrating flames, *M. Abdel-Raheem, S. Ibrahim, W. Malalasekera, M. Bragin* This paper presents large eddy simulations (LES) for transient propagating premixed flames inside a laboratory scale combustion chamber. During combustion, a number of instabilities can occur that will alter the shape of the flame and can lead to localized flame acceleration/deceleration. If this fact is not included in the combustion model, the predicted pressure will be under- or, over-predicted and may cause major safety threats. In studying explosion hazards, thermo-diffusive instability should be considered. The main focus for the current work is to examine the effects of thermos-diffusive instability, expressed by Lewis number (Le) and the assumption of neglecting that effect (i.e. unity and non-unity values), on the generated pressure, flame location and speed for 3 different fuels namely, CNG, LPG and Hydrogen at lean conditions with equivalence ratio of 0.8. The numerical results obtained are validated against published experimental data of for the selected chamber configuration.

8:30 Plenary Lecture 4

Modelling shocks and detonations in heterogeneous high explosives, *R. Saurel* Shock and detonations in heterogeneous materials differ widely of similar phenomena in gas mixtures as temperatures and velocities disequilibrium effects are present. Chemical decomposition phenomenon is different as well, the ignition being governed by local effects (hot spots), and obviously materials equations of state are far from those of gases.

The present talk is devoted to the presentation of modern technical material in some of these areas:

- Shock relations for multiphase mixtures with stiff mechanical relaxation (Kapila et al., 2001). These relations enable accurate computation of the post-shock state and energy partition among the phases (Saurel et al., 2007).

- Generalized Chapman-Jouguet conditions (Petitpas et al., 2009). Temperature disequilibrium among the phases being present in the reaction zone heat exchanges may have similar non-ideal effects as velocity divergence in curved front detonations.

- A flow model valid from the shock front where mechanical relaxation is stiff and results in velocity equilibrium to the expansion zone, far from the shock, where velocity disequilibrium are present (Saurel et al., 2014).

- A novel equation of state, simple and accurate for condensed energetic materials and temperature computation (Le Metayer and Saurel, 2015).

Chemical decomposition and hot spots modelling in this theoretical frame are in progress.

9:40 Gasdynamics of explosions 1

264- **Theory of Weak-Shocks Interactions with Transonic Mixing Layers,** *C. Huete, A. Sanchez, F. Williams, J. Urzay* This article extends to transonic mixing layers an analysis of Ligthill on the interaction between weak shocks and laminar boundary layers. As in the previous work, the analysis is carried out under linear-inviscid assumptions for the perturbation field, with streamwise changes of the base flow neglected, as it is appropriate given the slenderness of the mixing-layer flow. The steady-disturbance profile is determined by taking a Fourier transform along the longitudinal coordinate. Closed-form analytical functions for the pressure field are derived in the low-frequency and high frequency limits, and vorticity disturbances are obtained as functions of the pressure perturbations. The analysis provides, in particular, the effective distance of upstream influence of the pressure perturbation in the subsonic stream. The resulting value, which scales with the thickness of the subsonic layer, is much smaller than the upstream influence distances encountered in boundary layers. The results may be extended to address supersonic-combustion autoignition and flame-holding problems.

238- **Viscous solutions of the triple shock reflection problem,** *S. Lau-Chapdelaine, M. Radulescu, G. Sharpe* The reflection of a triple-shock configuration was studied numerically under conditions similar to those present in the creation of detonation cells. A double Mach reflection occurred due to the incident Mach stem reflecting. Kelvin-Helmholtz instabilities were absent and there was no bifurcation of the Mach stem before Reynolds' numbers corresponding to the induction length were reached. The wall jet was, however, strong enough to disturb the Mach stem, and the highest temperatures were seen along the contact surface and jet. A regular reflection occurred when the transverse wave reflected.

125- **Mach reflection during the oblique interaction of a condensed-phase explosive detonation reaction zone with a rigid wedge**, *J. Bdzil, M. Short, J. Quirk* A numerical study is presented of the oblique interaction of a step wedge with a supported shock in unreacted explosive and a resolved reaction zone detonation, both for the case of a condensed-phase explosive. The results are compared with the predictions of shock-polar theory, and are in good agreement for the nonreactive problem. For the problem of the direct numerical simulation of a resolved reaction zone detonation, the agreement with shock-polar theory is favorable only for the case of large wedge angles. For the case of small wedge angles, a curved Mach shock is observed that smoothly transitions into the shock of the incident detonation. The strong influence that the explosives' heat-release rate has on streamline curvature, explains the resolved reaction zone detonation observations.

9:40 Detonation dynamics 3

41- The Possibility of Detonation Stabilization in a Supersonic Flow of a Combustible Gas Mixture without Any Expenditure of Energy, *V. Levin, T. Zhuravskaya, I.S. Manuylovich,* The numerical investigation of detonation propagation in a stoichiometrical hydrogen-air mixture flowing with supersonic velocity into a plane channel has been carried out with the purpose of determination of conditions that guarantee detonation stabilization in the flow without any expenditure of energy. The possibility of stabilization of formed detonation wave without energy input in the combustible gas mixture flowing with supersonic velocity into the plane channel with narrowing has been determined. The stability of detonation stabilization in the channel with narrowing has been examined. In addition for some Mach numbers of the incoming flow the method of determination of the channel shape which gives detonation initiation and its stabilization in the flow without any energy input is proposed. A plane two-dimensional supersonic flow of the combustible gas mixture about the symmetrical semi-infinite plane obstacle placed along the stream was considered. The structure of the stabilized ahead of the obstacle detonation wave was studied. It has been established that the detonation wave is divided into three sections with different structures.

129- **A hydrodynamic simulation on reactive shock attenuation in the large-scale gap test of heavily aluminized RDX,** *B. Kim, M. Kim, J. Yoh* The present study aims at constructing a new rate law for the reactive flow of an aluminized RDX (PBXN-109) and simulating the sympathetic detonation of the pallet-packaged 8 high explosives with the AISI 9260 steel casing. The constitutive relations of reactive flow and unreacted/reacted EOS are established for performing a full detonation simulation with complex multi-material interactions and casing fragmentations. Here, the stochastic failure model namely Mott probability function is employed to describe the fragmentation process. The simulation is carried out for making a comparison to the measured pressure data of a pallet-packaged system obtained from 15 m and 20 m gauge locations away from the donor charge.

139- **Behavior of methane/oxygen gas detonation near propagating limit in small diameter tube: effect of tube diameter**, *K. Yoshida, K. Hayashi, Y. Morii, K. Murakami, A. Susa, N. Tsuboi, A. Hayashi* Detonation propagating limit is an important fundamental and practical problem for safety engineering point of view. The detailed structures and properties of the detonation have been studied using the experimental and numerical methods. However, the theory for predict detonation limits does not exist. Detonations in a circular tube were measured to observe a few modes, for example, single-spinning, two-headed, and multi-headed modes. The single spinning mode is the lowest mode in the limit mixtures in a circular tube to propagate with a helical track on the wall and to rotate around the tube axis. The single-spinning detonation is an important issue to predict detonation limits and safety problems because it

is the lowest mode of detonation. The present study aims to obtain the knowledge on the single-spinning detonation and the feature of the detonation near the detonation limit by using the smoked foil records and the velocity measurements in CH4/O2 gas mixture for various initial pressures and tube diameter. The existence ranges of the spinning detonation and the galloping detonation will be revealed by using smoked foil records and the velocity measurements. The influence of the initial condition was investigated by changing the initial pressure and the tube diameter. Regardless the tube diameter, the detonation velocity is less than the 80 % of C-J velocity as $\pi d/\lambda<1$. As $\pi d/\lambda<1$, the detonation velocity corresponds to the theoretical C-J velocity. The cellular patterns are classified into three different patterns, which are the small cells, the single-spinning mode and the multi-headed mode. The small cells mean that there exists small and increment size of the multi-headed cell patterns on the smoked foil record. The existing range of the single-spinning mode is $\pi d/\lambda>1$ and this is independent of the tube diameter. For $\pi d/\lambda<1$, the cellular patterns were the small cells for all of this case. The parameter $\pi d/\lambda$ is important to decide the propagating mode of the gaseous detonation. In both CASE A and CASE B, The small cells were observed on the beginning of the smoked pattern and the size of cellular patterns gradually increased. Then the cellular patterns changed from the small cells to the single-spinning mode. The single-spinning mode finally disappeared after the track angle changed from 45 deg. to smaller angle.

9:40 Ignition 1

263- Effects of natural convection on thermal explosions in spherical vessels, *I. Iglesias, A. Sanchez, F. Williams, A. Liñán* This paper investigates the effects of buoyancy on the development of thermal explosions in enclosed reactive systems. The analysis considers a gaseous mixture undergoing an irreversible exothermic reaction with large nondimensional activation energy in an isothermal spherical vessel. As in the classical convection-free Frank-Kamenetskii analysis, we investigate the existence of steady weakly reactive solutions with small nondimensional temperature increments of the order of the Frank-Kamenetskii value, with the explosion conditions indicated by the emergence of a bending bifurcation as the relevant conduction-reaction Damkohler number Da is increased to a critical value. In the nondimensional formulation, which employes the Boussinesq approximation, the convective-transport rates of momentum and energy are proportional to the Grashof number Gr, based on the characteristic induced velocity v_c resulting from a balance between the viscous stresses and buoyancy forces. For negligibly small values of Gr, the spherically symmetric density distribution determined by the reaction-conduction balance is seen to induce motion in the form of an annular vortex, symmetric about the equatorial plane, whose associated velocities, scaled with v_c, are found to be much smaller than unity along the lower stable branch of weakly reactive solutions. Correspondingly, the analytic description of the Frank-Kamenetskii vortex in the limit Da << 1 exhibits exceedingly small multiplicative factors for the different terms in the associated stream-function expansion in powers of Da. The analysis for Gr << 1 is extended to account for the corrections to the temperature field resulting from convective transport, giving results that are seen to remain accurate up to moderately large values of Gr, that being a direct result of the relatively small velocities induced. The asymptotic limit Gr >> 1, which applies to sufficiently large containers for which convective transport becomes dominant, is also addressed separately.

281- Effect of equivalence ratio on ignition and flame propagation of n-hexane-air mixtures using moving hot particles, *S. Coronel, J. Shepherd* Assessing the risk of accidental ignition of flammable mixtures is an issue of importance in industry and aviation. Of particular interest are the risks introduced by the use of carbon fiber reinforced polymers (CFRP) as an alternative to aluminum alloys in aircraft manufacturing. In aircraft, potential ignition sources include lightning strikes, sparks from electrical equipment, electrostatic discharge in fuel tanks, and overheated pumps. In the case of a lightning strike on the aircraft structure, hot particles are often ejected from the surface that is struck due to resistive heating. Such hot particles represent a potential ignition hazard if they are ejected into flammable vapor. With this motivation, the present study is a contribution to understanding the phenomena of ignition by a single hot (inert) particle under well characterized conditions. The aim of this work is to investigate the ignition in n-hexane-air mixtures (kerosene surrogate) using moving hot spheres. Tests are performed using alumina spheres with a diameter of 6 mm and with varying particle surface temperatures, 750-1100 K, and equivalence ratios, 0.9-2.0. The ignition threshold for the equivalence ratios tested was on average 970 K for a 6 mm alumina sphere traveling at 2.4 m/s. Interferometry images showed that for certain mixture compositions there is an interaction between the sphere and the flame that leads to: anchoring of the flame to the front stagnation point and puncturing of the flame front by the sphere.

267- Hot surface ignition and flow separation, *J. Melguizo Gavilanes, J. Shepherd* Ignition of combustible atmospheres by hot surfaces is a common issue in industrial safety. Determining critical conditions in terms of surface size and temperature are essential in order to evaluate the potential of an ignition hazard. In the present work numerical simulation of ignition by a rapidly heated surface is performed. Special attention is given to the near-wall buoyancy flow induced, and flow separation to gain insight on the dynamics, time and location of the ignition event. The ignition evolution is explained in detail by means of velocity, product mass fraction and temperature fields. Additionally, analysis of the individual contributions of the terms in the energy equation reveals the competition that ensues between the heat release due to the chemistry, and diffusive and convective losses in the vicinity of the hot surface. Ignition occurs when the heat release rate is greater than the rate at which heat is diffused back to the wall. Finally, results clearly show the importance of flow separation in creating zones/regions that are prone to ignition.

9:40 Flame instabilities 1

47- Diffusive-thermal instabilities of high Lewis number flames in micro flow reactor, *T. Miroshnichenko, V. Gubernov, R. Fursenko, S. Minaev, K. Maruta* We study the diffusive-thermal instabilities of rich hydrogen-air flames in micro flow reactor with controlled temperature profile. For this purpose the thermal-diffusion model with reduced two-step kinetics is used. New pulsating flame regime was found, which occurs as a result of diffusive-thermal instability via the supercritical Hopf bifurcation. The difference between Flame Repetitive Extinction and Ignition (FREI) regime and diffusive-thermal pulsations is studied.

35- Diffusive-thermal instability of low-lewis-number premixed flames in stretched flow of two slot burners, *R. Fursenko, S. Mokrin, S. Minaev, K. Maruta* Characteristics of lean premixed flames in stretched flow of two counterflow slot-jet burners were studied numerically and theoretically in the frame of thermal-diffusion model. Regime diagrams in equivalence ratio / stretch rate plane are plotted on the basis of numerical simulations and linear stability analysis of one-dimensional stationary solutions. The extension of flammability limits of low-Lewis-number stretched premixed flames related

with multidimensional flame structure is observed. Numerical and analytical results are compared with experimental data available in literature.

247- Numerical study of interaction between Darrieus-Landau instability and spatially periodic shear flow, *D. Valiev, A. Gruber, C. Law, J. Chen* It was recently shown that DL instability has a role in boundary layer flashback of premixed turbulent flames [1], actively contributing to flame acceleration through flame corrugation that, in turn, results in the creation of near-wall regions of flow reversal ahead of the flame sheet. The flame in the boundary layer behaves in a laminar fashion modulated by weak, highly anisotropic velocity fluctuations. It is seen that the flame acquires a corrugated shape with the characteristic time and length scales that can be correlated with the structures in the boundary layer. The oncoming prolongated velocity streaks with alternating regions of relatively high and low velocities interact with the initially planar flame. The observed flame shape evolution suggests that the streaky structure of the flow triggers the corresponding unstable wavelength of Darrieus-Landau (DL) instability, resulting in the flame acceleration and subsequent upstream propagation of a corrugated flame. Recent experimental investigations have confirmed the existence of the above mentioned flow reversal regions in both swirling and non-swirling configurations [2, 3, 4], with flame propagation upstream with velocities approximately two times larger than the laminar burning velocity. Several previous studies focused on the interaction of weak, homogeneous isotropic turbulence and DL instability [5, 6, 7]. In Refs. [6, 7] it was found that the effect of DL instability may be dominant when the turbulence intensity is low. In Ref. [8] it was found that a planar that is subjected to oncoming periodic shear flow can propagate with increased velocities in the absence of thermal expansion. However, there still remain many open questions regarding the interaction of anisotropic velocity fluctuations and flames with realistic expansion. We perform a detailed investigation of the role of DL instability on the regime of laminar flame front propagation subjected to external forcing by a spatially periodic shear flow that resembles the turbulent boundary layer's streaky pattern. The present study is focused on identifying conditions for which either intrinsic flame spatial scales or streaky structure spatial scales would be dominant in the process. The parametric study is focused on the variation of flame configuration and propagation speed dependent upon the amplitude and spatial scale of the oncoming periodic shear flow.

11:25 Detonation analogs 1

312- Invited review: Detonation analogs revisited, *A. Kasimov* The paper is an overview of developments of detonation analogs with a focus on recent results. Mathematical toy models due to Fickett and Majda are briefly discussed together with the analysis of their drawbacks and of recent proposals to overcome them. Implications of the analog modeling for the rational asymptotic analysis of detonation dynamics are also discussed, in particular in connection with recent results on the theory of weakly nonlinear multi-dimensional detonations.

38- Detonation wave driven by energy of carbon condensation, *A. Eremin* In this paper a new physical phenomenon detonation wave driven by energy of carbon condensation at self-decomposition of carbon suboxide C_3O_2 and acetylene, initiated by a shock wave, is described. The interconnection of kinetics of condensation and heat release processes is investigated and analyzed. It is shown that the most significant heat release proceeds during the last stage of the process the formation of condensed particles.

52- Modelling microbial chemo-tactic waves using adaptive mesh refinement, *S.A.E.G. Falle* Microbial transport in groundwater can be strongly influenced by chemo-taxis induced by chemical gradients and this can have a significant effect on the rate of degradation of groundwater contaminants. The main aim of this paper is to describe a method of simulating the propagation of a travelling microbial wave in a contaminated region and the resulting degradation of the contaminant. The presence of the chemo-tactic term and the relatively small microbial diffusion means that the wave contains a very sharp wave front or shock. We therefore use an upwind conservative numerical scheme to obtain accurate and numerically stable solutions. The accuracy of the method is verified by comparisons with an exact one-dimensional solution of a simplified problem. The method is combined with Adaptive Mesh Refinement (AMR) to simulate the propagation of a realistic chemo-tactic wave in one dimension. We also compute the propagation of chemo-tactic waves in two dimensions on the scale of a Petri dish. Even with AMR, this calculation is so expensive that it cannot be applied to groundwater pollution. However, one could use either a level set method or the simplified model calibrated to give the same wave speed as the full model. This technique makes it possible to study the propagation of such waves on scales of the order of kilometres, which typical for contaminated aquifers.

11:25 Detonation initiation and failure

77- Study of small-scale experiments of detonations in an aqueous foam confinement, *F. Ballanger, D. Counilh, N. Rambert, A. Lefrançois, J. Haas, A. Chinnayya* In the last decades, aqueous foams have been studied for their abilities to protect from blasts. To understand and to predict this protection, experiments of blast wave propagation (explosive detonation) in aqueous foams have been carried out recently. In order to explore more particularly the detonation conditions, we ignited HE hemispheres from 3 g to 120 g and placed, in some cases, an air exclusion volume to enhance post-combustion. Time-pressure histories have been recorded for each shot with a total of 23 incident or reflected pressure gauges to cover scaled distances from 0.2 $m.kg^{-1/}3$ to 5 $m.kg^{-1/3}$. Attenuation is explored through comparison of peak overpressures, arrival times and positive impulses in aqueous foam and in air. Therefore, we are able to assess of the validity or not of the Hopkinson-Cranz scaling laws in the foam for each of these parameters. Then, by comparing shots in air and in foam, we observe and quantify the mitigation the foam provides on each one of them. A numerical code has been developed during the past years in which the multiphase formalism is used to model the interactions of the liquid phase with the gaseous phase, as well as the interaction of the detonation products with the two-phase medium. The calculations reproduce with a good accuracy the experimental results.

123- Higher order DSD calibration of ammonium nitrate/fuel oil, *C. Chiquete, M. Short, S. Jackson, J. Bdzil* The Higher Order Detonation Shock Dynamics (HODSD) calibration of Ammonium Nitrate/Fuel Oil (ANFO) rate-stick data was revisited at a lower Chapman-Jouguet velocity than had been used previously. The HODSD calibration incorporates a higher order propagation law which includes the effects of transverse flow and shock acceleration omitted in a conventional DSD calibration. The results show an improved correspondence to the fitted rate-stick data and a significantly improved prediction of uncalibrated slab-geometry test detonation velocities with respect to the leading order DSD approach.

200- Method of characteristic analysis of gaseous detonations bounded by an inert gas, *R. Fievisohn, K. Yu* Detonations bounded by inert gases are found in vapor could explosions and explosions in free jets. This research focuses on modeling the bulk fluid flow accurately and rapidly without the need for expensive numerical simulations. Major flow features such as the

detonation, oblique shock, and contact surface are modeled analytically. Once these parameters are known, a method of characteristics solution is initialized to generate the remainder of the flowfield.

11:25 Ignition 2

254- **Laser-induced ignition of methane and biogas near the lean flammability limit,** *N. Peters, H. Morrow, B. Akih Kumgeh* Interest in fuel flexible combustion systems necessitate characterization of various fuels with respect to their combustion properties, such as ignition energy requirements. In this work we study laser ignition of methane and biogas near their lean flammability limits. A high energy Nd:YAG laser at 532 nm is used to induce breakdown and ignition of fuel/air mixtures. Plasma formation, flame initiation, quenching, and successful flame propagation are captured using high speed Schlieren imaging and laser interferometry. Minimum pulse and minimum ignition energies are determined for a range of equivalence ratios, also permitting the determination of flammability limits. These measurements offer insight into differences in biogas and methane ignition such as the higher energy requirements for biogas. The results and discussions advance our understanding of ignition requirements for various fuel/air systems.

180- **Comparison of the formation of ignition sources due to continuous and repetitive metallic friction**, *L. Meyer, M. Beyer, U. Krause* Within mechanical components friction situations of metallic surfaces can appear. Thereby the ignition sources hot surface and mechanically generated sparks can occur. Previous studies have shown, that with the use of stainless steels incendive hot surfaces can occur even before the conditions for spark formation are achieved. Previous studies have only considered friction situations with continuous friction, which may occur in bearings, seals and couplings in case of an error. In addition to the continuous friction situations, repetitive friction situations can be expected in fans, pumps and agitators in the event of a fault. In this work, the formation of ignition sources by repetitive friction were investigated and compared with the formation of ignition sources due to continuous friction. It is shown how different contact ratios and frequencies influence the temperature development. Furthermore, it was investigated by what factor the power density must be increased to achieve the same temperatures as they occur in continuous friction processes.

290- **Chemical kinetics of ignition of n-hexane by a moving hot sphere,** *R. Mevel, J. Melguizo Gavilanes, S. Coronel, J. Shepherd* The risk of accidental ignition of flammable mixtures by a hot surface is of particular importance for the commercial aviation industry. In the case of a lightning strike on the aircraft structure, hot particles might be ejected from the inner fuel tank surface and could potentially ignite the flammable vapor space of a fuel tank. Quantifying the risk of ignition of aviation fuels by hot particles is thus a key issue for both engineering design and safety analyses. In the present study, the kinetics of the ignition of n-hexane by a moving hot sphere has been analyzed. Non-reactive two-dimensional simulations have been performed to quantify the condition of temperature that the fluid experiences as it is heated by the hot sphere. Using these temperature profiles, the chemical activity predicted by several detailed reaction mechanisms as well as a one-step model has been studied. The results suggest that under the conditions presently considered, the low-temperature chemistry does not play a significant role in the ignition process due to the very short period spent by the mixture below 1000 K. Below the ignition threshold, the chemical activity is very low and the mixture essentially undergoes pyrolysis and partial oxidation.

11:25 Flame instabilities 2

261- **An analysis of flame instabilities based on Sivashinky equati**on, *J. Yanez, M. Kuznetsov* An analysis with the Sivashinski-Michelson equation was performed in order to describe the experimental results and its dynamic development in terms of the basic physical properties of combustible mixtures. It was found, that the burning velocity increased by the factor of 1.2-1.5 due to the flame instability. This value was proportional to the flame area amplification rather close to experimental data. The characteristic time of flame development with a cellular structure due to Landau-Darrieus instability was found to be much longer than the corresponding one for thermo-diffusion instability for lean mixtures. Also, we correlated the time required for instability development as a function of the mixture reactivity.

64- **Formation and evolution of distorted tulip flames**, *H. Xiao, R. Houim, E. Oran, J. Sun* The formation and evolution of tulip and distorted tulip flames (DTF) in an enclosure have been numerically studied using fully compressible computational fluid dynamics with high-order algorithms and adaptive mesh refinement (AMR). The goal is to produce an accurate calculation with a fine enough numerical mesh to resolve pressure waves and their interactions with flames and boundary layers, and then to compare these to prior experiments. The governing equations were solved using a fifth-order MUSCL algorithm with HLLC fluxes. AMR provided local mesh refinement to resolve important features of the flow and combustion, such as flame fronts, strong pressure waves, and boundary layers. The key features of flame-front evolution, including the flame shape variations, oscillating behavior and cusp collapsing, in the experiment are reproduced in the numerical simulation. In particular, the shape of the calculated DTF is quite close to the experimental observations. This will allow us to gain a deeper insight into the physical process and mechanisms controlling the flame evolution and perhaps some indication how the DTF arises. The computation described here is only one of a series that we have performed to try to understand the development of the tulip flame and the unusual development of a DTF. The entire series consists of variations in the aspect ratio and sizes of the tube, where the largest tube is 8 cm × 56 cm and the smallest is 1 cm by 7 cm. Even though various mechanisms for the development of the first tulip flame were postulated, it is extremely difficult to understand why the subsequent DTF and succeeding shapes develop. Of particular interest is the second set of cusps, and why and how this forms is unclear at this stage. The computations do, however, show that that pressure waves are extremely important. The movies (not shown in this abstract) of the schlieren images show pressure waves interacting and focusing, both in the burned and unburned regions, as the flame propagates down the tube. In addition, from a combination of our prior work and these computations, we believe that the presence of and changes in boundary layers and vorticity, all interacting with acoustic waves, is important and likely key to understanding the flame evolution. These will be shown and discussed in the presentation.

231- **Critical Peclet numbers for the onset of Darrieus-Landau instability in atmospheric-pressure methane-air flames**, *C. Bauwens, J. Bergthorson, S. Dorofeev* Experiments were performed examining the critical Peclet number for the onset of the Darrieus-Landau instability in spherical methane-air flames with flame diameters up to 2 m. This is a continuation of a previous study examining propane-air flames, however, the flame radius is tracked to larger scales and higher resolution imaging is used to capture the development of the cellular structures on the flame surface. For these atmospheric pressure methane-air flames, critical radii on the order of 20-30 cm are

observed. Throughout the range of methane concentrations studied, it will be shown that the critical radius increases with methane concentration, consistent with changes in mixture Markstein number. A linear relationship between critical Peclet number and Markstein length is also found across both methane-air and propane-air results. In addition, oscillatory flame propagation is observed in the cellular methane-air flames, consistent with results of previous large-scale experimental observations of propane-air mixtures.

14:00 Detonation analogs 2

126- **Magnetic detonation in crystals of nanomagnets,** *M. Modestov, V. Bychkov, O. Iukhymenko, M. Marklund* Recent experiments have discovered ultrafast propagation of spin avalanches in crystals of nanomagnets, which is 3 orders of magnitude faster than the traditionally studied magnetic deflagration. The new regime has been hypothetically identified as magnetic detonation. Here we demonstrate unequivocally the possibility of magnetic detonation in the crystals, as a front consisting of a leading shock and a zone of Zeeman energy release. We study the key features of the process and find that the magnetic detonation speed only slightly exceeds the sound speed in agreement with the experimental observations. For combustion science, our results provide a uniquephysical example of extremely weak detonation.

117- **Analog system of detonations with losses and pressure-dependent reaction rate**, *X. Mi, Y. Sun, J. Zhang, P. Hu, C. Wang* The existence of a critical condition (i.e., a condition at which detonation is no longer possible) when losses are present is one of the defining characteristics of detonation waves. For a detonation reaction rate that does not exhibit extreme sensitivity to the local thermodynamic state, it may not be possible to find a critical condition. However, for a sufficiently sensitive state dependence of reaction rate, detonation wave may be unstable, exhibiting regular or chaotic oscillations. This paper seeks to explore the relation between these two phenomena, namely, whether a detonation that is stable can exhibit a critical velocity for propagation. Instead of the reactive Euler equations, a one-dimensional analog system based on a reactive Burgers equation, which mimics the dynamics of detonations with losses and a pressure-dependent reaction rate law, is considered here. From the preliminary examinations of this analog system, it was shown that, as the state dependence of reaction rate is more sensitive than that of the rate of losses, the detonation system is expected to exhibit a critical point in the relation of detonation velocity vs. loss parameter, while this state dependence of reaction rate is not sufficiently sensitive for the ideal steady state detonation structure to be unstable to small one-dimensional perturbations.

240- **Chaos in a third order nonlinear evolution equation for pulsating detonations using Fickett's model,** *A. Bellerive, M. Radulescu* Perturbation theory was applied on Fickett's detonation analogue with a two step reaction to order three of the inverse activation energy, $\varepsilon=1/Ea$, resulting in a third order in time nonlinear evolution equation in the shock velocity perturbation. The evolution equation undergoes a Hopf bifurcation, followed by period doubling cascade to chaos. Some terms were omitted at order three due to the singular nature of the expansion. The results agree with numerical simulation on the same model as well as having many similarities with the Reactive Euler Case.

14:00 Gasdynamics of explosions 2

167- **Investigation of the pressure wave and hot gas kernel induced by low energy electrical discharges**, *S. Essmann, D. Markus, U. Maas* Electrical discharges are a common safety relevant ignition source. The processes governing the ignition by electrical discharges have been the subject of numerous experimental and numerical studies. Many of these studies consider ignition in automotive or aerospace applications where typical ignition energies are in the mJ range. In the present study we investigated discharges with energies ranging from 30 to 1000 μJ which is in the range of the minimum ignition energy (MIE) of many burnable gases. When an electric discharge occurs, the energy that was previously stored in the capacitor is discharged into a fairly small volume of gas. Eventually most of the energy goes into gas heating which occurs across several chemical pathways of plasma reactions, each having a different time scale. A substantial fraction of the heating, depending on the characteristics of the discharge, takes place within tens to hundreds of nanoseconds. This leads to the formation of a roughly cylindrical kernel in the inter-electrode region where temperature and pressure are much higher than in the surrounding gas. This kernel rapidly expands and after several 100 ns a shock wave detaches from the kernel perimeter. Over the course of its propagation it decays into a sound wave or, more generally, a pressure wave. The radial location of both the pressure wave front and the kernel (pressure wave radius and kernel radius) at a certain instant hold information about the discharge. The goal of this study is to characterise low energy discharges by utilising a combination of experimental and numerical techniques. We used schlieren imaging to measure the radii and compared these to data obtained with one-dimensional numerical simulations. The results show that the pressure wave radius is a function of discharge energy and increases with increasing energy. The simulations indicate that this is due to the faster expansion of the hot kernel at early times. In contrast, the kernel radius is a function of energy density. Increasing the spark radius in the simulation results in greater kernel radii but does not affect the radial location of the pressure wave at later instants. While the qualitative agreement between experiment and simulation is good, more information about the early times is needed. Thus, in future work we plan to change the experimental setup so earlier points in time will be accessible. Furthermore, a two-dimensional simulation could directly show the influence of spark channel length and consider fluid dynamics effects like recirculation at the electrode tips.

214- An immersed boundary method to simulate compressible reactive flows featuring shock-wave interactions with three-dimensional solid obstacles, *R. Boukharfane, B. Bouvelle, Z. Bouali, A. Mura* The present paper describes the development and implementation of an immersed boundary method (IB) aimed at simulating compressible reactive flows around three-dimensional complex solid bodies. The boundaries of the immersed objects are represented with a finite number of Lagrangian points, which are distributed over the fluid-solid interface. The flow field is described with a fully compressible reactive multicomponent Navier-Stokes solver that makes use of high-order numerical schemes applied to structured Cartesian grids. The corresponding density-based finite difference numerical scheme is thus suited to compressible reactive flows representative of either combustion in high-speed flows or detonation. The numerical algorithm is based on a third-order accurate total variation diminishing (TVD) Runge Kutta time integration scheme. It employs a seventh-order accurate weighted essentially non-oscillatory (WENO) scheme to discretize the non-linear advective terms while an eighth-order accurate centered finite difference scheme is retained for the molecular viscous and diffusive contributions. The numerical solver thus offers an interesting combination of existing methods suited to the present purpose of studying compressible reactive flows featuring shock-wave interaction with three-dimensional solid obstacles. The immersed boundary methodology makes uses of a discrete forcing approach, which guarantees the imposition of no-slip boundary conditions over the fluid-body

interface. The main features of this immersed boundary methodology are described below with special emphasis placed on the treatment of boundary conditions at the immersed surface. The resulting solver has been verified by considering a complete procedure that gathers several elementary verification subsets including, among others, two-dimensional subsonic and supersonic flows around a cylinder, flow over a circular bump, subsonic Blasius flow over a flat plate, etc. The performance of the new algorithm are illustrated herein on two distinct geometries: (i) the two dimensional supersonic non-reactive flow of air around a cylinder and (ii) the three-dimensional flow developing around spherical-nosed projectiles fired into hydrogen-air mixtures at detonative speeds.

234- Long distance propagation of shock waves in the open atmosphere, *C. Proust, K. Vilalta* Despite significant progresses in the understanding of the formation and propagation of pressure waves in the open atmosphere in the past decades, experience form past accidents (AZF, Toulouse, 2001, Billy-Berclau, 2003 and even Buncefied 2005) reveals that overpressure levels may be greatly ill estimated. This is obviously a concern when the protection of citizens is concerned. There are some indications that both the topography and weather conditions may play a significant role but this remains rather qualitative and there is a need to clarify such points. In this paper, the results of a preliminary experimental campaign are presented in which up to 500 kg eq TNT was detonated in the open atmosphere and the pressure field measured up to 10 kms.

14:00 Ignition 3

256- Ignition delay and flame structure of particle combustion in hydrogen/air mixtures at concentrations below the gas flammability limit, *C. Cloney, R.C. Ripley, M.J. Pegg, P.R. Amyotte* It has long been known that combining a combustible solid particulate with a flammable gas in air may provide a fast-reacting explosive mixture, even when the concentration of each fuel individually is too low to propagate a flame. These so-called hybrid mixture" systems may arise as industrial process hazards and are relevant to mining (e.g., coal/methane), pharmaceutical (e.g., lactose/vaporized solvents such as methanol), and manufacturing industries (e.g., nylon fibres/combustible fumes). In the current investigation, transient, spherically symmetric, numerical simulations are performed for combustion of solid particles in flammable gas/air mixtures at concentrations below the gas lower flammability limit. Both n-hexane (droplets) and n-octadecane (solid) particles are simulated to facilitate comparison with previous multiphase investigation results. The n-hexane combustion mechanism is taken from the literature and the n-octadecane mechanism is developed based on assumptions previously applied for hexadecane combustion. The simulation results illustrate the impact of flammable vapour addition to solid particle combustion and provide valuable insight into the ignition and flame propagation associated with industrial explosion hazards.

30- Reaction front propagation initiated by a hot spot in premixed n-heptane/air mixture at low temperature, *P. Dai, Z. Chen* The ignition and reaction front propagation process of n-heptane/air mixture initiated by a hot spot in 1D planar and spherical systems is numerically investigated considering detailed chemistry. It is found that at low temperature, n-heptane/air mixture undergoes a three-stage ignition process, which is sequentially dominated by low-, intermediate- and high-temperature ignition. At proper temperature gradient, these three ignition stages may all couple with corresponding pressure waves and either generate detonation wave or cause autoignition in front of the propagating reaction front. The complex wave phenomenon of n-heptane/air mixture indicates the significant difference between the ignition modes of large hydrocarbon fuels at low temperature and those of simple fuels or large hydrocarbon fuels at high temperature.

60- Auto-ignition of premixed methane/air mixture in the presence of dust, *V. Leschevich, O. Penyazkov, S. Shimchenko* The some quantity of solid particles is always presented in gas media and the effect of their presence can become significant in several cases. In this study high speed digital imaging has been performed to visualize auto-ignition phenomena of stoichiometric methane - air, coal dust air and hybrid coal dust methane - air mixtures at temperatures close to 1000 K and pressures 1-2 MPa. The conditions were generated by rapid compression machine and direct light emission from test chamber was visualized by high speed camera. It was found that at 100 K methane ignition can occur only when some amount of reactive particles are presented in the test volume. The possibility of specially added coal dust to initiate methane ignition was established by experiments with hybrid coal dust methane - air mixture. The intensive motion of burning particles on video allowed to use their displacements in order to determine velocity field of a gas flow inside test chamber. The perspectives of this new experimental method were considered. The proposed method was tested in this study and data analysis algorithm was developed. Experiments were carried for heated by compression coal dust-air mixture. Velocities of burning particle were measured using successive frames from video. The distributions of radial velocities along chamber radius obtained at different time moments clearly showed changes of gas flow structure. The proposed technique can be applied for optimization of aerodynamics inside RCM.

14:00 Turbulent flames 1

79- Turbulent diffusion of combustion gaseous admixtures, *T. Elperin, N. Kleeorin, M. Liberman, I. Rogachevskii* We study turbulent diffusion of chemically reacting gaseous admixtures in a developed turbulence using the spectral tau-approximation that is valid for large Reynolds and Peclet numbers. It is shown that turbulent diffusion of the reacting species can be strongly depleted by a large factor of the turbulent Damköhler number that is the ratio of turbulent and chemical times. The derived theoretical dependence of a turbulent diffusion coefficient versus the turbulent Damköhler number is in a good agreement with that obtained previously in the numerical modeling of a reactive front propagating in a turbulent flow and described by the Kolmogorov-Petrovskii-Piskunov-Fisher equation. In a fully developed turbulence and at large Peclet numbers the turbulent cross-effects are much larger than the molecular ones.

308- A jet-stirred apparatus for turbulent combustion experiments, *A. A. Davani, P. D. Ronney* A novel jet-stirred combustion chamber is designed to study turbulent premixed flames. In the new approach, multiple impinging turbulent jets are used to stir the mixture. It is well known that pair of counterflowing turbulent jets produces nearly a constant intensity along the jet axes. In this study, different numbers of impinging jets in various configurations are used to produce isotropic turbulence intensity. FLUENT simulations have been conducted to assess the viability of the proposed chamber. In order to be able to compare different configurations, three different non dimensional indices are introduces. Mean flow index; Homogeneity index, and Isotropicity index. Using these indices one can compare various chambers including conventional Fan-stirred Reactor. Results show that a concentric inlet/outlet chamber with 8 inlets and 8 outlets with inlet velocity of 20 m/s and initial intensity of 15% produces near zero mean flow and 2.5 m/s turbulence intensity which is much more higher than reported values for Fan-stirred chamber.

95- Flame speeds and self-similar propagation of expanding premixed turbulent flames at high Reynolds numbers, *S. Shy,*

L. Chen, H. Huang, W. Li This note presents flame speeds and their scaling on large Reynolds-number expanding turbulent premixed flames that propagate in statistically homogeneous isotropic turbulence. Experiments were carried out in a dual-chamber explosion facility, where a large fan-stirred 3D cruciform burner (inner chamber) was resided in a high-pressure outer chamber. Two different mixtures with different Lewis number (Le) are measured, respectively lean methane/air at the equivalence ratio ϕ= 0.9 with Le = 1 and lean syngas (35%H_2/65%CO)/air at ϕ= 0.5 with the effective Le = 0.76. Thus, the effect of Le on turbulent flame speeds and self-similar propagation are discussed and compared with a recent finding by Chaudhuri et al. (2012) using unity Lewis number expanding turbulent flames in a much smaller dual-chamber, fan-stirred vessel.

15:45 Detonation analogs 3

296- **Weakly nonlinear dissipative detonations**, *L. Faria, A. Kasimov, R. Rosales* We propose a multidimensional weakly nonlinear asymptotic theory of detonations that is derived from the reactive compressible Navier-Stokes equations. In order to retain all dissipative effects (i.e. heat dissipation, species diffusion, and viscosity), we scale the Reynolds, Prandtl, and Lewis numbers in a way that allows to balance various nonlinearities present in the governing equations. Our final result is a set of three partial differential equations which describe, in the distinguished limit considered, dissipative detonations. The present work extends our earlier asymptotic theory that treats weakly nonlinear non-dissipative detonations and retains much of the complex dynamics of gaseous detonations.

307- **Laser supported detonation in silica-based optical fibers,** *V. Efremov, A. Frolov, V. Fortov* Silica-based optical fibers demonstrate existence of two catastrophic damage propagation velocities caused by laser radiation. Low velocity mode was named burning. Here we present experimental study of fast detonation-like mode of laser induced damage propagation. This propagation regime is two orders of magnitude faster than known published data on burning fiber glass. This mode is new object of laser destruction of silica-based optical fibers end study of such bulk damage becomes rather significant due to world progress in optical communication link application. Tested regime demonstrates near constant velocities during 200ns in the range of laser intensity 2-4.5 GW/cm^2 . After passing both slow and fast process of destruction the optical fibers obtained irreversible residual damages. Remaining damages of fibers are strongly dependent on the type of process. We have investigated residual damage of the optical fibers by scanning electron microscope. Melted and crushability zones in the damaged optical fibers have been visualized.

283- **Spectral and nonlinear stability of viscous strong and weak detonation waves in Majda's qualitative model**, *G. Lyng* We combine analytical and numerical Evans-function techniques to evaluate the spectral and nonlinear stability of viscous detonation waves. In the relatively simple case of Majda's qualitative combustion model, this program has been completely carried out, and we show how to obtain nonlinear stability results for both strong (Lax-type) and weak (undercompressive) detonation waves. Finally, we discuss the extension of this program to the physically interesting case of the Navier-Stokes equations modeling a compressible mixture of reacting gases.

294- **A toy model for multi-dimensional cellular detonations**, *L. Faria, A. Kasimov, R. Rosales* In this paper, we propose and analyze a two-dimensional analog for unstable detonation waves. The simplified model extends the scalar forced Burgers equation, that we proposed earlier, and it is shown to capture some of the multi-dimensional nature of detonations waves, including formation of cellular patterns. The linear stability problem for the model is analyzed by means of Laplace transform. It is observed that nonzero transverse wave numbers typically possess the maximum growth rate. By numerical simulations, we also show that solutions of the model tend, in the long time limit, to form multi-dimensional cellular patterns.

15:45 Detonation initiation

45- **Numerical simulation of direct detonation initiation in H2/O2/Ar mixtures with detailed chemistry**, *C. Qi, Z. Chen* Direct initiation of a cylindrical detonation for H2/O2/Ar mixtures initially at 0.2 atm and 298 K is simulated using the in-house code A-SURF. Detailed hydrogen mechanism is employed and the ideal strong blast wave model is adopted as the initial condition. This paper focuses on the quasi-steady state and re-acceleration process in the critical regime. Shock-reference-frame is used to demonstrate the coupling between the pressure pulse and heat release at the re-acceleration stage. Particle tracking method is used to show particle heat release rates and particle pressure-specific volume plane, which helps to distinguish different stages of evolution of direct detonation initiation.

112- **Energy input into the spark at the direct detonation initiation**, *K. Korytchenko, V. Golota, D. Kudin, O. Sakun* Spark discharge is a simple sourse of direct detonation initiation in gases. However, the efficiency of total energy consumption for spark discharge initiation is very low. To improve the efficiency of spark detonation initiation in gases, it is necessary to identify the interrelation between the parameters of the electrical circuit and the processes occurring in the spark channel. The mechanisms which determine basic interrelationships between the processes were identified. As a result, a model for the spark detonation initiation which allows predicting the presence or absence of initiation depending on the parameters of electrical discharge circuit was created. The effect of vibrational temperature on the chemical reaction rate was taken into account. The developed model allows revealing the area, form, quantity and time at which the spark discharge energy is released or absorbed.

209- **Detonation onset in acetylene – oxygen mixture,** *N. Smirnov, V.F. Nikitin, Yu.G. Phylippov, J. Koo* Detonation of acetylene mixed with oxygen in various proportions is studied using mathematical modeling and experimental combustion chamber. Simplified kinetics of acetylene burning was compiled from various sources, it includes 11 reactions with 9 components. Defragration to detonation transition is obtained in a cylindrical tube with a portion of obstacles modeling Shchelkin spiral; the transition takes place in this portion for a wide range of initial mixture composition. Modified ka-omega turbulence model is used to simulate flame acceleration in the Shchelkin spiral portion of the system. The sizes of the detonation chamber and the turbulent spiral ring portion are similar to those used in the experiments. The results are compared with experiments and with theoretical data on Chapman Jouguet detonation velocity.

250- **On analogy of 2D and 3D combustible mixture flows**, *V. Levin, I. Manuylovich, V.V. Markov* The study was carried out to examine the new methods of detonation initiation and to analyze the possible use of solutions of 2D non-stationary flows of combustible mixture to evaluate the stationary supersonic flows in 3D channels of variable cross-section. The results of numerical simulation of detonation in a flat chamber with movable walls and detonation in 3D helical channels or 3D channels of square section, blown by supersonic flows of combustible mixture, are presented and compared. The study is carried out in a framework of one-step combustion kinetics by numerical method based on the S.K. Godunov scheme.

15:45 Ignition 4

202- Numerical simulation of ignition in ABC – flow modeling 3D turbulence using a GPU-based approach, *E. Sereshchenko, R. Fursenko, S. Minaev, S. Shy* The influence of premixed gases properties on ignition energy in the ABC-Flow in the frame of thermal-diffusion model was investigated numerically using GPU computing processor. The effect of Lewis number, vortexes size and flow intensity, on ignition energy have been studied. It was found that in large-scale vortexes flow, the ignition energy is almost constant until the turbulent intensity exceeds some critical value, then the rapidly increase of ignition energy is observed. The numerical results show that in the case of fixed value of flow-intensity, there is a critical vortexes size corresponding to the maximal ignition energy.

10- Wall film evaporation causing pre-ignition in turbo-charged gasoline engines, *N. Peters, G. Paczko, H. Pitsch* Turbo-charging of modern gasoline engines may reduce the fuel consumption considerably. A drawback of this technology is the occurrence of stochastic pre-ignition events, which may initiate a randomly localized flame kernel and subsequent turbulent flame propagation. There is the hypothesis that oil intrusion causes the first pre-ignition event. The objective of the present paper is to test whether in addition to above-mentioned hypotheses gas dynamic effects could also cause lower pre-ignition delay times. We have shown that when a liquid like n-heptane evaporates from a wall layer, a shorter overall auto-ignition time results. Our calculations also show that the cumulative effect of weak pressure waves, on the other hand, does not lead to a significant reduction of the ignition delay time.

23- End-gas autoignition in premixed hydrogen/air mixture, *H. Yu, Z. Chen* Boosted direct injection spark ignition (DISI) engine is promising since it has higher fuel efficiency and higher power density compared to traditional gasoline engine. However, in highly-boosted gasoline engines operating at low-speed high-load regime, there is strong tendency of knock since the premixture is compressed to high temperature and pressure. It is generally accepted that knock in spark ignition engine (SIE) might be caused by end-gas autoignition. The objectives of this study are to identify possible autoignition modes of end-gas and to investigate the pressure wave and reaction interaction using 1D simulation with detailed chemistry. While multidimensional experiments and simulations mentioned above describe the end-gas autoignition process similar to that occurs in practice, 1D simulations can give more details and insights into the mechanism of autoignition and pressure wave-reaction interaction. Flame propagation and autoignition modes for stoichiometric H_2/air in a 1D chamber is studied by numerical simulation considering detailed chemistry and transport. Depending on the initial temperature and pressure, three typical reaction modes for end-gas are observed: no autoignition, autoignition without detonation, and autoignition with detonation. The amplitude of pressure oscilation is small when there is no end-gas autoignition. However, when end-gas autoignition occurs, high amplitude of pressure oscilation is observed and knock occurs. Moreover, it is found that detonation development during end-gas autoignition can cause extremely high amplitude pressure oscilation inside the closed chamber. According to the analysis on pressure wave and reaction interaction, high reactivity, enough sensitivity of heat release to compression, and enough time for transition are crucial for detonation development during end-gas autoignition.

62- Experimental and kinetic modeling of the oxidation of synthetic jet fuels and surrogates. *P. Dagaut, F. Karsenty, G. Dayma, Z. Serinyel* The interest for synthetic and/or bio-derived jet fuels is increasing since they could contribute to reducing dependence of air transportation on fossil fuels and carbon footprint. Kerosene type fuel can be produced through a complex process involving Fischer-Tropsch synthesis of paraffins that can be post-processed or blended to meet jet fuel specifications. Synthetic jet fuels mainly contain n-alkanes, iso-alkanes and cyclo-alkanes, with eventual aromatic fractions. Such fuel can be useful for reducing soot and unburned hydrocarbons emissions and fossil carbon dioxide emissions. Synthetic jet fuels are a good alternative to conventional oil-derived jet fuels. The purpose of this work is to study the kinetics of oxidation of alternative jet fuels (Gas-to-liquid or GtL and Coal-to-liquid or CtL) and representative surrogates in a JSR operating under the same conditions (temperature, 550-1150 K; pressure, 10 bar; equivalence ratio, 0.5-2). This study is complementary to earlier kinetic measurements and modeling where simpler and less representative model fuels were used. To experimentally represent the selected synthetic jet fuels we have designed surrogates consisting of few representative species. We studied the oxidation of representative mixtures, a 100% GtL, and a 100% CtL in a jet-stirred reactor (JSR) at an equivalence ratio of1. A detailed kinetic reaction mechanism was developed and validated by comparison with the present experimental results and those obtained previously.

15:45 Turbulent flames 2

91- Sensitivity of scaling exponents for turbulent burning velocity to evaluation method: a numerical study, *S. Verma, A. Lipatnikov* Although turbulent flame speed and burning velocity were in focus of experimental, theoretical, and numerical research into premixed combustion for decades, obtained results are still contradictory. In particular, turbulent flame speeds and burning velocities measured by various groups are strongly scattered even if the basic conditions of the experiments were similar, i.e. the fuel, equivalence ratio, pressure, or temperature was the same, while rms turbulent velocities or turbulence length scales were comparable. The use of different methods for evaluating turbulent burning velocity is widely recognized to significantly contribute to the quantitative differences between the measured values. However, as far as qualitative trends in the behavior of the burning velocity are concerned, their sensitivity to evaluation method has not yet been investigated properly. In particular, it is not yet clear whether or not the scaling exponents for the dependence of turbulent burning velocity on rms turbulent velocity, length scale, and laminar flame speed are substantially sensitive to the use of various methods for evaluating the burning velocity. The present numerical study aims at addressing the issue. For this purpose, RANS simulations of a conical confined flame stabilized behind abrupt extension of a channel were performed by using the TFC model of premixed turbulent combustion. This numerical approach was recently validated against PSI experimental data. In the present work, the simulations were run for a wide range of rms turbulent velocities, length scales, and laminar flame speeds, with various methods being applied to the computed fields of the mean velocity and combustion progress variable in order to evaluate differently defined turbulent flame speeds and burning velocities. Scaling exponents for them as functions of rms turbulent velocity, length scale, or laminar flame speed were determined and compared with each over. Moreover, because the TFC model of premixed turbulent combustion is based on a theoretical expression for turbulent burning velocity derived in the statistically planar, 1D case, the scaling exponents resulting from the theoretical expression were considered to be reference quantities for comparison. Obtained results show sensitivity of the scaling exponents to the evaluation method and various methods are assessed by comparing the scaling exponents associated with them with the aforementioned theoretical scaling exponents.

96- Transported joint PDF simulation of a turbulent ethanol spray flame combined with a spray flamelet model, *Y. Hu, H. Olguin, E. Gutheil* In spray flames, the presence of the evaporating liquid adds challenges to the modeling of these flames. Most often, in pure gas flows or flame simulations, a mixture fraction is used to describe the mixing state, and a presumed β-function accounts for its turbulent character; however, this simplification is not valid in two-phase flows. In order to avoid this assumption, a transported probability density function (PDF) provides a suitable approach. This method also shows the advantage that the joint PDF of more than one variable about the thermo or hydro-dynamic state of flow may be included and solved without additional assumption of the statistical independence of variables, which is usually applied in the presumed PDF approach. The transported PDF method was first proposed for pure gas combustion simulations, and it shows its great potential for a wide range of applications. Some studies on the applications of this method in multiphase combustion have been reported earlier. The consideration of detailed chemistry in combustion modeling is of primary importance for a better design of efficient combustion systems. For this purpose, flamelet models provide a suitable way with reasonable computational cost. Hollmann and Gutheil extended this method for the generation of spray flamelet structures influenced by the evaporating fuel spray. The numerical simulation of the EtF6 spray flame of Gounder et al. is performed using a combined approach including a transported joint PDF of gas enthalpy and mixture fraction of gaseous species and a spray flamelet model for ethanol/air combustion. Different models for the scalar dissipation rate of the mixture fraction do not show significant differences, and for the present jet flame, the algebraic model of χ is suitable. For more complex spray flames, this conclusion may need reconsideration. All major spray flame characteristics including Sauter mean diameter, spray velocity and its turbulent fluctuation as well as gas temperature show good agreement with experimental results.

121- Simulation of turbulent lifted flames and their transient propagation, *S. Ruan, Z. Chen, N. Swaminathan* Numerical simulation of turbulent lifted flames and their transient propagation from initial ignition to final stabilization were performed using a partially premixed flame model including both premixed and non-premixed combustion contribution. Computations were performed over a wide range of inlet nozzle diameters and velocity for hydrogen, methane and propane lifted flames. The model gives very good results for lift-off height for all the test cases. The computed time series of lift-off height for methane flames compared reasonably with experimental measurement. The temporal evolution of the H_2 lifted flames ignited at different positions was studied. It is found that flame ignited at the stoichiometric mixture can quickly grow and split into an upstream propagating part and a downstream propagating part. The upstream propagating flame brush show both lean and rich branches. The flame propagation can be divided into an early stage where intense heat release causes reverse mean flow that aids the flame propagation at the upstream direction at a relatively high speed, and a later stage where the flame propagation is slow, before the flame stabilises. Further analysis of the temporal evolution can shed light in the proposal of scaling law that governs this transient flame propagation behaviour.

110- Enhancing the stability limits of a low swirl non-premixed turbulent lifted biogas flame, *M. Saediamiri, M. Birouk, J. Kozinski* The main objective of the present study was to develop and examine a fuel nozzle geometry that leads to a faster decay of the jet flow without affecting its volumetric flow capacity. This is achieved by discharging the fuel through a central hole and several surrounding/peripheral smaller holes/slots. The ultimate aim was to stabilize a lifted flame much closer to the nozzle exit and more importantly to create conditions which allow a stable lifted flame to operate over a much wider range of flow conditions.

8:30 Plenary Lecture 5

Nanoenergetics and combustion, *R.A. Yetter* In the nanotechnology community, there has been tremendous progress in the molecular sciences toward the total command of chemistry at all length scales. This progress has been inspired primarily by advances in the structural determination of biological systems. Similar advancements in assembly of molecular and nanoscale elements have been made in the pharmaceutical and microelectronics fields as well. These developments make it clear that in the foreseeable future it will be possible to synthesize any desired macroscopic structure with precise location of every atom. Functional nanomaterials are currently being produced by many different types of fabrication methodologies including self-assembly and supramolecular chemistry, additive manufacturing, and combustion synthesis. While such techniques have had widespread usage for non-reactive materials, considerably less attention has been given to reactive systems. However, many areas of combustion have the potential to be influenced by nanotechnology as a result of future fuels, propellants, pyrotechnics, explosives, and reactive materials having nanoscale features. In combustion applications, much of the highly desirable traits of nanosized materials can be attributed to their high specific surface area (high reactivity) and potential ability to store energy in surfaces. The ability to control the nanoscale structure and organization of energetic and reactive materials offers an unprecedented level of control over reaction and response characteristics of such materials. Surface functionalization may also make it possible to produce smart fuels and propellants, and fabrication of addressable energetic materials may enable a reaction to be switched on or off, or enable a deflagration to transition to a detonation or a homogeneous explosion on command. Assembled energetic particles and rods, nanolayered reactants, and porous substrates offer the potential to store high energy and insensitive materials in small volumes with reaction and quench length scales not achievable in the past. Such nanoenergetic materials offer long shelf life and nanosecond response times to produce localized heat, ultra high pressure bursts, and desired gas products. Various reactive and energetic materials are being investigated; examples include nanothermites and intermetallics, functionalized graphene sheets, and nanoporous silicon. Graphene sheets, because of their large surface areas, are excellent carriers of nanoparticles that may be functionalized to act as energetic materials or catalysts. Nanoporous silicon, again because of its high surface area and well-studied chemistries, allows for controllable feature design and organization to study the influence of multiscale characteristics on the ignition and propagation of reactive materials. This paper reviews the design, reactivity, and applications of several functional nanomaterials to combustion systems, particularly high speed propagating systems, and concludes by considering future research directions in the combustion and nanotechnology fields.

9:40 Detonation structure

56- The Influence of high-frequency instabilities on the direct initiation of two-dimensional gaseous detonations, *H.D. Ng, C. Kiyanda, G. Morgan, N. Nikiforakis* The effect of high-frequency instabilities on the direct initiation of gaseous detonations is investigated in this work. The analysis is carried out using two-dimensional, high- resolution numerical simulations and the ideal detonation model governed by the reactive Euler' equations with a one-step Arrhenius kinetics. General-purpose computing on graphics processing units (GPGPU) is utilized in this study to reduce the simulation runtime, allowing a high-resolution mesh throughout the complete domain. An initial sinusoidal perturbation on the surface of the high energy source region with different amplitudes and wavelengths is imposed to trigger instabilities at the front of the decaying reactive blast wave. The parametric study performed in this work, with different perturbation amplitudes and wavelengths, shows that the frequency of the perturbation plays an important role in either facilitating or suppressing the initiation. While low frequency instabilities may have an adverse effect on the direct detonation initiation, it appears that fine scale instabilities generated by the high frequency, small amplitude perturbations more readily stimulate the onset of detonation.

107- A Unifying Thermodynamic Model for the Rate of Energy Release in the Reaction Zone of Solid Secondary Explosives, *B. Henson, L. Smilowitz* The difficulties of extrapolating temperature dependent chemical rate constants obtained by measurements of thermal decomposition or ignition under non-shock conditions to the detonation regime are well known. We have previously presented evidence of a single mechanism limiting chemical energy release for an important secondary explosive, HMX, for which ignition data are available over a wide range of temperature. We provide this evidence as an Arrhenius plot of the logarithm of the time to ignition as a function of the inverse boundary temperature for temperatures spanning the full range of response for this molecule, from the minimum thermal ignition temperature to detonation. We have provided a mechanistic understanding for the slope of the line fitting these data, and therefore a model for the activation energy of the chemical process limiting rate and energy release in the solid decomposition of this molecule. Rather than the typical association of this activation energy with that activating the breaking of a covalent bond we show that the activation energy measured for the suite of ignition data for HMX can be determined as a function of the condensed phase thermodynamics of the molecule, specifically the bulk phase free energies of sublimation and vaporization. We present an important extension of these ideas to other molecules of the class of solid secondary explosives. The thermodynamic nature of the model for the single rate dependence in this example allows for a reduced representation of the rate constant as a universal function of the sublimation and vaporization free energies. This allows direct comparison of ignition data for a host of molecules for which data are available over a more limited range than are available for HMX. We discuss these ideas in the context of thermal rate constants and their application to phenomena in solid detonation.

31- Acoustic timescale characterization of unreacted pockets in unstable detonation waves, *J. Regele* Volumes of unreacted fluid surrounded by combustion products are observed in unstable cellular detonations. The reaction of these unreacted pockets has been shown to occur as surface reactions and through homogeneous reactions that occur after transverse waves impact each other or reflect off a wall. It is unclear whether these fast reactions produce compression waves that may interact with the lead detonation front. The ratio of the heat release to acoustic time has been used to characterize the tendency for reactions to produce compression waves. This approach is used to analyze unreacted pocket reactions in unstable detonation waves and assess the probability that compression waves may form. Furthermore, numerical simulations are performed of unreacted pockets to determine the anticipated compression wave amplitude for the timescale ratios measured in experimental results.

9:40 Shock tube ignition 2

262- Shock tube measurements of species time-histories during jet fuel pyrolysis and oxidation, *Y. Zhu, S. Wang, D. Davidson, R. Hanson* The development of compact chemical kinetics model for jet fuel pyrolysis and oxidation requires

accurate target data for real jet fuel. Kinetics models based on surrogate fuel mixtures of a few archetypal components and their accompanying detailed reaction mechanisms have been developed but are difficult to implement into CFD codes because of their size. Several reduced mechanism approaches using surrogate models as starting points have been proposed, but these are still are not directly linked to real jet fuel. H. Wang has proposed a new approach, a hybrid modeling scheme, that couples a small jet fuel decomposition reaction sub-mechanism with a compact, C_0-C_4 oxidation sub-mechanism. In this approach, the jet fuel decomposition mechanism is constrained to fit experimental data on fuel cracking patterns. The object of the present work is to provide initial species time-history data for the development of this model and ignition delay time data to test the model. Distillate-based kerosenic fuels, including JP-8, have three major types of components: paraffins, cycloparaffins and aromatics. During high-temperature gas-phase pyrolysis, the majority of the carbon in these original jet fuel molecules quickly converts to a reduced set of smaller stable intermediate hydrocarbons. This set of intermediate products includes ethylene C_2H_4, propene C_3H_6, different isomers of butene C_4H_8, methane CH_4, hydrogen H_2, and small aromatics such as benzene C_6H_6 or toluene C_7H_8. In this study we provide quantitative measurements of fuel, C_2H_4, C_3H_6 and CH_4 using using shock tube/laser absorption methods. These data can then be implemented to constrain the decomposition sub-mechanism of the hybrid model. The overall performance of the hybrid model can be tested by comparison of model simulations with ignition delay time measurements. A preliminary version of H. Wang's experimentally-constrained pyrolysis detailed oxidation (Hybrid ECP-DO) model) based on pyrolysis measurements for POSF10264 JP-8 fuel has been used to compare with these ignition delay time measurements.

269- **Investigation of ignition behavior of dimethyl and ethyl isomers of cycloalkanes and furans,** *M. Eldeeb, B. Akih Kumgeh* The high-temperature auto-ignition delay times of dimethyl and ethyl isomers of cyclohexane and furan are carried out behind reflected shock waves at average pressures of 5.0 and 12.0 atm. The study is aimed at establishing reactivity differences between these dimethyl and ethyl isomers which could further be explored in chemical kinetic modeling. The two hydrocarbon classes are designed to test whether the observed trend is indicative of general reactivity differences between dimethyl and ethyl isomers of cyclic hydrocarbons, oxygenated or non-oxygenated. It is observed that 2,5-dimethyl furan ignition delay times are up to 5 times longer than those of the more reactive ethyl furan. The dimethyl cyclohexane investigated is a mixture of 1,3-cis-dimethyl and 1,3-trans-dimethyl cyclohexane. In the case of the cyclohexanes, a similar trend is observed such that 1,3-dimethyl cyclohexane has longer ignition delay times than the ethyl isomer, albeit to a lesser extent than observed with the furans. These observations align with another literature study of alkyl benzene isomers by Shen and Oehlschlaeger [Combust. Flame, 2009], showing that the ignition delay times of 1,3-dimethyl benzene (m-xylene), are up to 3 times longer than those of ethyl benzene. The pronounced differences in the high-temperature ignition delay times of these isomers are clearly established using the shock tube technique and motivate further mechanistic explorations of distinguishing reaction pathways, without necessarily invoking the more complex low-temperature chemistry.

55- **Nitromethane ignition behind reflected shock waves,** *O. Mathieu, B. Giri, J. Mertens, E. Petersen* Due to its properties as a fuel component, there is a lot of interest around the detailed understanding of nitromethane' combustion chemistry. When blended with gasoline, nitromethane (NM) induces an increase in octane sensitivity (RON-MON), which is beneficial to prevent knock in modern, direct injected, boosted gasoline engines. Nitromethane also has a high lubricity, which is interesting for model and racing engines. Additionally, the relatively small size of NM with regards to its oxygen content allows the introduction of more fuels into the cylinder for a given quantity of air, leading to a higher energy output, useful for racing engines. Finally, NM is used as a reference component to understand the combustion mechanism of solid propellant and is considered as a possible replacement for hydrazine as a monopropellant. Despite these various interests, the combustion chemistry of NM has been investigated in only a few studies. To help improving predictions on NM' combustion, the aim of the present study was to measure ignition delay time for NM over large ranges of temperature, pressure, dilution and equivalence ratio in a shock tube.

9:40 Laminar flames 1

7- **Studying the effect of H2, O2 and CO2/N2 addition on the laminar flame speed of CH4/LPG-air mixtures**, *A. Ibrahim, S. Ahmed* Global warming and the ever increasing emission levels of combustion engines have forced the engine manufacturers to look for alternative fuels for better engine performance and low emissions. Gaseous fuel mixtures such as biogas, syngas, and liquefied petroleum gas (LPG) are new alternative fuels that have great potential to be used with combustion engines. In the present work, laminar flame speeds (SL) of alternative fuel mixtures, mainly LPG (60% butane, 20% iso-butane and 20% propane) and methane have been studies using the tube method at ambient conditions. In addition, the effect of adding other gases and fuels such as hydrogen, oxygen, carbon dioxide and nitrogen on SL have also been investigated. The results show that the change in the fuel mixture composition directly affects SL. Measurements of S_L of CH_4/LPG-air mixtures have found to be 52 cm/s at ϕ=1.1 with 60% LPG in the mixture, which is higher than S_L of both pure fuels at the same ϕ. Moreover, the addition of H_2 and O_2 to the fuel mixtures increase S_L notably, while the addition of CO_2/N_2 mixture to the fuel mixture, to simulate the EGR effect, decreases S_L of CH_4/LPG-air mixtures.

166- **Premixed flame propagation between two closely spaced parallel plates**, *D. Fernandez-Galisteo, J. Gross, V. Kurdyumov, P. Ronney* The propagation of slow quasi-isobaric premixed flames between two closely spaced parallel and adiabatic plates is investigated numerically with the use of a quasi-2D formulation based on an averaging of the flow quantities across the direction perpendicular to the plates. The formulation arises when the ratio of the plates separation to the flame thickness, denoted as the Peclet number, becomes small. Front shapes and propagation rates are computed based on this formulation to capture the effect of the intrinsic instability mechanisms.

221- **Laminar flame speeds of pentanol isomers: an experimental and modeling study**, *D. Nativel, M. Barone, F. Gourmel, M. Idir, N. Chaumeix* In order to decrease green-house gases and increase our energetic independence, new combustion modes are currently being developed that will likely require fuel reformulation. Furthermore, regulations impose blending actual fuels with biofuel up to 20%. Consequently, it is mandatory to study the impact of biofuel addition on fundamental combustion parameters and especially on pollutant emissions. Ethanol for example is widely used alone or blended with gasoline. However, ethanol is problematic due to both its source of supply and its pollutant emissions. To overcome these two aspects, heavier alcohols, such as 1-pentanol and iso-pentanol, are foreseen as a suitable replacement for ethanol, they constitute the next generation of biofuels. Moreover, pentanol isomers have several advantages compared to ethanol such as a higher energy density and a lower hygroscopicity. The primary objective of the present work is to rigorously obtain new experimental data for iso-

pentanol and 1-pentanol in a 56 L spherical bomb. Laminar flame speeds of iso-pentanol and 1-pentanol in air were measured at three initial temperatures 353, 433 and 473K. The initial pressure was 1 bar and the equivalence ratios varied from 0.7 to 1.5. The effects of initial temperature on the laminar burning velocities of iso-pentanol and 1-pentanol will be discussed. The mechanism of 1-pentanol oxidation from Togbe et al.[1] was used to simulate laminar flame speeds of 1-pentanol/air mixtures.

9:40 Dust combustion 1

84- Effect of radiation on the propagation of planar coal dust flames in air, *R. Houim, E. Oran* The dynamics and structure of flames propagating through suspensions of organic dust in air mixtures depend on many factors including volatile content, particle concentration, particle diameter, etc. Radiation is often important in these flame and can sometimes be the dominant mode of heat transfer to the preheat zone. Nevertheless, radiation is often neglected in numerical simulations of dust flames due its inherent complexity and high computational cost. The radiation diffusion approximation is sometimes invoked even though the products may be optically intermediate. There may be optically thick regions as well as optically thin regions in realistic explosion scenarios, such as those that involve dust layers. Many of the standard radiation models are not accurate for both optically thick and optically thin regions. Recently developed filtered spherical harmonics approximations to the radiative transfer equation work in both optically thick and optically thin media and are relatively simple to implement into compressible reactive gas-dynamic codes using traditional explicit numerical methods. Numerical simulations of one-dimensional coal-dust flames in air with equivalence ratios of 1.2 and 2.4 were conducted using a granular two-fluid model to evaluate the influence of thermal radiation on flame propagation and ignition. Radiative energy transport was assumed to be gray and was modeled with a third-order filtered spherical harmonics approximation to the radiative transfer equation. Two geometrical configurations were considered, flame propagation in an open tube and flame propagation in an enclosed tube with two-chambers separated by a transparent window. The results indicate that radiation has a significant effect on the acceleration of the flame for both dust concentrations. Initially the flame propagates a relatively low velocity, ~1 m/s, from the closed end of the duct. The incident radiation field increases as the flame propagates into the duct due to increasing optical thickness of the product zone. As a result, the rate of radiative heat transfer to the coal particles in the preheat zone increases. Eventually, radiation becomes the dominant mode of heat transfer and the flame accelerates to ~16 m/s for the near stoichiometric case and ~5 m/s for the richer case when it reaches the end of the duct. Furthermore, radiation was significant enough to ignite particles on the opposite side of a transparent window that blocks both conduction and convective heat transfer. These results confirm that radiative heat transfer can have a significant and even dominant effect on flame propagation through dust suspensions.

137- Comparison of combustion characteristics of magnesium and aluminum powders, *R. Lomba, S. Bernard, F. Halter, C. Chauveau, P. Gillard, C. Mounaim-Rousselle, T. Tahtouh, O. Guezet* This work presents an experimental study of combustion characteristics of micron-sized aluminum and magnesium under constant volume combustion experiments. Burning velocities were estimated from the measured pressure traces using both a simplified model for aerosol combustion on closed spherical bombs and a semi-empirical correlation, and compared to previous literature. Flame temperatures were measured by bi-color pyrometry. For aluminum powders, it was observed a flame temperature decrease for powders with a mean diameter smaller than 12 μm, which supports the idea that the flame moves closer to the particle's surface, since flame temperatures were close to aluminum boiling point. For 17.9 μm aluminum powders, flame temperatures were close to predicted adiabatic flame temperature and alumina vaporization-dissociation temperature, indicating a classical vapor phase flame under a diffusion-controlled mechanism. The presence of vapor-phase species was quantified by comparing a simulated non-gray body emitter spectrum equation to the experimental spectrum. Experiments presented in this work successfully illustrated the differences on combustion characteristics for magnesium and aluminum powders of different particle sizes. Molecular AlO emissions detected in this work suggest that a vapor phase aluminum-air flame is present for mean particle diameters as fine as 7 µm. Presence of gaseous MgO during magnesium combustion indicates a detached vapor-phase reaction.

190- On conditions for self-sustained combustion of pulverised coal particle-laden mixtures following localised forced ignition: a direct numerical simulation, *T. Brosh, F. Marincola, D. Patel, D. Wacks, N. Chakraborty* The effects of particle equivalence ratio (Phi_p), equivalence ratio of primary volatile fuel in the background gas (Phi), different particle diameter (a_p) and turbulence velocity fluctuations (i.e. u') on early stages of combustion subsequent to successful ignition have been analysed based on Direct Numerical Simulations. The coal particles are treated as point sources and tracked in a Lagrangian manner, where the coupling between Eulerian gaseous and Lagrangian particulate phases has been achieved by appropriate source terms in the mass, momentum, energy and species conservation equations. The localised forced ignition is accounted by a source term in the energy transport equation that deposits energy for a stipulated time interval. . Particular attention has been paid to the analysis of the scalar dissipation rate, which determines the rate of micro-mixing and can greatly affect the extent of burning in coal particle-laden mixtures. It has been found that an increase in u' helps to mix the devolatilised fuel with surrounding air, but flame quenches for high values of u'. The mean scalar dissipation rate of mixture fraction has been found to be strongly affected by u', whereas Phi_p , Phi and a_p have been found to affect the man value of N_{ξ} through their influences on devolatilisation rate. It has been demonstrated that high values of N_{ξ} are associated with small values of reaction progress variable (i.e. c). It has furthermore been demonstrated that cases which show high values of N_{ξ} are more prone to flame extinction without the aid of external energy addition following successful ignition.

11:25 Deflagration to detonation transition 5

275- Effects of boundary layer on flame propagation generated by forced ignition behind an incident shock wave in DDT process, *S. Ishihara, S. Tamura, K. Ishii, H. Kataoka* In order to investigate the effects of boundary layer on the flame propagation which induce detonation initiation, an ethylene-oxygen mixture was forcibly ignited behind an incident shock wave using laser breakdown. The ignition timing was controlled and the ignition position from the upper wall was varied as 2.5 mm, 5.5 mm and 11 mm, so that the mixture was ignited at inside or outside of the boundary layer. The process of flame propagation was visualized by Schlieren imaging. It was found that DDT with high repeatability could be caused by forced ignition independent of the forced ignition position. Independent of the boundary layer thickness, laminar or turbulent boundary layer and ignition position, the flame was affected by the boundary layer and transformed. For ignition inside of the boundary layer, the flame front was stretched near the wall, resulting in DDT near the stretched flame front. The

required time for DDT and the process of detonation initiation were not affected by the ignition position and the incident shock Mach number for turbulent boundary layer. Therefore, DDT induced in the present work was not affected by the type of forced ignition. On the other hand, in the case of the forced ignition outside of the boundary layer, the propagating flame keeps laminar and spherical before contacting to boundary layer or wall. The height and width of flame kernel increased linearly with increase in time. After interacting with turbulent boundary layer, the flame was wrinkled by turbulent boundary layers, resulting in prompt detonation transition.

161- Influence of water mist on flame acceleration, transition to detonation and detonation propagation in H2-Air Mixtures, *L. Boeck, A. Kink, D. Oezdin, J. Hasslberger, T. Sattelmayer* The influence of water mist on explosion of H2-air mixtures is studied experimentally in a closed channel with rectangular cross section. The investigated range of H_2 concentrations covers slow flames, accelerating flames, transition to detonation and detonations. Water loading ratios relevant for severe accident scenarios in nuclear power plants are examined. A system for water mist generation and injection was designed such that the experimental conditions are well defined. The water loading ratio is determined by real-time extinction measurement. Laser diffraction measurement provides the droplet size distribution. Water mist injection results in lower overpressure and retarded transition to detonation compared to dry H_2-air mixtures. The effect of 0.11-0.12 kg/m^3; water loading ratio is comparable to a decrease in H_2 concentration by 0.6 vol. % in the deflagration regime and by 1-2 vol. % in the detonation regime, while transition to detonation is retarded more significantly.

243- Influence of blockage ratio on the DDT and detonation propagation limits for an orifice plate filled tube, *M. Cross, G. Ciccarelli* The accidental release of fuel vapor into the atmosphere during an industrial accident can result in an explosion if a suitable ignition source is present. In the worst case scenario, a detonation wave can form and propagate through the fuel vapor air cloud causing mass destruction of a plant. In a recent study performed by Cross and Ciccarelli (2015), the detonation limits were measured by an experiment involving the transmission of a CJ detonation wave from a smooth tube into an orifice plate filled tube of the same diameter. These may be considered propagation limits (as opposed to DDT limits) since there is no need for flame acceleration and the establishment of the initial hot spot to start the detonation wave. Cross and Ciccarelli showed that for equally spaced 75 mm diameter orifice-plates (BR=44%) the measured propagation limits for hydrogen-air and ethylene-air are similar to the DDT limits; at the limits, the ratio of the orifice plate diameter and the detonation cell size is roughly unity ($d/\lambda=1$). In this study the influence of the orifice plate BR (0.44 - 0.81) on the DDT and detonation propagation limits was investigated for hydrogen-air and ethylene-air mixtures. Experiments were performed in an obstacle laden tube to measure the DDT and detonation propagation limits for hydrogen-air and ethylene-air mixtures. The experimental results demonstrated that the detonation propagation and the DDT limits are strongly affected by the orifice plate BR. For the 100 mm diameter tube used in the experiment the propagation and DDT limits are similar for an orifice plate with BR= 0.44. Both the propagation and the DDT limits narrow with increasing BR, more significantly for the DDT limits. The narrowing of the limits with increasing BR also corresponds to a larger deviation from the $d/\lambda=1$ detonation limit criterion. The results indicate that the beneficial effects of the orifice plate in providing a reflection surface diminishes with increased BR due to the increased effect of shock wave weakening by the diffraction process.

11:25 Shock tube ignition 3

63- Experimental and numerical study of 1-Pentanol pyrolysis in a shock tube at high pressure and high temperature, *D. Nativel, R. Grosseuvres, A. Comandini, S. Abid, N. Chaumeix* Due to the increase of greenhouse gases and the finite sources of fossil energies, alternative fuels are the focus of many current research programs. Moreover, European regulation imposes a proportion of 20% of biofuel in conventional fuels. Currently, ethanol is widely used as biofuel but it has several drawbacks such as a low energy density and source of supply related to food-stock. Heavier alcohols are foreseen since they have higher energy densities and are less hygroscopic. Among all the heavier alcohols, 1-pentanol seems to be a good candidate. A better understanding of its decomposition, at engine-like combustion conditions, is a requirement, as a first step, in order to construct a detailed kinetic mechanism that will describe its combustion. In the present study, new experimental data on 1-pentanol decomposition are acquired using a heated high pressure shock tube coupled to a Gas Chromatograph equipped with different detectors (FID, MS). This analytical system allowed an on-line sampling of the gases behind reflected shock waves via a high speed valve. As a first step, this new method was assessed through the study of the n-heptane pyrolysis behind reflected shock waves. N-heptane was chosen because its chemistry is well established. Indeed, it has been subject to numerous experimental and modeling studies which led to a comprehensive and detailed understanding of the associated chemistry. The methodology validation is presented, then the results obtained for the decomposition of 1-pentanol pyrolysis was undertaken. A comparison with simulated results based on Togbe; et al. mechanism and Heufer et al. mechanism are also presented.

43- Shock-tube study of the addition effect of CF2BrCl on the ignition of light hydrocarbons, *O. Mathieu, C. Gregoire, E. Petersen* After the Montreal protocol in 1987, many efficient fire suppressants have been phased out due to their ozone-depleting properties. Two of the most important agents that have been banned, in terms of both efficiency and usage, were CF3Br (Halon 1301) and CF2BrCl (Halon 1211). Although the production of these two components was stopped, it is worth mentioning that their usage is still allowed through recycling and that Halon 1211 is still widely used in many applications, notably in the military and aviation areas. To limit their usage to the most efficient way and to find suitable replacements, it is therefore necessary to understand the details of their chemical effects during combustion. While CF3Br has been the topic of numerous studies, it is worth mentioning that, to the best of the authors' knowledge, there is no experimental or numerical study of the effects of Halon 1211 on the combustion of any fuel. To help in the development of models and to assess the effect of Halon 1211 on light hydrocarbons of interest for many industries, ignition delay times of methane, ethylene, and propane, doped with the equivalent to 10% of the fuel concentration as Halon 1211, have been measured in a shock tube. Mixtures where highly diluted in Ar (around 98% dilution by volume), and a large range of equivalence ratios was investigated (0.5, 1.0, and 2.0) at a pressure around 1.8 atm. Results from the present study were compared to data recently obtained by the authors' group with other fire suppressants, namely CF3Br (Halon 1301) addition to methane and propane and CF3I (Halon 13001) addition to methane, ethylene, and propane. Note that mixture of CF_3Br with C_2H_4 was also investigated during the present study to allow for a direct comparison between the effects of the two agents. Presented in

this paper are details on the experimental setup, followed by a presentation and discussion of the results.

37- Shock tube and modeling study of chemical ionization in the oxidation of acetylene and methane mixtures, *G. Agafonov, D. Mikhailov, V. Smirnov, A. Tereza, P. Vlasov, I. Zhil'tsova* The results of experimental measurements of the concentration of free electrons by a microwave interferometer and by the electric probe method during oxidation of acetylene and methane mixtures behind reflected shock waves are presented. The detailed kinetic model of chemical ionization was constructed on the basis of our soot formation kinetic model. The results of experimental measurements and detailed kinetic modeling are in good qualitative and quantitative agreement.

11:25 Laminar flames 2

158- Burning velocities of CH4/air/water-mist premixed flames near the extinction limit, *Y. Ogami, M. Ito, T. Daitoku, T. Tsuruda* The flame extinction of CH_4/air premixed flame by water mist addition was investigated experimentally using the two-dimensional Bunsen flame. The characteristics of water mist, i.e., the particle size distribution, the mean droplet diameters, and the water mist mass fraction, were obtained basing on Stokes' law. The flame extinction limits were measured for various conditions of the equivalence ratio. Estimation of heat losses by water mist at the extinction limit was conducted by using the vaporization Damköhler number. The burning velocities were also measured by the angle method, and the correlation between the burning velocity and the heat loss parameter was investigated.

171- Laminar burning speeds of α-pinene/benzene/air mixtures involved in the combustion in forest fires, *B. Coudour, C. Khaled, F. Halter, C. Mounaim-Rousselle, G. Jean-Pierre* Forest fires are a growing issue with regards to the physical planning aspect and the preservation of the local territory. In some parts of the Mediterranean, bushes have taken over control the undergrowth and fire outbreaks in these zones are feared for their dangerousness causing unstoppable forest fires. These fires can be unpredictable and may kill firefighters on the field or civilians. One of these unpredictable behavior is called accelerating forest fire (AFF) or eruptive fire. An AFF is characterized by an augmentation of the rate of spread and of the energy released by the fire so it can be almost regarded as a flashover if we focus on the visual aspect. The reasons which bring to this phenomenon are not very well understood even if we know that it occurs in very particular conditions. Therefore, AFFs reported in the literature always happen in summer during particular dry seasons and in typical topographies like thalwegs and canyons. The phenomenon reaches principally the Mediterranean countries in lands covered by aromatic plant species. Another noteworthy particularity is that this kind of fires does not accelerate just after the starting fire but always spend at least one hour before accelerating. All these parameters lead to the main hypothesis based on a thermochemical approach. This thermochemical approach supports that Volatile Organic Compounds (VOCs) coming from smokes and heated vegetation are able to create a flammable atmosphere near the fire front, especially in recirculation zones where heavy compounds can easily accumulate. Some authors already demonstrated that the Mediterranean vegetation emits much more when exposed to high temperatures than in normal conditions of temperature. Regarding these works which study biogenic VOC emissions, α-pinene ($C_{10}H_{16}$) and its isomers were found to be the main compounds emitted among Mediterranean plant species. As regards the forest fire smokes, several studies have been done during a forest fire to analyze the smokes and the principal VOC appears to be benzene (C_6H_6). It is well known that carbon monoxide and carbon dioxide are predominant in forest fire smokes but VOCs represent heavier molecules which are more likely to accumulate near the ground around vegetation which is where AFFs are propagating. The fact that α-pinene and benzene have very low values of lower flammability limits, near 1% vol. in air strengthens our hypothesis. We chose to study mixtures of α-pinene/benzene/air by varying the temperature (from 75 to 180°C), the equivalence ratio (from 0.7 to 1.4) and the fuel proportion (from 20%-80% to 80%-20 of α-pinene and benzene) in order to reproduce the conditions of different starting points of an AFF, more or less close to the fire front. In this study, we focused on two combustion characteristics: laminar burning speeds and Markstein lengths. It turns out that the maximal laminar burning speed is shifted from 1.1, for mixtures rich in α-pinene, to 1.2, for mixtures rich in benzene. It is also noticeable that the laminar burning speeds increase and that flame becomes more stable with the increase of benzene percentage.

106- Experimental and modeling investigation of laminar flame speeds of styrene, *A. Comandini, N. Chaumeix* Laminar flame speeds of styrene were measured in a spherical bomb heated to 343.2 K, 373.2 K, and 403.2 K at an initial pressure of 1 bar and over a wide range of equivalence ratios. The experimental results were used to develop a chemical kinetic model which is able to simulate quite accurately the measured flame speeds as well as the temperature dependence observed in the results, in addition to the data available in literature. Sensitivity analyses of the flame speed were also performed in order to understand the influence of the various aromatic reactions on the simulation results at the different conditions considered in the study.

11:25 Dust combustion 2

371- Neutralization of airborne contaminants, *J. Boris, G. Patnaik* This paper addresses the following question: Can an airborne cloud of a chemical or other unwanted agent be neutralized effectively in an urban geometry by injecting a suitable reacting œremediant into the cloud in sufficient amounts and at appropriate locations? The transport and dispersion of potentially dangerous, contaminants is controlled principally by the wind in an outdoor environment, its turbulent gusts, and how this complex airflow interacts with the geometry of the buildings and terrain. The possible effectiveness of reactive agent neutralization, or mitigation, is a complex matter involving chemical reaction of the agent and the remediant, progressive dilution of the two reactants, and fluid dynamic mixing of the reactants over time. Anyone contemplating in situ remediation needs to know where and when to deliver a remediant and what amounts are necessary.

82- Influence of radiative preheating on flame propagation in gaseous mixtures seeded with inert particles, *M. Liberman, M. Ivanov, A. Kiverin* We study a flame propagating in the gaseous combustible mixture with suspended inert solid micro particles. The gaseous mixture is assumed to be transparent for thermal radiation emitted by the hot combustion products, while particles absorb and reemit the radiation. Thermal radiation heats the particles, which in turn transfer the heat to the surrounding unburned gaseous mixture by means of thermal heat transfer. It is shown that depending on reactivity of the gaseous mixture and correspondingly on the value of the laminar flame normal velocity the radiative preheating causes either modest increase of the temperature ahead of the flame and corresponding modest increase of the combustion velocity for the fast flame (H_2/O_2), a noticeable increase of the temperature ahead of the flame and corresponding increase of the combustion velocity for a slower flame (H_2/air), or it may be a dominant mechanism of the combustion wave propagation. Depending on the non-uniform temperature distribution caused

by the radiative preheating and the steepness of the temperature gradient formed in the unburned mixture, either deflagration or detonation can be initiated via the Zeldovich's gradient mechanism. Initiation of deflagration and detonation is illustrated for example of the flame in gaseous H_2/O_2 mixture with non-uniform distribution of the suspended particles, such that the particles number density is relatively small in the close vicinity ahead of the flame and increases farther ahead of the flame. The preheating caused by the thermal radiation triggers additional source of ignition ahead of the flame, initiating either deflagration or detonation. The ignition and the resulting combustion regimes depend on the number density profile and on the temperature profile, which is formed in effect of radiation absorption and gas-dynamic expansion.

242- Simultaneous mist and flame propagation characterisation studies in a fully-confined bomb, *D. Pugh, P.J. Bowen, A.P. Crayford, D. De la Rosa, L. Bernard* Two-phase, or mist, incidents represent a complex potential risk for process industries, and are not well understood when compared to more common gaseous or liquid releases. Research is complicated not only by the understanding of multifaceted reaction chemistry, but also the development of intricate and robust experimental facilities that characterise droplet formation, in addition to the propagation of flames through turbulent flow fields. Development of such systems enables comprehensive investigation of the underlying mechanisms that contribute to two-phase explosions and in particular the potential for acceleration of the flame. Cardiff's large (34 L) Constant-Volume Combustion Bomb (CVCB) has previously been used to investigate flame propagation with both gaseous and pre-vaporised reactants, and has now been modified to generate and burn two-phase mixtures. The presented work outlines changes made to the vessel (based on a previous, smaller cloud chamber design) to develop the Dynamic-Volume Combustion Bomb (DVCB), which utilises rapid decompression to cool reactants, and form quasi-homogenous mists. Some of the challenges encountered when developing the facility are discussed, in addition to the presentation and discussion of preliminary commissioning results. Simultaneous mist and flame-speed characterisation has been achieved reducing uncertainty over initial pre-ignition droplet size, which is shown to be sensitive to starting temperature specification. In the droplet size range 4-12 μm and equivalence ratio 1.05-1.50, no discernible enhancement effects have been observed. However, the study is ongoing, with further work undertaken to improve the experimental and analytical technique.

14:00 Deflagration to detonation transition 6

189- Numerical simulation on mechanism of flame acceleration and deflagration to detonation transition for ethylene-oxygen system, *W. Han, C. Wang, C.K. Law* In the paper flame acceleration and deflagration-to-detonation transition (DDT) and the propagating detonation followed is simulated by using a high-resolution parallel code based on 5-th order weighted essentially non-oscillatory WENO scheme for ethylene-oxygen system. It is found that there are two modes of the transition to detonation in the microscale and macroscale channels. In microscale channel, whole process of DDT contains main stages: exponent acceleration of flame; linear acceleration of flame; abrupt acceleration to overdriven detonation due to directly initiating unreacted gas by a strong and curved leading shock; eventually pulsating detonation with a velocity below CJ value; in the stages of the propagation of pulsating detonation new mechanisms also are observed. For the macroscale DDT, there are several stages: initially slow acceleration of flame; turbulent flame with precursor compression wave; overdriven detonation due to local explosion induced by strong shock; cellular detonation; as the strong overdriven decays and gradually evolves into cellular detonation with triple point configuration, meanwhile the retonation wave also is observed. These results will have an important application value for the design of explosion disaster prevention and detonation propulsion.

169- Large eddy simulation of deflagration to detonation transition using artificial thickening, *S. Yu, S. Navarro-Martinez* Accurate predictions of Deflagration to Detonation Transition (DDT) in large configurations are difficult to obtain. DDT is a highly non-linear process, and very sensitive to initial fluid disturbances and chemical compositions. In the present work a new LES model is presented to predict DDT. The approach follows the compressible Artificial Thickening Model (ATF) where the flow features are thickened, so they can be captured by a coarse mesh. The behaviour of the model is investigated in one-dimensional laminar flames and detonation waves. The model is then applied to a canonical three-dimensional problem of shock-induced DDT on a rectangular channel

156- Transition to detonation in non-uniform H_2-air: chemical kinetics of shock-induced strong ignition, *L. Boeck, J. Hasslberger, T. Sattelmayer* Extensive knowledge is available on explosions in homogeneous gas mixtures. Mixtures of H_2 and air have been investigated particularly in the context of nuclear reactor safety. However, a major current knowledge gap concerns the influence of mixture inhomogeneity. Spatial concentration gradients are omnipresent in real-world accident scenarios. We address this knowledge gap experimentally, reducing complexity by investigating one-dimensional, transverse concentration gradients. In the present paper we analyze transition to detonation. We use highly time-resolved optical diagnostics and pressure measurements to gain insight into the mechanism of transition. Based on the observations we define critical conditions for transition by shock reflection off obstacles by simulating detailed chemical kinetics behind a reflected shock and using the extended second explosion limit as a threshold. Beyond this limit, local explosions occur which initiate transition to detonation. We find that critical conditions can be expressed in terms of deflagration overpressure for a wide range of H_2 concentrations. This proves true both for homogeneous and non-uniform mixtures.

14:00 Turbulent Flames 3

92- Modelling of progress variable variance transport in head on quenching of turbulent premixed flames: a direct numerical simulation analysis, *J. Lai, N. Chakraborty* The ammonium dinitramide (ADN) based liquid propellant is a kind of green propellants and can be used in small rocket. In this paper, the combustion process of ADN-based liquid propellant in attitude control engine is investigated experimentally and numerically. In the experiment, the pressure, the temperature and the characteristic species concentrations of CO and NO in the combustion chamber are measured to estimate the performance of thruster. In the simulation work, the non equilibrium model for porous media is used to describe the heat transfer in catalyst bed and interaction between liquid droplet and porous media is also considered. A simplified chemical mechanism is used to model the reactions between ADN and CH_3OH in gas phase. The numerical results are in agreement with the experimental results. The results show that there are two stages of temperature increasing in the ADN-CH_3OH combustion process. In the thruster, the decomposition of ADN and the oxidization of methanol do not happen synchronously. Since the combustion is non-adiabatic, the transformation from N_2O to N_2 and the oxidization of CH_3OH can not be completed in the combustion chamber.

29- Structures of turbulent bunsen flames in the corrugated-flamelet regime, *J. Furukawa, Y. Yoshida, F.A. Williams* Structures of turbulent Bunsen flames in the corrugated-flamelet regime were investigated by use of a three-color six-beam LDV system. Four different mixtures with identical laminar burning velocities were selected, to facilitate comparisons lean and rich methane, and lean and rich propane. A bimodal distribution, not previously reported in the literature, was observed in the radial component of gas velocity off-axis in the turbulent flame brush. Results were the same for lean and rich methane flames but differed for lean and rich propane flames. The differences were explained by preferential diffusion associated with turbulence-induced flamelet curvature. A model for scaling that effect is proposed. Progress-variable fields also are deduced, exhibiting a bubble at the tip of the turbulent flame brush, associated with flapping of nearly vertical flamelets there.

80- Numerical investigation of turbulent lean premixed hydrogen-carbon monoxide combustion at elevated pressures, *R. Dinesh, H. Shalaby, K.H. Luo, D. Thevenin* This work describes analyses of impact of chemical kinetic mechanisms on species mass fraction distributions and effects of preferential diffusion on flame structure and propagation of turbulent lean premixed high hydrogen content syngas flames using direct numerical simulations (DNS). The present study has two principal aims. The first is to investigate the impact of detailed chemical kinetic model employing in DNS on prediction of species mass fractions of lean premixed HHC H_2/CO syngas turbulent flame at elevated pressure. The second aim is to study the preferential diffusion (non-unity Lewis number) effect on flame structure and propagation of lean premixed HHC H_2/CO syngas turbulent flame at elevated pressure. In all test cases, two-dimensional DNS were performed for HHC lean premixed H_2/CO syngas fuel mixture with 70% of H_2 and 30% of CO by volume with an equivalence ratio of 0.7. The centrally-ignited outwardly propagating lean premixed HHC syngas flames have been simulated using DNS incorporating detailed chemistry and multicomponent diffusion transport models. The time-dependent compressible DNS code ParComb solves the continuity equation, Navier-Stokes momentum equations, the energy equation, species balance equations together with auxiliary equations such as the state equation. To compare the prediction of radical species mass fraction distribution between two chemical kinetics mechanisms at different pressure levels, six DNS simulations at different pressure levels with the inclusion of non-unity Lewis numbers were performed by employing detailed chemical mechanism of Goswami et. al. and Mass and Pope. In the present study, three different pressure values of p=1bar, 2bar and 4bar at constant turbulent Reynolds number of Re_t=150 were considered. To compare the results between non-unity Lewis number and unity Lewis number at elevated pressure, one DNS test case with non-unity Lewis number and another DNS test case with unity Lewis number were performed at elevated pressure value of p=4bar, and at turbulent Reynolds number of Re_t=150 by employing the detailed chemical mechanism of Goswami et. al.. In the sensitivity study of chemical kinetic mechanisms with DNS at elevated pressure, a comparison of radical species distributions between two detailed chemical reaction mechanisms at identical elevated pressures highlight key differences in radical species formations such as H, OH and HO_2. In the preferential diffusion study case, it is found that non-unity Lewis number effects play a significant role in the local chemical reaction as well as diffusional-thermal cellular flame structure and heat release rate in the thin reaction zone at elevated pressures for turbulent lean premixed HHC H_2/CO flames.

14:00 Ignition 5

187- Ignition delay and MIE measurement for n-decane/air mixture induced by laser-spark, *N. Mokrani, S. Rudz, P. Gillard* This study provides experimental results about the Minimum Ignition Energy (MIE) and the ignition delay for six equivalence ratios (phi=0.65; 0.9; 1.1; 1.3; 1.6; 2.0) of n-decane/air mixtures. The first part of this work deals with the measurements of the absorbed energy by the plasma during the ignition. Then ignition delay is measured using two apparatus: photodiode and spectrometer. Lastly a correlation between ignition delay and absorbed energy is proposed. This work provides useful complements to existing works mainly focused on decane spray ignition or gaseous ignition at high pressure.

90- Initiation of detonation in iso-octane/air mixture under high pressure and temperature condition in closed cylinder, *Z. Wang, X. He , H. Liu, Y. Qi, P. Zhang, J. Wang* Detonation could occur in current internal combustion engines with advanced combustion technology. To reveal the mechanism of detonation initiation under engine-like conditions, this study presents the most frequently observed detonation initiation mode (shock wave reflection induced detonation, SWRID) in stoichiometric iso-octane/air mixture under high temperature and high pressure conditions in closed cylinder. The SWRID consists of four stages: (1) the end gas was compressed by spark triggered deflagration, (2) A local end gas auto-ignition generates a shock wave and the shock wave propagates into the unburned mixture, (3) The incident shock wave is reflected by the cylinder wall, (4) When the incident shock wave propagates to the region that the reflected shock wave interferes with the incident shock wave, detonation is initiated, which causes detonation propagation.

147- Experimental investigation of co-flow effect on ignition process of a methane jet diffusion flame, *Q. Wang, J. Yang, Y. Wang, Y. Zhang, C. Zhao* The co-flow air effect on the ignition process of a methane jet diffusion flame has been investigated by high speed color and schlieren imaging techniques experimentally. The methane flow rate is kept at constant (Re=55.4), while the co-flow air flow rate changes (Re from 171 to 5985), creating a wide range of the air/fuel velocity ratios varying from 0.36 to 12.5. Special digital image processing techniques are applied to visualise the otherwise invisible weak blue flame during ignition process. The enhanced images have shown clearly that a sooty diffusion flame is initially formed inside a blue flame pocket at low air velocities. When the co-flow air flow rate exceeds 75 l/min, only blue flame can be observed. The flame height is shorter at higher co-flow air rates, which is due to the enhanced fuel/air mixing at larger velocity gradients. The fuel flow, flame and hot gas interactions with the cold air flow are investigated by visualising and analysis of the schlieren images. It is found that a hot gas bulge is formed due to the excessive fuel exiting before ignition and a hot laminar central jet is formed with the help of co-flow effect. The hot gas bulge tip and bottom moving velocities are found to increase with the co-flow air flow rates.

14:00 Dust combustion 3

235- Experimental investigation of the mechanisms of cellular instabilities developing on two-phase flames, *R. Thimothée, C. Chauveau, F. Halter, I. Gökalp* The spray combustion is on practical importance in motorization domain and in industrial applications. To face the complexity of study, simplified models are used to ease and to control the aspects of the two-phase combustion. The aerosol of mono-sized droplets uniformly distributed was demonstrated as a suitable experimental configuration for a fundamental study. At the first experimentations, it was found that a two-phase flame can burn faster than its equivalent gaseous flame. This non-expected result has been largely confirmed since and it was recently proven that

this flame promotion phenomenon was due to the cellular aspect of the two-phase flame surface. The presence of fuel droplets triggers cells development on the flame surface which increases the fuel mass flow form the fresh gases toward the reactive zone. As the cellular instabilities play an essential role in the phenomenon of improving the combustion, the prediction of the onset of cellularity for two-phase mixtures seems to be essential from a scientific point of view. The present study proposes an experimental approach in order to isolate and investigate the responsible mechanisms of the cells development. The gradient of gaseous fuel concentration formed around the droplets during the evaporation resulting from the heat release of the flame has been selected as hypothetical mechanism. The strategy consists in suppress this phenomenon by replacing the aerosol fuel by an inert fuel and the water was employed to this purpose. Additionally, two different flammable mixtures were explored in order to control and investigate the effect the diffusivity disparity (between thermal and mass) induced by the gradient of fuel concentration. A methane-air mixture was used for the equidiffusive property and a propane-air mixture for the non-equidiffusive property. A dual chamber apparatus was employed to access safe operation and constant-pressure measurements which are well suitable for flame instabilities studies. The condensation technique of expansion cooling (based on the Wilson's cloud chamber principle) was used to generate well-defined monodisperse droplets with a narrow size distribution. A conventional shadowgraphy system is employed in order to visualize the flame morphology. The droplets diameter measurements of the aerosol were performed by means of a Sympatec HELOS laser diffraction particle size analyzer. It was found that the flames become cellular only for the case of a non-equidiffusive mixture where the thermal diffusion is less than the mass diffusion within the reactive zone (for a Lewis number lower than 1). Those results suggest that the gradient of gaseous fuel concentration could be one of significant mechanisms of cells formation by affording a suitable diffusivity disparity leading to an unstable flame regime.

228- **An attempt to observe the discrete flame propagation regime in aluminum dust clouds,** *A. Wright, S. Goroshin, A. Higgins* The heterogeneous combustion of solid particles in a gaseous oxidizer is typically modeled by homogenizing the effects of the discrete heat sources (i.e., particles) throughout the medium. Recent developments, however, have shown that under certain conditions, the discrete nature of these combustion processes should be considered as they can lead to unusual flame properties. Experimental measurements of flame speeds are performed in order to validate this discrete flame propagation regime, and flame instabilities inherent to the flames being tested are investigated.

259- **Combustion time and ignition temperature of iron particles in different oxidizing environments**, *A. Wright, S. Goroshin, A. Higgins* The burning time of single particles is an important measurement for modeling the heterogeneous combustion of metal powders. A new experimental apparatus was established in order to investigate the combustion time and ignition temperature of iron particles in different oxidizing environments. The theoretical relation between burn time and the square of the particle diameter for diffusively controlled particle combustion is outlined, and a method for determining particle size distributions is developed.

15:45 Reaction Dynamics 2

177- An approximate method for solving the problem of the establishment of chemical equilibrium in the products of explosion of gas mixture, *V. Shargatov, S. Gubin, A. Krivosheev* Based on the assumption of the existence of the partial chemical equilibrium in the detonation products an approximate method for calculating composition of the detonation products is developed. The method uses the assumption of the existence of extremum of Helmholtz free energy for a given density, temperature, and molecular weight of the detonation products mixture. Without significant loss of accuracy to the solution of stiff differential equations detailed kinetic mechanism can be replaced by one differential equation and a system of algebraic equations. This method is always consistent with the detailed mechanism and can be used separately or in conjunction with the decision of a stiff system, replacing it when bimolecular reactions are near to equilibrium.

201- **Elevated pressure and temperature effect to laminar flame speed of acetone/air mixture,** *Y. Wu, V. Modica, F. Grisch* Acetone is not only important as an intermediate produced in hydrocarbon oxidation, but is also of interest since it is used as fuel tracer in laser induced fluorescence measurements. The fuel tracer added into the combustible should not disturb the reactive flow. A well understanding of the combustion characteristics can be used to evaluate the usefulness of acetone as a fuel tracer, among which laminar flame speed is one of the most essential physical properties. In this work, a high pressure combustion chamber was specifically developed to measure laminar flame speed of acetone/air using a premixed Bunsen liked burner. The experimental work was firstly performed by measuring the laminar flame speed of gaseous CH_4/air for validating the experimental setup. The acetone/air combustion was then investigated for measuring laminar flame speed over a large range conditions including initial mixture temperature (373K- 473K), pressure (0.1MPa-0.5MPa) and equivalence ratios (0.6-1.3). The experiments were complemented and compared with numerical simulations conducted with Cosilab software using published detailed kinetic mechanism models. The observed results are compared with previous experimental data found in the literature. Further experimental data analysis was finally investigated and a correlation relationship of acetone/air laminar flame speed with pressure, temperature and equivalence ratio dependency was proposed.

130- **A novel application of an isoconversional method for thermal decomposition kinetics of heavily aluminized RDX**, *Y. Kim, J. Yoh, J. Park* DSC experiments are conducted to extract kinetics of a multi-purpose energetic material which is comprised of 50% RDX (cyclotrimethylene-trinitramine) and 35% aluminum powder with 15% HTPB (hydroxyl-terminated polybutadiene) binder, and its initial density after pressing is 1.78g/cc. The use of isoconversional method to extract the kinetics theoretically does not require numerical fitting. Because the scheme is essentially a single step with a multiple set of Arrhenius parameters that evolve with the reaction progress, there is an obvious computational advantage over any multi-step kinetics. To validate the present kinetics, a thermal decomposition test is performed to compare the simulation result that utilizes the present kinetics. Results confirm the applicability of the kinetic scheme to the practical thermal stimulus test of energetic materials.

298- **Continuation analysis of complex chemical mechanisms for jet-fuels combustion in PSR,** *L. Acampora, E. Mancusi, F. Marra* Limit combustion phenomena, such as ignition, are rather sensitive to chemical kinetics and these properties are therefore used to physically characterize the behaviour of different fuels. In the framework of bifurcation theory, the ignition and extinction phenomena for combustion occurring in a Perfectly Stirred Reactor correspond to saddle-node bifurcation points and leads to the classical S-shaped steady-state curve. Then, the location of ignition and extinction conditions and their dependence on the main parameters (like pressure, equivalence ratio, residence time or inlet temperature in

reactors) can be reformulated as a problem of bifurcation analysis. Even when the reactive mixture is described by a simple surrogate, but in conjunction with very complex and detailed chemical mechanism, with several hundreds of species and thousands of chemical reactions, the computation of the bifurcation diagram becomes computationally very demanding. In this work we explore this issue. The several steps required to formulate a complete continuation algorithm are analysed from a computational point of view and convenient formulations or approaches are introduced to make viable this kind of analysis even adopting desktop class computers. It is shown that the adoption of a Broyden type corrector in the continuation algorithm outperform for this problem the usually adopted Newton type correctors. Consequently, we introduce a suitable algorithm to investigate ignition, extinction and linear stability of the air-fuel mixtures in PSR. The algorithm is based on the well-known Keller pseudo-arclenght continuation method in order to compute steady state solution curve. The solutions stability and then ignition and extinction states are identified by test functions based on the numerical eigenvalues of the Jacobian of the governing system of equations. The algorithm is implemented in the numerical computing environment Matlab coupled with the CANTERA Toolbox for managing of complex chemical kinetic mechanisms and species properties. The algorithm is thus easily applicable to chemical schemes available in the standard CHEMKIN format. To demonstrate the capability of the resulting method, the characteristic S-Shaped curve, including non-stable branches, for different Air-Jet Fuels mixtures have been computed.

15:45 Turbulent flames 4

28- **Premixed flame propagation in high-intensity turbulence: investigating the role of detailed chemistry**, *G. Nivarti, S. Cant* Experimentally observed dynamics of premixed flames in high-intensity turbulence remain unexplained to date. Until recently, DNS of turbulent reactive flows has been restricted to moderate intensities due to the prohibitive computational expense involved at higher intensities. Previously, we conducted a parametric DNS study of stoichiometric methane-air flames using single-step chemistry by varying the inflow turbulence intensity in a 3D inflow-outflow configuration. These simulations exhibited the bending phenomenon and an associated critical turbulence intensity similar to recent experiments. In the present work, the underlying mechanisms have been investigated by conducting two separate simulations at the critical turbulence intensity with a) single-step chemistry and b) detailed chemistry, respectively. Both flames are found to exhibit similar properties and it is hypothesised that flame surface area variations may contribute significantly to the turbulent flame speed at the critical turbulence intensity.

211- **Relevance of basic turbulent premixed combustion models for accurate simulations of V-shaped flames**, *K. Kha, C. Locier, V. Robin, A. Mura, M. Champion* The present study is devoted to the modeling of turbulent premixed combustion. The final objective is to introduce algebraic closures for turbulent combustion as simple as possible but also realistic enough to handle a wide possible range of variations in the turbulent combustion regime. Therefore, it is chosen here to focus on algebraic expressions for the mean chemical rate itself, without solving any additional modeled transport equations. Thus, the challenge is now to propose closures that involve only the smallest possible number of relevant modeling parameters. These models are then applied to the numerical simulation of a turbulent premixed V-shaped flame. From a practical point of view, the cheapness of such computational tools clearly offers one of its greatest advantages. Moreover, the obtained results display a fairly good level of agreement with available experimental data. Nevertheless, the sensitivity of these results to the modeling parameters values as well as the analysis of the behavior of these basic closures deserve to be studied in details. To account for the possible local variations in the turbulent combustion regime, a relevant criterion must be set forth and it is based here on algebraic expressions for the progress variable segregation rate.

74- **Influence of heat release in a premixed flame on weakly turbulent flow of unburned gas: a DNS study,** *A. Lipatnikov, J. Chomiak, V. Sabelnikov, S. Nishiki, T. Hasegawa* Data obtained earlier in unsteady 3D Direct Numerical Simulations (DNSs) of statistically planar, 1D, adiabatic, premixed, weakly turbulent flames characterized by various density ratios are analyzed in order to gain insight into the influence of combustion on the flow of unburned gas upstream the instantaneous flame front. Obtained results indicate that, under conditions of the present DNSs, (i) the flame front propagates upstream through flow regions characterized locally by higher strain rates when compared to vorticity and (ii) heat release affects the upstream flow by yielding such local regions. These effects are associated with local high-pressure regions that are induced due to heat release in the downstream flame front and push away the flow upstream the front, thus, promoting the upstream propagation of the front. In the case of laminar burning, such a physical mechanism was discovered by Darrieus and Landau who independently predicted the hydrodynamic instability of premixed flames. Moreover, local peaks are observed in the small-scale branch of spectra of transverse velocity fluctuations in the unburned gas, whereas the counterpart spectra of transverse vorticity fluctuations monotonously decrease in the same range of wavenumbers. Furthermore, the unit vector that is locally normal to the reaction surface aligns preferentially with the most expansive strain rate within the preheat zone of the instantaneous flame front. When a distance from the reaction surface is increased, the preferential alignment is reduced and vanishes if the distance is about twice laminar flame thickness. However, in the unburned gas in the vicinity of the front, the preferential alignment of the aforementioned unit vector with the most compressive strain rate is not observed, contrary to common expectations. The latter effect appears to be another manifestation of substantial influence of heat release in the front on the upstream turbulent flow of unburned gas. Thus, under conditions of the present DNSs, heat release in flame fronts substantially perturbs the pressure field and upstream fluctuating flow of unburned gas and, in particular, yields local regions characterized by higher strain rates when compared to vorticity, with the flame front preferentially propagating upstream through those regions. Such a scenario differs substantially from the classical paradigm of an increase in the flame front surface area by turbulent stretching. Further studies of premixed burning in more intense turbulence can provide a deeper insight into the main driving forces of premixed turbulent combustion and conditions under that the Kolmogorov theory of turbulence could be appropriate for characterizing the flow of unburned gas within a premixed turbulent flame brush.

89- **Blow-off characteristics of turbulent premixed flames in curved-wall jet burner,** *M. Mansour, O. Mannaa, S. Chung* This study concerns the flame dynamics of a curved-wall jet (CWJ) stabilized turbulent premixed flame as it approaches blow-off conditions. Time resolved OH planar laser-induced fluorescence (PLIF) delineated reaction zone contours and simultaneously stereoscopic particle image velocimetry (SPIV) quantified the turbulent flow field features. Ethylene/air flames were stabilized in CWJ burner to determine the sequence of events leading to blowoff. For stably burning flames far from blowoff, flames are characterized with a recirculation zone (RZ) upstream for flame

stabilization followed by an intense turbulent interaction jet (IJ) and merged-jet regions downstream; the flame front counterparts the shear layer vortices. Near blowoff, as the velocity of reactants increases, high local stretch rates exceed the extinction stretch rates instantaneously resulting in localized flame extinction along the IJ region. As Reynolds number (Re) increases, flames become shorter and are entrained by larger amounts of cold reactants. The increased strain rates together with heat loss effects result in further fragmentation of the flame, eventually leading to the complete quenching of the flame. This is explained in terms of local turbulent Karlovitz stretch factor (K) and principal flow strain rates associated with C contours. Hydrogen addition and increasing the RZ size lessen the tendency of flames to be locally extinguished.

15:45 Shock ignition

13- Numerical study of shock-induced combustion in a hypersonic non-uniformly premixed hydrogen/air flow, *K. Iwata, S. Nakaya, M. Tsue* A parametric numerical study was performed to study the effects of non-uniform composition of hydrogen-air premixed flow on oblique detonation and shock-induced combustion structures formed on the surface of a hypersonic spherical projectile. Axisymmetric two-dimensional Navie-Stokes equations were solved with a detailed chemical kinetic mechanism involving 9 species. Smooth-front oblique detonation formed on the hypersonic projectile at a Mach number of 6.46 under uniformly stoichiometric condition was taken as the completely premixed case. Hydrogen mole fraction was distributed at the inlet boundary based on the Gaussian function. As the centerline equivalence ratio increased, deformed oblique detonation, unsteady oscillating shock-induced combustion with non-uniform corrugations, steady shock-induced combustion with and without the minimum induction length outside the central region, and the nose confined combustion occurred. Analyses on induction length combined with 0D additional simulations demonstrated that as the non-uniformity increased, a reactivity distribution became strongly influential on the non-uniform structures in addition to a Mach number distribution, and finally the post-shock flow field became the most determinant factor.

120- Explosion-induced ignition and combustion of acetylene clouds, *A. Kuhl, H. Reichenbach, J. Bell, V.* Beckner We investigate the explosion-induced ignition and combustion of acetylene clouds in a rectangular chamber (10 x 10 x 39 cm). In the experiments, a 0.2 g PETN charge was located at x = 9.7 cm, and a soap bubble (d = 5 cm) filled with pure acetylene was located at x = 27 cm. Detonation of the charge created a blast wave that crushed the soap bubble, inducing mixing with air; after 27s, the cloud ignited forming a turbulent combustion cloud. This problem was simulated with our compressible AMR code. The flow was modeled by the compressible Navier-Stokes equations under the unity Lewis number assumption. Arrhenius-based kinetics were used to model ignition. Adaptive mesh refinement was used to capture turbulent mixing on the grid (iLES approach). Computed pressures were found to be in agreement with measured pressure histories.

155- Self-ignition of high-pressure hydrogen released by reproducible rupture of diaphragm, *W. Kaneko, K. Hayashi, K. Ishii* In the present work, self-ignition of high-pressure hydrogen, which is released to air through a diaphragm, has been studied experimentally under various test conditions. Diaphragms with several thickness and scores are ruptured by high-pressure hydrogen, and rupture pressure and formation of a shock wave in the tube are experimentally observed. Behavior of the ruptured diaphragm and self-ignition is photographed by a high-speed camera, and intensity of the flame is measured by photomultiplier. As a result, self-ignition causes a ring-shaped flame and the flame travels to the downstream along a jet boundary between hydrogen jet and air.

314- Effects of opening conditions on the self-ignition of high pressurized hydrogen released through a tube, *H. Lee, S. Lee, J. Park, I. Jeung* The effects of opening conditions on the self-ignition of high pressurized hydrogen released through a tube is studied. From previous results, the ignition mechanism and essentials to initiate the ignition is heating of the air and sufficient mixing, which are affected by the burst pressure and the length of the tube. However, its understanding is imperfect since the initial flow can be different as an open condition is varied. A new experiment apparatus is introduced in order to observe the bursting instant and to observe any effect of open condition of a disk on the self-ignition. Visualization images for the whole tube is obtained and different ignition patterns with various open area of disks is investigated. According to the direct images, a small and weak flame is observed near the disk, however this initial ignition cannot affect the whole process of the self-ignition. Furthermore, the experiment showed that flame development was always initiated near the boundary layer first and expanded to the center of the tube. Relating the open area ratio and the pressure measurements, the pressure decreased as the open area ratio decreased. Taking the pressure ratio of measurements to the shock tube theory, self-ignition was only observed down to pressure ratio decreased to 0.8 as the open area ratio is reduced by 0.5.

15:45 Heterogeneous combustion

68- On numerical model of two-dimensional heterogeneous combustion in porous media, *N. Lutsenko* The time-dependent problems of heterogeneous combustion in porous objects are considered when the gas pressure at object boundaries is known but the flow rate and velocity of the gas filtration at the inlet to the porous objects are unknown. In such porous objects the flow rate of oxidant, which enters into the reaction zone in porous object, regulates itself. An original numerical method, based on a combination of explicit and implicit finite-difference schemes, has been developed for investigating the unsteady two-dimensional gas flows in such porous objects with zones of heterogeneous reactions. Used approach enables to solve problems of filtration combustion for both forced filtration and free convection, so it can be efficiently applied for modeling the combustion zones in porous media, which may arise from natural or man-caused disasters. Some plane time-dependent problems of heterogeneous combustion in porous objects have been solved numerically using proposed numerical method. It is shown that gas, moving up, tends to go around the heated part of the object and prefers to flow in the cold part of the object. When the combustion wave propagates inside the porous object, burning the solid combustible substance completely, it cannot reach the part of the object, located lower the certain lines. The slope of these lines depends on the gas flow rate, which is determined by the gas pressure at the inlet to the porous object.

111- Effect of the initial diameter on the vaporization rate of fuel droplet in turbulent atmosphere: experimental data, *M. Birouk, P. Toews, I. Chowdhury* The present paper reports new experimental data on the effect of droplet initial diameter on the vaporization rate of a fuel droplet evaporating in turbulent atmosphere at room conditions. A 14 microns diameter cross fiber setup was designed and used to suspend a fuel droplet. Tests were performed in quiescent and convective flow conditions at atmospheric pressure and elevated temperature.

175- Asymptotic analysis of quasi-steady heptane droplet combustion supported by cool-flame chemistry, *K. Seshadri, N. Peters, F. Williams, V. Nayagam* A skeletal chemical-kinetic mechanism for heptane cool flames is simplified to the maximum extent possible by introduction of steady-state

approximations for intermediaries, following procedures employed previously. A pair of ordinary differential equations in mixture-fraction space is thereby obtained, describing the quasi-steady structures of the temperature and heptylketohydroperoxide (KET) fields. Application of activation-energy asymptotics for the partial-burning regime to this pair of equations is shown to provide convenient expressions for flame structures and extinction. With the mixture-fraction co-ordinate related to radius, these results are used to address droplet-combustion experiments that have been performed in the International Space Station (ISS). Droplet diameters at extinction are predicted as a function of the oxygen concentration in the atmosphere, and compared with measurements. While the results are encouraging, there are noticeable differences that point to deficiencies in the analysis resulting from oversimplifications. Further investigation therefore is recommended.

293 Effects of droplet size on hypergolic combustion of hydrazine spray, *H. Tani, H. Terashima, R. Kurose, A. Kitano, M. Koshi, Y. Daimon* The Hydrazine (N2H4) spray jets in gaseous Nitrogen Tetroxide (NTO), in fact the equilibrium of NO2 and N2O4 flows were simulated to explore the influence of the droplet size on the hypergolic ignition and flame dynamics in N2H4/NTO bipropellant thrusters. The Navier-Stokes equations with the use of a detailed chemical kinetics mechanism and dispersed droplets with evaporation models were solved in a manner of direct numerical simulations. The ignition delay time was longer as the droplet size was smaller because the smaller droplets enhanced the evaporation and decreased the temperature of the N_2H_4 vapor and NO_2 gas mixtures. Therefore, the key for the fast ignition of the N_2H_4 spray is not to generate the finer spray but to keep the temperature of the N_2H_4 vapor relatively high. As for the flame dynamics, the sinusoidal behavior of the decomposition flames was most significant in the case under which the droplet size was not smallest or largest. In the smaller droplet cases, the temperature of the N_2H_4 vapor became too low to induce the cyclic auto-ignition of the N_2H_4 vapor and NO_2 gas mixtures near the flame edges. In the larger droplet cases, the concentration of the N_2H_4 vapor was too low to cause the cyclic auto-ignition. This result suggests that the droplet size affects the mole fraction and temperature of the N_2H_4 vapor flows, and then they have a large impact on the flame dynamics. The sinusoidal behavior of the decomposition flames enhanced the mixing and reactions of the fuels, i.e. N_2H_4, NH_3 and H_2. This means that the finest spray is not always best for the hypergolic propellant combustion.

9:40 (all day) Posters 3

199- A novel flame chemiluminescence measurement using a digital colour camera, *J. Yang, Z. Ma, Y. Zhang* Flame chemiluminescence measurement is a useful combustion diagnostics tool. For a premixed hydrocarbon flame, the greenish-blue flame colour is attribute to the presence and mixing of CH* (430 nm) and C_2* (C_2* Swan system, dominative emissive band peaks at 473.71 and 516.52 nm) radical chemiluminescence emissions. The CH*/C_2* chemiluminescence ratio has been shown have a linear response to equivalence ratio for premixed flame, which could use to measure the fuel/air mixing ratio in its reaction room. Conventional chemiluminescnece measurement approaches (spectral, grey-scale and colour-modeled chemiluminescence measurements) all have their disadvantage. For this reason, a novel flame CH* and C_2* chemiluminescence measurement method using a digital colour camera was proposed. This method is based on assuming the premixed flame chemiluminescence only attributed to CH* (430 nm) and C_2* (516 nm). The calculation depends on the knowledge of the colour camera RGB sensor channel spectral sensitivity range and the filter transfer factors. Since R channel is non-sensible at both 430 and 516 nm wavelengths, only G and B channels are employed for calculation. The CH* and C_2* chemiluminescence concentration expressions are discussed under two different conditions based on G channel sensitivity range (covers and not covers 430 nm). Through the measurements of C3H8 premixed flame from φ= 0.93 to 1.53, the experimental estimations have validated that the high accuracy of the proposed colour-calculated chemiluminescence measurement. At last, the results were compared with conventional colour-modelled chemiluminescence measurement. The trends are similar, but it has small difference, especially in higher φ conditions.

203- Modeling and numerical simulation of layered coal-dust explosions behind a propagating shock wave, *T. Kanno, A. Matsuo* Dust lifting behind shock waves is a process that is especially interesting for engineers and researchers dealing with safety problems connected with dust explosions. When a shock wave propagates over a dust layer composed of dust particles, the particles are lifted and dispersed, leading to a dust cloud in the shock induced flow. This phenomenon often occurs in tunnels of coal mine or ducts of facility, and is serious industry issue. Lifting particles have very high combustion velocity because more dispersed particle acquires more oxygen, which is necessary for combustion. Consequently, this larger dust cloud in the presence of an ignition source cloud creates a more severe dust explosion. The problems of lifting and dispersing of a dust layer behind a propagating shock wave must therefore be understood to ensure safety regarding dust explosion hazards. In addition, this problem has been contributed by many researchers in terms of collisions of particles and a curvature of the shock wave due to interference between fluid and particles. Although some works have investigated the dust lifting phenomena, few consider the combustion characteristics behind propagating shock wave, which can hardly be obtained experimentally. Recently, numerical analysis of the structure of a layered coal dust explosion was performed based on Euler-Euler approache, which treats particle phase as continuous phase. The purpose of this study is therefore to investigate the initial process of the layered coal-dust explosions behind a propagating shock wave by using numerical simulation based on Euler-Lagrange approache. The accuracy of the numerical analysis is also evaluated by comparing simulation and experimental results.

212- Burning velocity blending laws for methane/air and hydrogen/air blends, *T. Al-Mughanam, D. Bradley, M. Lawes, R. Mumby* There is increasing interest in supplementing natural gas supplies with the addition of hydrogen for both heating and transportation fuel purposes. This has led to a number of experimental and chemical kinetic studies of the burning velocities, u_l, of such blends with air. The interest in this extends beyond these practicalities to the general problem of deriving satisfactory blending laws for fuels with very different chemical kinetics and burning velocities. The present paper explores the application of six different laws for predicting the burning velocities of blends of H_2/air and CH_4/air, with the same equivalence ratio, ϕ. A proposed law is presented based on an observed correlation, between the heat of reaction of one mole of mixture, Q, and ul, but confined to fuels in the same family. This provides an approximately linear reltionship, for each separate family of fuels.The infulence of the heat release profile upon ul became apparent through the seminal work of analytical expressions for ul by Spalding. Thus, implying the value of ul is dependent not only upon Q, but also upon the profile of the heat release rate through the flame, suggesting a blending law in terms of Qul rather than soley of Q. Values of u_l for the component mixtures were plotted against Qxu_l. As is known for both the component mixtures and the blend, the value of ul for

the blend can be found. It is shown that, this and a modified Le Chatelier both give satisfactory predictions.

216- Criterions for the stability of flame propagation and deflagration detonation transition of carbon monoxide-oxygen mixture, *Y. Sun, C. Wang* This paper mainly discusses the combustion instability, the criterion of deflagration to detonation transition (DDT), and the stability of the detonation wave. The research work includes: 1. By adopting the linear stability analysis and the small disturbance along with the time evolution, we analyze the stability of the combustion flame, and obtain the criterion of stable propagation of flame. 2. Using linear stability theory to analyze the deflagration mechanism of methane and carbon monoxide. The criterions of deflagration to detonation transition for the two gases are proposed. 3. Using Lyapunov stability theory to analyze the stability of the detonation wave, and put forward the criterion of detonation stability.

220- Modeling study of pulsed and continuous detonation in propane/air mixture, *V. Kopchenov, D. Babushenko, P. Kuleshov, N. Titova, A. Starik* The reduced reaction mechanism for high temperature (1100K) ignition and combustion of propane-air mixture has been developed. This mechanism possesses higher prediction ability compared to proposed earlier quasi-global mechanism and applied for numerical simulation of detonation combustion. The flow regimes with pulsed shock-induced and continuous rotating detonation combustion have been analyzed with the usage of reduced and quasi-global mechanisms. It was shown that the influence of the applied reaction mechanism on the predicted characteristics of detonation combustion can be essential, especially, at the stages of detonation initiation and detonation wave breakdown, where kinetic effects are the most important. To describe properly these regimes it is needed to apply the reaction mechanisms that enable to reproduce principal features of ignition and energy release during combustion with reasonable accuracy.

230- Shock in reactive cross-flow under partial confinement, *J. Burr, K. Yu* Rotating detonation engines (RDEs) have garnered interest because of their simplicity and potential for high thermodynamic efficiency. This study is motivated to better understand RDE-relevant flow structures, particularly the interaction of the detonation wave with a cross-flow of reactants, through the use of a linear array of fuel and oxidizer injectors. A shock wave, generated by a pulse detonation engine, was directed into a cross-flow composed of a stoichiometric hydrogen-oxygen mixture with an option for helium dilution. The behavior of the shock is measured in cases where the cross-flow height is 5, 10, 15, and 20 times the detonation cell size of the cross-flow mixture. Measurements are made using shadowgraph flow visualization and pressure transducers. This paper presents the results of this investigation with a particular interest in the impact of the cross-flow height on the shock propagation velocity and characteristics. The results shed light on flow structures that are present during RDE operation.

233- Multi-dimensional transport: DNS analysis and incorporation into the Reaction-Diffusion Manifold (REDIM) method, *R. Schießl, V. Bykov, U. Maas* In this paper, the mutual alignment of the local diffusion fluxes of different state variables in a non- premixed turbulent combustion scenario is studied using 3D DNS data. It is found that the diffusive fluxes (as inferred from spatial gradients) of different species display a considerable directional scatter. This scatter is not fully random, but approximately restricted to a two-dimensional subspace of the three-dimensional geometrical space. These observations may be important in the context of computational models for a simplified description of reaction-diffusion systems. To assess this importance, the significance of the multi- dimensional transport for the REDIM-approach is studied. In the REDIM method, one- two- and three dimensional gradient estimates can generically be accounted for. REDIMs for identical boundary conditions, but with different dimensionality of the gradient estimate are computed and compared. The difference, while noticeable, is overall quite small. This indicates that, at least for the conditions of the studied flames, the two-dimensional diffusive transport has little influence on the overall behavior of the reaction-diffusion system.

239- Thermal radiation contribution to metal dust explosions, *R. Ben Moussa, C. Proust, M. Guessasma, K. Saleh, J. Fortin* Dust explosions remain a safety and scientific challenge. There has been a gradual evolution in the prevention and mitigation of dust explosions over the past twenty years. This evolution results partly from a better understanding of the phenomena involved, namely the propagation of the flame through dust clouds, properties and characteristics of dust explosion, the ignition and the combustion time of particles and incidence of the size and concentration of particles. Today, the modeling of this type of explosions is generally derived from that of gas explosion because of the similarities between the flame propagation process in both media at least for some categories of dusts. Flour, starches and sulfur powder certainly belong to this panel because it was shown that the particles are gasified ahead of the combustion zone and that heat conduction through the front leads to this transformation. The situation might be different if the particles do not evaporate and/or if the major part of the combustion process is heterogeneous. This may occur with fine metal particles as aluminum. In particular, the combustion process might be heterogeneous and results in the presence of solid residues at very high temperature potentially transferring most of the thermal energy to the reactants (aluminum particles) by thermal radiation. Only very few experimental observations and theoretical considerations are available but seem to cofirm that thermal radiation exchange is significant in the thermal balance of the flame and that it could lead to a dramatic acceleration of the flame. The aim of this work is to further investigate this phenomenology.

246- Two-dimensional numerical simulations of cellular detonation diffraction in channels, *J. Li, H.D. Ng, N. Jianguo, J.H.S. Lee* In this study, high-resolution numerical simulations are performed to investigate gaseous cellular detonation diffraction from a channel using the reactive Euler equations with a three-step chain-branching chemical kinetics model. The chemical parameters are varied such that the detonation wave is stable with highly regular cellular structure to weakly unstable. For the highly stable case, the deceleration of the diverging wave due to curvature leads to the global decoupling of the reaction zone with the leading shock front. Below the critical channel width failure is observed from a continuous enlargement and subsequently disappearance of detonation cells. For the successful transmission, the cellular structure survives and re-establishes at further distance. For the successful transmission, the cellular structure survives and re-establishes at further distance. The distinct feature of shock folding or kink resulted from the interplay of transverse rarefaction waves with the accelerating detonation front near the channel central axis appears to be the origin of the re-coupling between the reaction zone and the leading front for re-initiation. From the numerical results it is found that the critical channel width over the detonation cell size is about 10, which is comparable with the experimental observation. For the weakly unstable mixture, more spontaneous formation of transverse waves is observed at the diverging front generating finer cells and facilitating the transmission.

249- Numerical simulation of multidimensional modes of gaseous detonation, *V.A. Levin, I.S. Manuylovich, V.V. Markov* The results of numerical simulation of spontaneous formation of

3D cellular and spin detonation in propane-air mixture are presented. Propagation of diverging cylindrical detonation wave is examined. The results of three-dimensional detonation initiation in channels of fixed square, rectangular, circular and elliptical cross sections are presented. Spontaneous formation of 3D cellular and spin detonation is obtained and discussed. Stability of spin detonation with respect to sharp change of the tube diameter is analyzed.

252- 2D and 3D detonation in layered reacting mixtures, *V.A. Levin, I.S. Manuylovich, V.V. Markov* The paper considers problems of detonation initiation in the supersonic flow of stoichiometric propane-air mixture, which partially or fully fills in the channel cross-section. The initiation in the flow takes place due to a bench or a wall, which fully blocks the channel, and in the medium at rest it is caused by explosion. The investigation is performed within the framework of single-stage combustion kinetics by the numerical method based on the S.K. Godunov scheme.

253- Detached eddy simulation of high turbulent swirling reacting flow in a premixed model burner, *Z. Mansouri, M. Aouissi, E. Abdallah, T. Boushaki* This work discusses an unsteady numerical simulation of the reacting swirling flow in a lean premixed burner, which is solved by ANSYS Fluent software. The combustor is operated with air and propane at atmospheric pressure and a global equivalence ratio ϕ= 0.5. Detached Eddy Simulation model and Finite-Rate/Eddy Dissipation model for turbulence-chemistry interaction are used. The applied approach is useful to capture the vortex-flame interaction, and the DES model can predict the unsteady behavior of the flow with all distinctive features. Comparing with experimental data, the performance DES in predicting the high swirling flow properties (axial velocity profiles) is competitive. The dynamic of the flame and its interactions with the PVC is characterized. The flame front is wrinkled with both small and large scale structures .The IRZ extends inside the converging-diverging nozzle and subsequently the flame is stabilized upstream the combustion chamber inlet, showing a tendency to flashback in the contraction. The flashback might be prevented by the PVC originating in the same location. The PVC found as a double coherent structure and performs a rotational motion around the central axis.

255- O-Revealer: novel technology for demining of histosols by the controlled use of smouldering combustion, *G. Rein, X. Huang, F. Restuccia, T. McArdle, P. Idoux* For more than thirty years after the 1982 Falkland War, only 5,000 out of the original 20,000 anti-personal (AP) and 5,000 anti-tank (AT) mines placed by the Argentine forces have been demined, due to the slow pace and expensive conventional demining technologies. In this work, a novel technology (O-Revealer) was proposed to detect various types of landmines buried in peat using the controlled smoldering combustion. Two types of mines, Italian SB-33 Anti-Personnel plastic landmine, and Serbian PROM-1 anti-tank metal landmine were selected. Their corresponding dummy were built and buried in peat with the moisture content (MC) ranging from very dry (5%) to normal (130%) conditions. In all cases, the smouldering fire burns across the peat, left the dummy exposed to the open for easy identification and removal. As the peat MC increased, the temperatures inside and outside the dummy and the fire spread rate decreased. For the SB-33 dummy, the results showed that the fire was strong enough to melt the polycarbonate shell, and to heat the explosive charge above the minimum thermal-runaway temperature (240°C) for 30 min for dry peat at 50% MC. For a wetter peat at 100% MC or above, the dummy did not reach the threshold of thermal runaway. For the PROM-1 dummy, the results showed that the peak temperature inside was 205°C for the very dry peat at 5% MC, well below the thermal runaway temperature. This study proves the concept of the novel technology in small-scale laboratory conditions. We envision that O-Revealer will be applied in small plots of land, one at a time by each team, and following a strategy of combining it with other demining methods. Although not all organic lands or weather conditions will be apt to this technology, we have identified the Falkland Islands as the first site of immediate interest for this technology, and it can be further applied into many more minefields around the world.

83- Development of file format and database infrastructure for high explosive reference data, *C. Kiyanda, M. Boyce, H.D. Ng* The development of high explosive (HE) models requires calibration, verification, and validation against experimental data, typically shock Hugoniot, wave curvature, isothermal compression measurements, etc. To palliate the lack of a convenient resource to collect, compare, and share reference HE data, computational tools are developed. These comprise an extensible file format that minimizes the possible loss of metadata associated with the relevant scientific data and a web-enabled database that allows the exploration of multiple data sets by users. An emphasis is put, in the system design, on an open collaboration strategy.

273- Three-dimensional cellular structure and propagation process of spherical detonation, *R. Iida, M. Asahara, A. Hayashi, N. Tsuboi* Three-dimensional numerical simulation is performed to figure out spherical detonation cell structure and its propagation process. The numerical system as well as the chemical reaction model is validated by comparing with the experimental results. The spherical detonation cell structure is found numerically and is similar to that found experimentally a long time ago. It is also found that the cell structure is sometimes curved probably due to spherical expansion behavior. The curved cell structure will be presented at the conference.

274- Thrust performance evaluation of a rotating detonation engine with a conical plug, *K. Ishihara, Y. Kato, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki* Detonation engines are classified into two types of a pulse detonation engine (PDE) and a rotating detonation engine (RDE). The RDE has characteristic channel, composed of a double cylinder. Detonation waves in RDEs propagate in the circumferential direction to the channel and continue to propagate as long as the propellant is continuously supplied into the channel. Therefore, the ignition and the deflagration to detonation transition (DDT) in RDEs are only once. The advantages of RDEs are not only simple structure without compressors and high thermal efficiency but also the miniaturization of combustors, high thermal density and high frequency operation at kHz order. From the above, RDEs have a potential to make significant improvements to the performance of main engines for aerospace vehicles.However, there are several challenges (elucidation of the flow in the RDE channel, performance evaluation, high heat load, and so on) that must solve. Therefore, in recent years, many research institutions have been engaging in resolution of them towards practical use.In this study, we focused the thrust performance of RDEs towards the application of RDEs to the rocket engines as the final goal. Researchers about RDEs have been studying about each element. However, it's necessary to clarify how each element affects the thrust performance for practical use since the internal flow of the RDE channel is the very complex flow shown in Figure 1. Therefore, we measured each element at same time and compare and verify them. In addition, we evaluated the effect of a conical plug of which the apex angle was 30 degree as the initial stage since a development of nozzles is also important for practical use. Therefore, We have developed the thrust measurement system of the rotating detonation engines, and the acquisition of the thrust of the rotating detonation engines in ethylene oxygen mixture was carried out. As a result, the specific impulse of the

rotating detonation engine was achieved 96 ~ 151 s, and it was confirmed that the thrust performance of the rotating detonation engine improved 6 ~ 11% by attaching a conical plug of which the apex angle was 30 degree. In addition, the thrust history, the pressure history and propagation states of detonation waves were obtained at the same time and compared. Therefore, it is necessary that the equivalence ratio is greater than to obtain the stable thrust.

277- Study on intensity of blast wave generated from vessel bursting by gas explosion, *T. Matsunaga, T. Mogi, R. Dobashi* In this experimental study, to investigate the blast wave from bursting vessels as a result of excessive high pressure arised by gas explosions, explosions experiments were performed in vessels which had various strengths. The blast wave was generated from jetting out of high pressure mixture and combustion reaction. The effect of combustion reaction on generation of blast wave might be not so small.

287- The application of Krylov implicit integration factor method in numerical simulation of deflagration to detonation, *C. Wang, Y. Bi, J. Ding* The process of deflagration to detonation transition for combustible gas involves very complicated physical mechanism and is across multiple time and space scales. Due to non-stiff advection-diffusion terms and stiff reaction terms in Navier-Stokes equations, it is very difficult to adopt direct numerical simulation to investigate the different time scale problems. Small time step is required for explicit scheme, however implicit scheme demands the solution of the large nonlinear equations. In this paper, we use Krylov implicit integration factor method to solve time-dependent partial differential equations with stiff reactive terms. We utilize explicit scheme to discretize the non-stiff terms and implicit scheme to discretize the stiff reactive terms. Large time step size is obtained. On the other hand, large sparse matrix is mapped to the Krylov subspace, and thus the dimension of the Krylov subspace is much smaller than that of large sparse matrix, which saves computational cost.

285- Experimental and numerical study of oxygen enrichment on methane diffusion flame in a triple port burner, *Y. Li, C. Wu* Oxy-enriched combustion technology is one of cost-effective approaches to improve the flame stability and combustion efficiency. In general, a triple port burner can provide a simple diffusion flame to investigate the oxygen enrichment effect on the flame characteristics. In this study, the flame shape would shift from normal diffusion flame (NDF) to inverse diffusion flame (IDF) accompanying with changing flame color when the oxygen concentration in oxidizer is increasing. The operational range of IDF with various velocity ratios and oxygen enrichments is demonstrated. It appears that length of IDF becomes shorter as oxygen enrichment is increasing. Besides, numerical simulation for two cases Ω=40% and 60%) is also performed and indicates the significant increase of carbon monoxide concentration in IDF. It is argued that increasing oxygen in IDF would improve the oxidation reaction of soot and lead to abundant carbon monoxide production.

305- Flame propagation of highly reactive combustible mixtures in closed pipe with L/D of 51, *S. Sulaiman, R. MdKasmani, A. Mustafa, M. Hassim, R. Rasit Ali, N. Ibrahim, K. Kidam* Flame propagation in a confined pipe with diameter 0.1 m and 5.1 m long, given a length to diameter ratio (L/D) of 51, was experimentally studied. Hydrogen and acetylene were used as reactive combustible mixture with various concentrations to observe the explosion flame propagation trend in the pipe. Experimental work was operated at ambient condition. Results showed that both gaseous have a consistent trend of flame propagation in one-half of total pipe length in which the acceleration is due to the piston-like effect. Beyond the distance, the effect of oscillating pressure, acoustic pressure wave and a fast flame contributes to the maximum overpressure profiles of both gases. However, the retonation effect was only observed in acetylene/air explosion but not in hydrogen explosion.

309- Investigation on shock wave focusing in 2-stage PDE, *Z. Hao* A 2-stage pulsed detonation device was assembled and examined in an experimental program. Non-reaction experiments and initiation experiments on shock wave focus were carried out respectively. Non-reaction experiments were carried out to find better configuration of resonator, then the best resonator was chosen to carry out initiation experiments using petrol as fuel. The influences of resonator size, resonator curvature, resonator stretch angle, resonator airflow exit area, nozzle diverging angle and 'L'on shock wave focus were studied. It was found that with the increase of partial-spherical resonator size, α-frequency decreases and the quantity of β-frequency decreases; effectiveness of the partial-spherical resonator with D=74mm is the best. As the curvature of resonator increasesα-frequency increases and the dynamic pressure amplitude of resonator bottom decreases. As the incidence angle of resonator increases, resonant frequency increases. As airflow exit area decreases, resonant frequency of resonator increases and the dynamic pressure amplitude of resonator bottom increases. As nozzle diverging angle increases, the highest α-frequency increases and the quantity of β-frequency increases. When the nozzle diverging angle is 30°, the dynamic pressure amplitude of resonator bottom is maximal. As 'L' increases, resonant frequency decreases and the dynamic pressure amplitude of resonator bottom decreases. During initiation experiments, three distinct combustion models were found.