# Introduction

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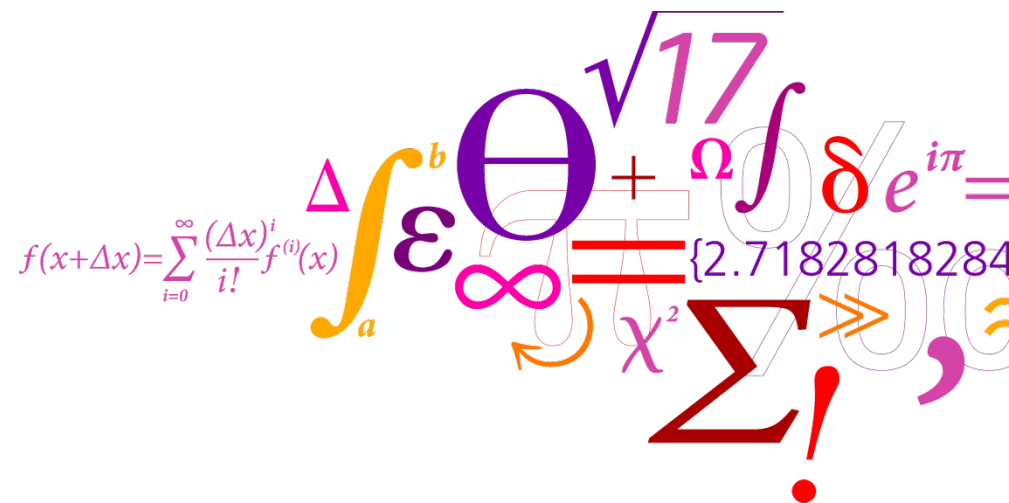
**RADIADE**
**RADIA**tion modeling and verification in marine **D**iesel **E**ngines

## Purpose:

- **The social/commercial purpose** of this project is to enable more accurate and detailed model prediction of nitrogen oxides ($NO_x$) and soot formation in marine diesel engines. Such model improvements are essential in order to meet future emission regulations without sacrificing the high fuel efficiency of these engines accompanied by increase of carbon dioxide ($CO_2$) emissions.

- **The scientific purpose** of the project is to improve computational tools for modeling of radiant heat transfer and integrate them into existing complex and computationally demanding CFD models of fluid flow. As well as to improve understanding of the complex coupling between the radiant heat transfer, rate of combustion progress and formation of harmful products in combustion processes.

## Project partners:

- DTU Mechanical Engineering
- DTU Chemical Engineering
- MAN Diesel & Turbo
- Sandia National Laboratories
- Lund University
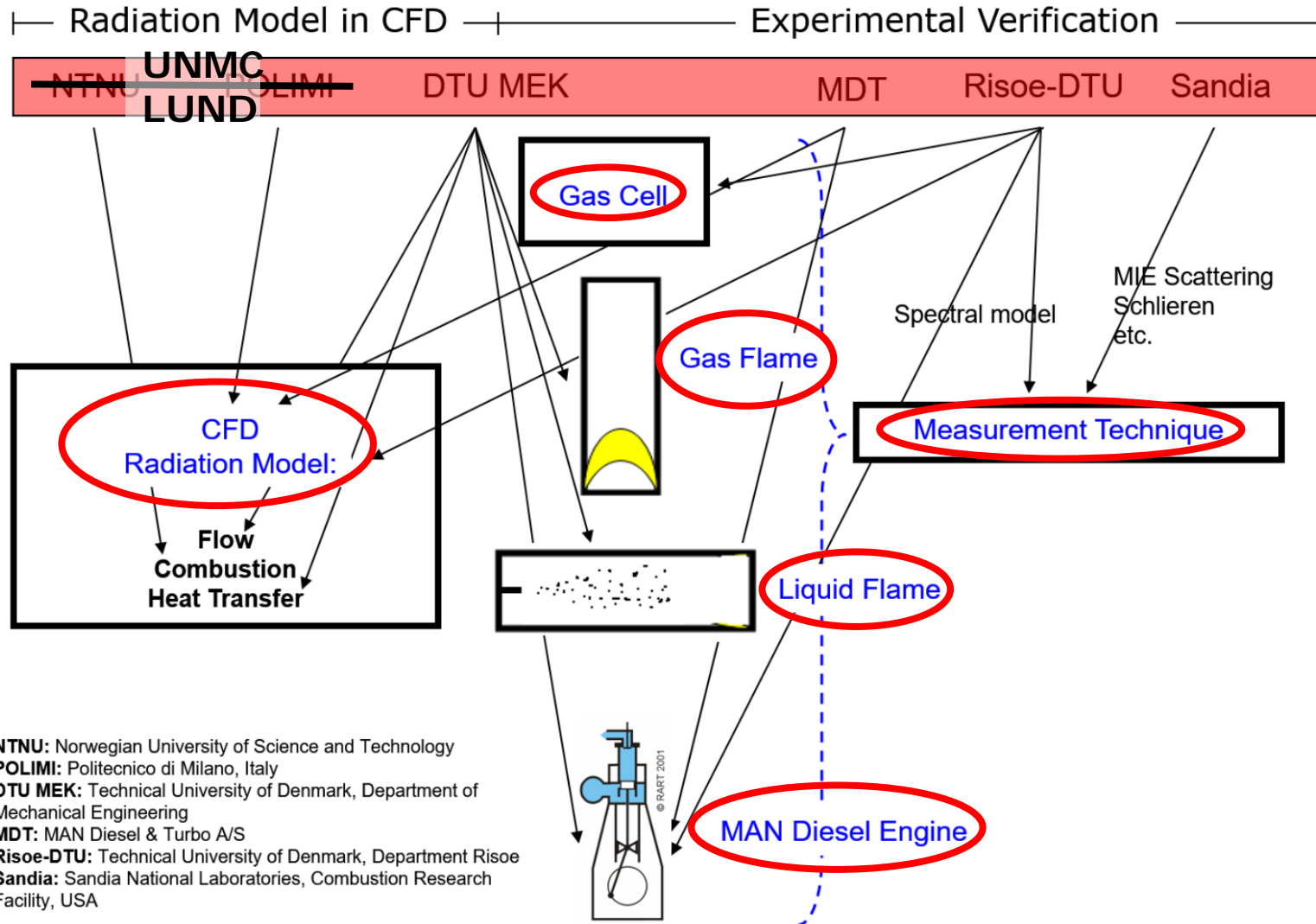- University of Nottingham, Malaysia Campus

**Support:**
Innovation Fund Denmark 12,3 mio DKKR and
project partners          9,7 mio DKKR

# RADIADE Collaboration Structure

## How far did we get?
- Collaboration
- Research
- Where do we go from here?

# RADIADE – Publication list

[1]   Evseev V, Fateev A, Clausen S, "High-resolution transmission measurements of CO2 at high temperatures for industrial applications" **Journal of Quantitative Spectroscopy & Radiative Heat Transfer** 113, 2222-2233, 2012.

[2]   Haider, S., Pang, K.M., Ivarsson, J., Schramm, J. "Combustion and radiation modeling of laminar premixed flames using OpenFOAM: A numerical investigation of radiative heat tranfer in the RADIADE project". Proceedings of the **27th CIMAC World Congress**, Shanghai, May 13-16, China 2013.

[3]   Pang, K.M., Ivarsson, A., Haider, S., Schramm, J. "Development and validation of a local time stepping solver for laminar and turbulent flame modeling". Proceedings of the **8th International OpenFOAM Workshop**, Jeju, June 11-14, Korea 2013.

[4]   Poon, H.M., Ng, H.K., Gan, S., Pang, K.M., Schramm, J., "Evaluation and Development of Reduction Scheme for Chemical Kinetic Mechanism of Biodiesel and Diesel Fuel Surrogates" **SAE International Journal of Fuels and Lubricants** 6 (3), 2013-01-2630, 2013.

[5]   Christiansen, C.A. "RADIADE Task 2" Internt notat.

[6]   Skeen, S., Manin, J., Dalen, K., Pickett, L. "Extinction-based Imaging of Soot Processes over a range of Diesel Operating Conditions". 8th U.S. National Combustion Meeting, University of Utah, May 19-22, 2013.

[7]   Pang, K.M., Jangi, M., Bai, X., Schramm, J. "Investigation of Chemical Kinetics on Soot Formation Event of n-Heptane Spray Combustion" SAE paper no. 2014-01-1254. **SAE Technical Papers** 2014.

[8]   Skeen, S., Manin, J., Dalen, K., Ivarsson, A. "Quantitative Spatially Resolved Measurements of Total Radiation in Spray Flames" SAE paper no. 2014-01-1252. **SAE Technical Papers** 2014.

[9]   Poon, H.M., Ng, H.K., Gan, S., Pang, K.M., Schramm, J., "Chemical Kinetic Mechanism Reduction Scheme for Diesel Fuel Surrogate" **Applied Mechanics and Materials**, Vols. 541-542, pp 1006-1010, 2014.

[10]   Poon, H.M., Ng, H.K., Gan, S., Pang, K.M., Schramm, J., "Development and Validation of Chemical Kinetic Mechanism Reduction Scheme for Large-Scale Mechanism". **SAE International Journal of Fuels and Lubricants** 7 (3), 2014-01-2576, 2014.

[11]   Schramm, J. "Understanding heat transfer phenomena in IC engines.The influence on formation of emissions" Proceedings of the "**Energy and Environment for the Future Conference**", Innovation Fund Denmark, Copenhagen, November 2014.

[12]   Pang KM, Schramm J. " RADIADE: Modelling of soot formation event in n-heptane and diesel spray combustion" Poster presented at the "**Energy and Environment for the Future Conference**", Innovation Fund Denmark, Copenhagen, November 2014.

[13]   Haider S, Schramm, J, Ivarsson A "Combustion and radiation modeling using OpenFOAM" Poster presented at the "**Energy and Environment for the Future Conference**", Innovation Fund Denmark, Copenhagen, November 2014.

[14]   Dalen KR, Westlye FR, Ivarsson A "RADIADE – Radiation modeling and verification in marine diesel engines" Poster presented at the "**Energy and Environment for the Future Conference**", Innovation Fund Denmark, Copenhagen, November 2014.

[15]  Pang KM, Jangi M, Bai XS, Schramm J "Evaluation and Optimization of Phenomenological Multi-Step Soot Model for Spray Combustion under Diesel Engine-like Operating Conditions". **Combustion Theory and Modeling**, 2015 (accepted for publication).

[16]    Alberti, M., Weber, R., Mancini, M. Fateev, A., Clausen, S. "Validation of HITEMP-2010 for carbon dioxide
And water vapour at high temperatures and atmospheric pressures in 450-7600 cm$^{-1}$ spectral range" **Journal of
Quantitative Spectroscopy & Radiative Transfer**, vol: 157, pages: 14-33, 2015.

[17]    Pang KM, Poon HM,  Ng HK, Gan S, Schramm J "Soot formation modeling of n-dodecane and diesel sprays
under engine-like conditions".  SAE paper no. 2015-24-2468, **SAE Technical Papers**, 2015.

[18]    Christiansen, CA, Stolberg-Rohr, T , Fateev, A, Clausen S "High temperature and high pressure gas cell for
quantitative spectroscopic measurements". **Journal of Quantitative Spectroscopy & Radiative Heat Transfer**, 169, 96-103, 2016

[19]    Pang KM, Karvounis, N.  Walther J.H., Schramm  J "Numerical investigation of soot formation and oxidation
processes under large two-stroke marine diesel engine-like conditions using integrated CFD-chemical kinetics".
**Applied Energy** 169, 874-887, 2016.

[20]    Westlye F, Ivarsson A et. al. "Penetration and combustion characteristics of cavitating and non-cavitating fuel
injectors under diesel engine conditions". SAE paper no. 2016-01-0860. **SAE Technical Papers** 2016.

[21]   Poon, HM, Pang KM, Ng HK, Gan S, Schramm J, "Development of  Multi-Component Diesel Surrogate  Fuel Models – Part I: Validation
of Reduced Mechanisms of Diesel Fuel Constituents in 0-D Kinetic Simulations" **Fuel**, vol: 180, pages: 433-441, 2016.

[22]   Poon, HM, Pang KM, Ng HK, Gan S, Schramm J, "Development of  Multi-Component Diesel
Surrogate  Fuel Models – Part II: Validation of the Integrated Mechanisms in 0_D Kinetics and 2_D CFD
Spray Combustion  Simulations" **Fuel**, vol: 181, pages: 120-130, 2016.

[23]    Haider, S, Ivarsson A, Pang KM, Schramm J, Mansouri SH, "CFD modelling of radiative heat transfer
of an in-house helium stabilized laminar premixed flat flame" **HEFAT** 2016.

[24]    Pang KM, Karvounis N, Schramm J, Walther J "Modelling of combustion and pollutant formation in a
large two-stroke marine diesel engine using integrated CFD-skeletal chemical mechanism" **ECCOMAS**
Congress 2016.

[25]    Cheng X, Ng HK, Gan S, Ho JH, Pang KM, "Development and validation of a generic reduced chemical kinetic
mechanism for CFD spray combustion modelling of biodiesel fuels" **Combustion & Flame,** vol.162, pp 2354-2370**,**
2015.

To be published:

[26]    Westlye F, Penny K, Ivarsson A, Skeen S, Manin J, Pickett L, Diffuse back-illumination for high temporal
resolution extinction imaging" **Applied Optics** 2016 (To be published, 2017)

[27]    Westlye F, et. al "High speed extinction imaging of optically thick flames at diesel engine conditions"  (To be
published, 2017).

[28]    Schramm J, Jørgensen MC, Hult J, Mayer S. "Estimation of radiative heat transfer through a slow speed two-stroke diesel engine cylinder
wall" (To be published, 2017)

[29]    Haider, S, Ivarsson A, Pang KM, Schramm J, Mansouri SH, "CFD modelling of radiative heat transfer of a
diesel spray" (To be published)

[30]    Stolberg-Rohr T, Christiansen CA, Fateev A, Clausen S, "Radiative properties of CO2 at high pressure up to 100 bar and 1273 K." (To be
published)

[31]    Fateev A,  Clausen S. "Radiative properties of H2O at high pressure and temperature" (To be published)