Current and future R&D activities at GexCon

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GexCon R&D

Outline

- Introduction: CMI, CMR, GexCon & the CFD code FLACS
- Recent work:
  - Buncefield and experiments with 'flexible obstructions'
- Ongoing work:
  - Two-phase releases
  - Dust explosion experiments in full-scale coal mill
  - Dust and gas explosions in 3.6-m flame acceleration tube
- Future prospects
  - Wind energy
  - Joint Industry Project: 'FLACS 2011 and beyond'

CMI, CMR & GexCon

1857-1925: **Christian Michelsen**

- Lawyer, ship owner, prime minister of Norway from 1905 to 1907, ...

1930: **Christian Michelsen Institute** (CMI)

- Independent research foundation in Bergen
- Science, medicine, the humanities, etc.
- Dust explosion test laboratory (1975) and large scale dust explosion research (from 1980)
- Gas Safety Programs and of the CFD-code FLACS (FLame ACceleration Simulator (from 1980)

Pioneering large-scale explosion work at CMI

Flame acceleration experiments in 10-m³ pipe, Raufoss, Norway, ~1980

R.K. ECKHOFF K. FUHRE

J.E. VINNEM J.H.S. LEE O. KREST

ACCELERATION PLATE STRUCTURE BEING PUSHED INTO IGNITION TUBE

Lunch-time, Eckhoff, Pedersen and Fuhre. Stordalen, ~1985

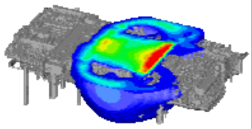
CMI, CMR & GexCon

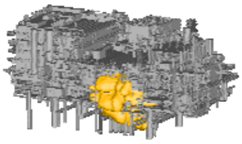
1992: **Christian Michelsen Research** (CMR)

- Currently owned by University of Bergen (80 %), and three industry partners

1998: **GexCon** – Global Explosion Consultants

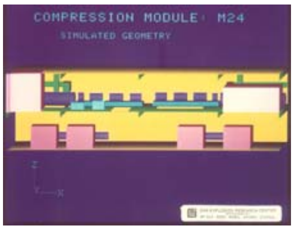
- Owned by CMR (100%)
- About 40 employees: Bergen, US, UK & Sweden
- Five departments:
  - **R&D** – developing, maintaining and validating FLACS
  - **Software** – marketing and sale of FLACS
  - **Gas Consultants** – consultancy services with FLACS
  - **Process safety** – risk assessments and ATEX
  - **Labs** – laboratory & large-scale experimental testing





Test Facilities at Fantoft & Sotra

The CFD code FLACS



FLACS-86

1980: FLACS development initiated at CMI

1980 -1986: First gas explosion safety program: BP, Elf, Esso (Exxon), Mobil, Norsk Hydro and Statoil

1986: The CFD-tool FLACS-86 released

1992: CMI explosion group part of CMR

1998: GexCon AS established

2006: FLACS V8.1 and DESC 1.0

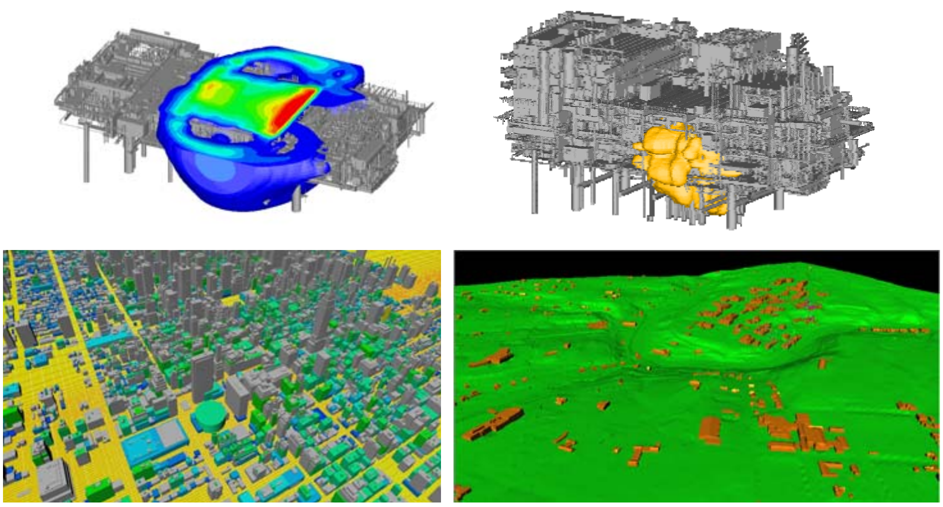
2008: FLACS V9.0 – QT and Windows^{TM}

2009: Initiated work on 'FLACS-Wind'

FLACS

DESC

Application areas for FLACS



GexCon R&D

- Development of the CFD code FLACS:
  - Effective handling of large-scale geometries
  - Release and dispersion of flammable and toxic material
  - Fast, accurate, and robust explosion calculations:
    - Flammable gases & vapours
    - Mists & sprays
    - Dust clouds
    - Blast waves from high-explosives
  - Renewable energy: hydrogen, biofuels, wind energy, …
- Research = validate, improve, validate, improve, …

Recent R&D work

- Vegetation and flame acceleration
  - FLACS simulations related to Buncefield
  - Small-scale experiments with flexible obstructions

Buncefield

Objective of CFD study with FLACS:

- Provide a foundation for establishing the probable explosion event
- Understand the mechanisms at work

A site survey showed that road sides along the outside of the perimeter of the tank farm were densely planted with trees, coppice and undergrowth

The “congestion” (metres of branches per cubic metre of volume) was at least as high as that of pipework in a densely congested process area

A detailed geometry model was constructed in FLACS, emphasising the congestion by trees

Photo of Hertfordshire Oil Storage Ltd. and Fuji building prior to the accident – note the low congestion on site and trees outside perimeter

FLACS model of Buncefield

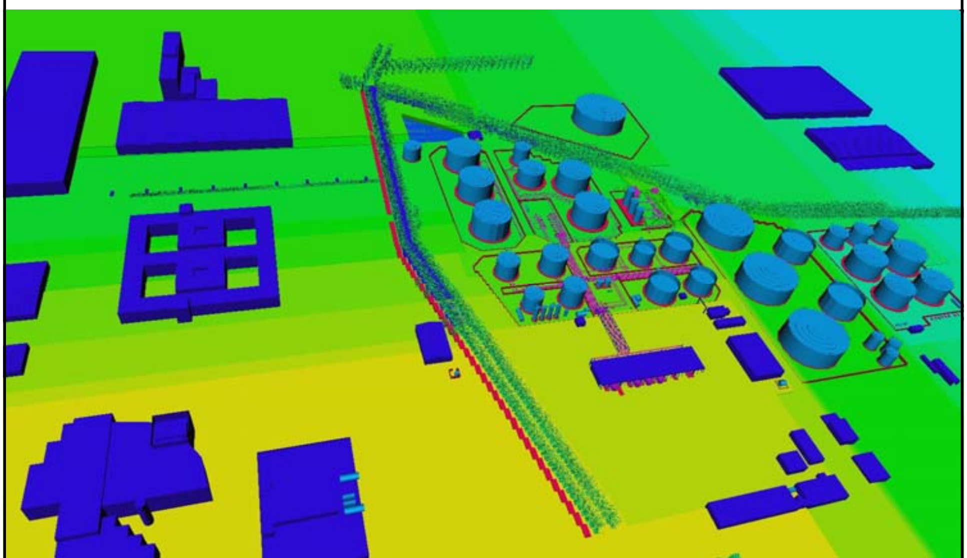
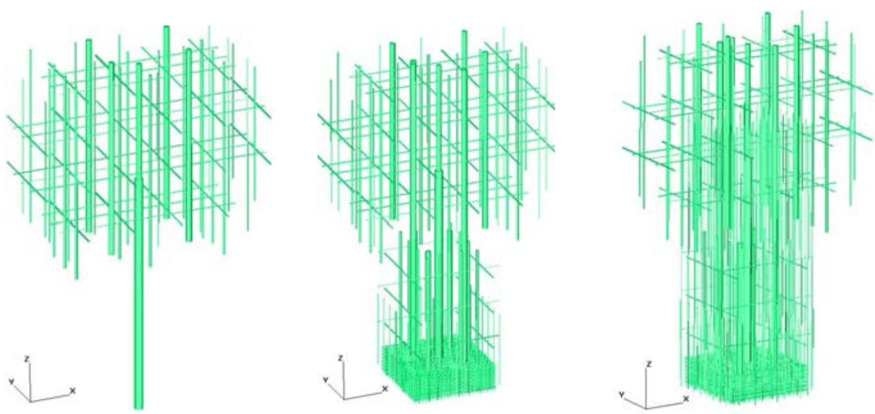
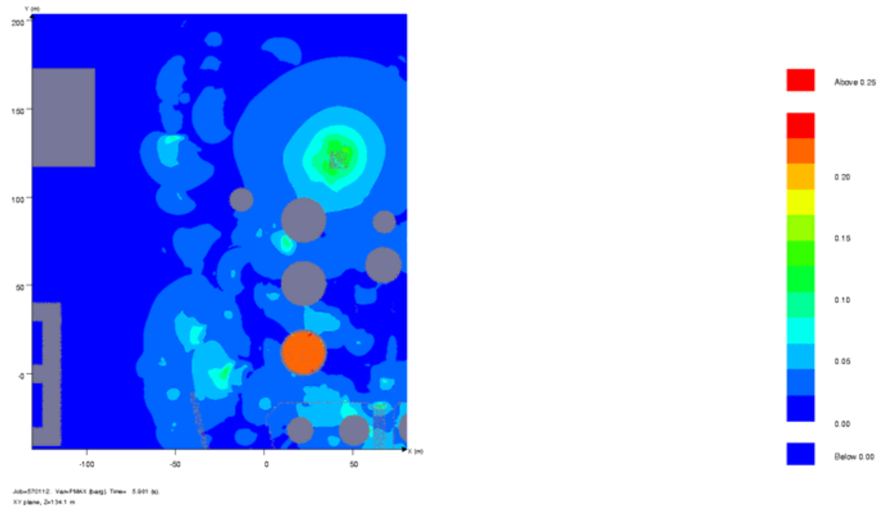


Photo of trees in Buncefield Lane, from Hertfordshire Fire & Rescue Service (HFRS)

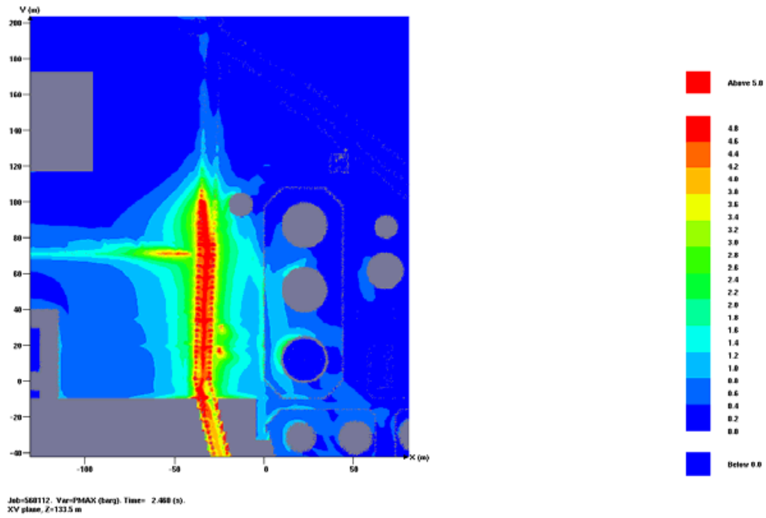
Normal, coppiced with undergrowth and enhanced density tree (ref. HFRS photo)



Maximum pressure for 5 m high cloud, without trees, and ignition at pump house



Maximum pressure for 5 m high cloud, with trees, and ignition at pump house



Preliminary conclusions

- In 2007, FLACS was used as a tool to simulate ignition and subsequent flame propagation and overpressure development at Buncefield
- High flame acceleration and overpressures were observed along the lanes which were congested by trees and undergrowth
- The simulations do not provide clear indications of the preferred ignition location – although it in principle could have been either the Pump house or the Northgate Emergency Generator, the damage assessment tends to favour the Pump house.

Preliminary conclusions

- The simulations with tree congestion included show explosion overpressures exceeding those required to explain the observed damage (reported by April 2008) in the car parks and buildings to the west
- Simulations without trees gave very low over-pressures
- These results support the main conclusion that trees provided congestion sufficient to accelerate a flame burning through a large cloud to high speeds, thus giving rise to significant over-pressures
- A paper describing the simulations by GexCon will be presented at the 2009 International Symposium: "Beyond Regulatory Compliance, Making Safety Second Nature", Mary Kay O'Connor Safety Center, October 27-28, 2009

Explosion experiments with flexible obstructions

Experimental setup

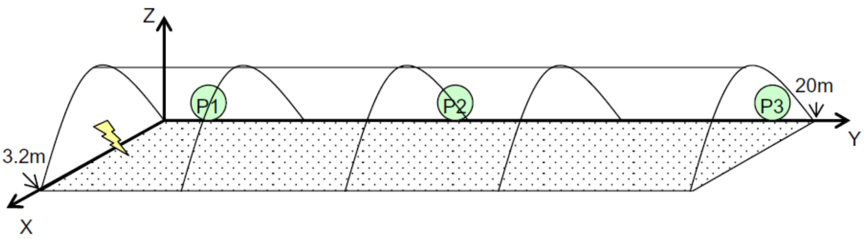


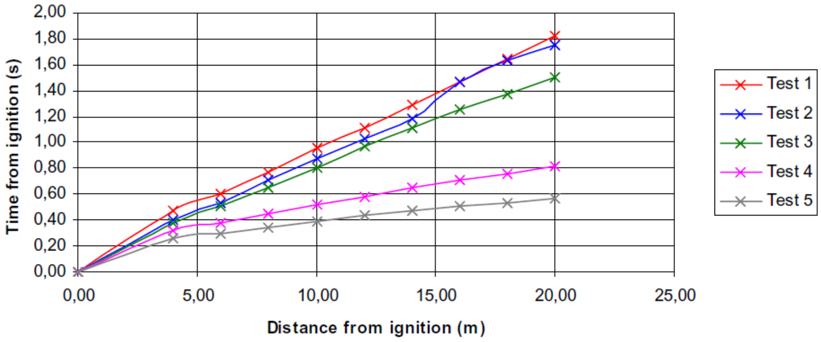
Figure 2.1 Schematic drawing of the experimental set-up used during this work showing the position of the ignition source and pressure transducers.

20 metres long tent (80 m^3), stoichiometric propane-air, 0.15 mm plastic sheet (stapled)

Flexible obstructions

Results

Flame speeds in the range 10-15 m/s in the initial tests (1-3), 30-40 m/s for one row of branches (test 4), and 50-60 m/s for two rows (test 5) – generally low explosion pressures



The full report from this work is available at: http://www.fabig.com/Publications/

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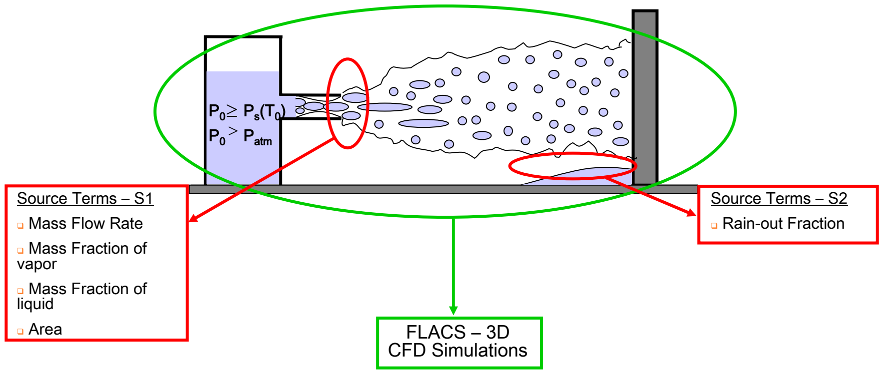
Ongoing R&D work

- Two-phase releases.
  - Two-phase jets
  - Pool spread
- Dust explosion experiments in full-scale coal mill
- Dust and gas explosions in a 3.6-m flame acceleration tube

Two-phase flow and flashing jets

- Improved modelling of two-phase jets in FLACS (PhD)



- Mixture of dry air, droplets and vapour
- Homogeneous equilibrium model + Evaporation of droplets
- Ongoing: Lagrangian description of droplets/particles

Two-phase flow and flashing jets

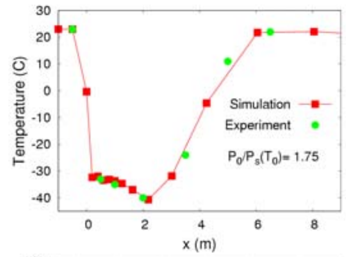
- Validation against FLIE-INERIS experiments

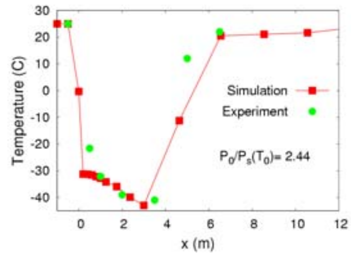
Impinging two-phase jet – from the INERIS test series report

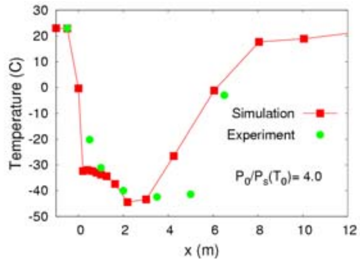
- 94 two-phase releases of propane and butane (free and impinging)
- Measurement of rain-out and droplets characteristics with PDA
- Measurement of temperature along the jet-axis

Two-phase flow and flashing jets

- Two-phase butane jets from INERIS tests - Temperature

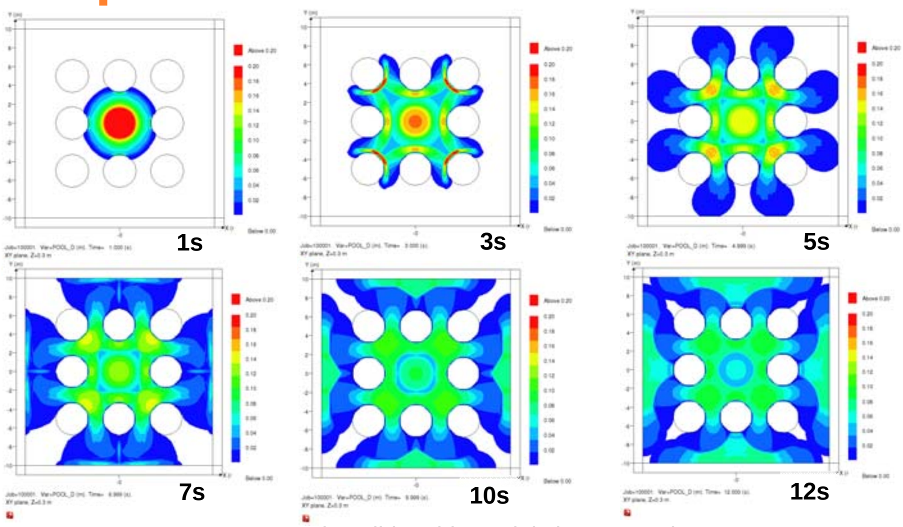






From: Ichard, M., Hansen, O.R., Melheim, J.A. (2009). Modelling of flashing releases around buildings. Proceedings of the 89th Annual Meeting of American Meteorological Society, Phoenix, AZ, 2009, Paper J14.2.

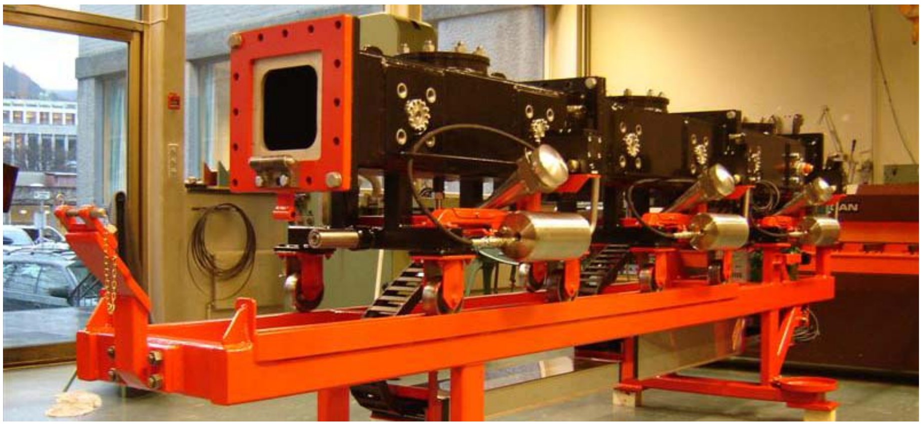
Spill in a tank farm model



A paper describing this work is in preparation

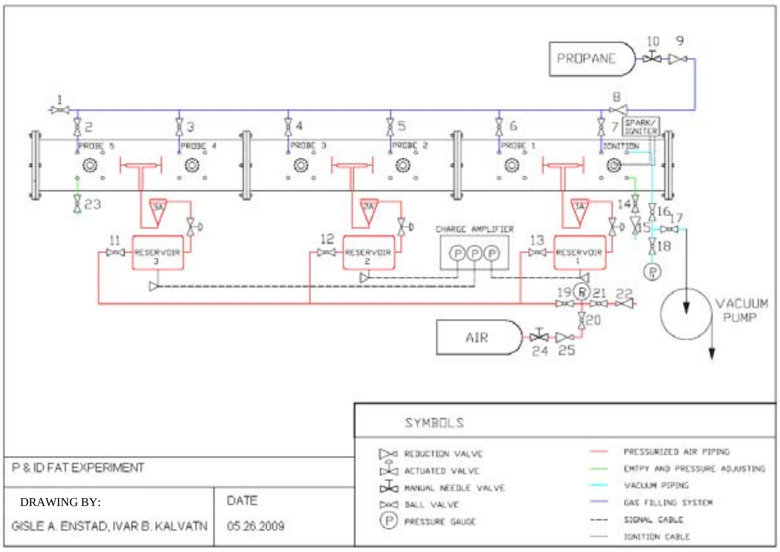
Explosion experiments in full-scale coal mill

Explosion experiments in Flame Acceleration Tube

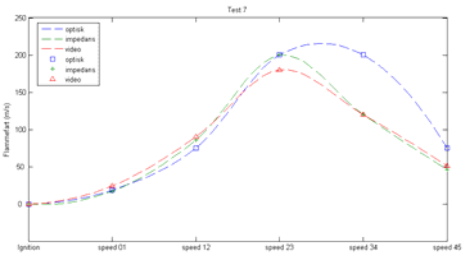


Flame probes (ref. glass tube experiment)

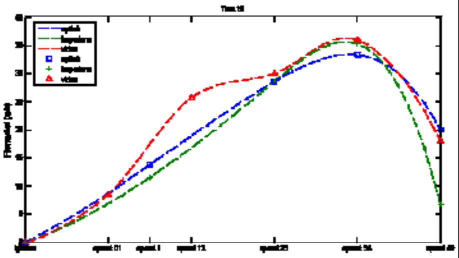
The Flame Acceleration Tube



Some preliminary results



Propane-air mixtures



Clouds of maize starch in air

This work is currently ongoing, but a work in progress poster will be presented at the 22nd International Colloquium on the Dynamics of Explosives and Reactive systems, (ICDERS), 27-31 July 2009, Minsk, Belarus.

Future prospects

- Wind energy
  - Marine boundary layer (wind-wave interactions)
  - Energy capture (subgrid models)
  - Wind farm optimization
- Joint Industry Project (JIP)
  - 'FLACS 2011 and beyond'

NORCOWE

Norwegian Centre for Offshore Wind Energy

Organized in five work packages (WPs):

WP1 – Wind and ocean conditions

WP2 – Offshore wind technology and innovative concepts

WP3 – Offshore deployment and operation

WP4 – Wind farm optimisation

WP5 – Common themes

- Education
- Safety
- Environment
- Test facilities and infrastructure

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Wind and ocean conditions WP1

Climatology of met/ocean conditions:

- Optimize wind farm location
- Downscaling and reanalyses

Modelling the marine boundary layer:

- Implementing and validating MBL models
- Boundary conditions and terrain/sea
- Publications and presentations

MBL = Marine Boundary Layer ('surroundings')

Short-term forecasting (1-2 days)

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Offshore wind technology and innovative concepts WP2

Dynamic response

Wind energy capture:

- Subgrid models for wind turbines
- Energy capture and wake effects
- Validation against experiments

Innovative concepts

Component and systems development

Reliability and lifetime

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Offshore deployment and operation WP3

Asset management

Single turbine control systems

- Relevant input to Energy Capture (WP2.2), and Nowcasting (WP4.1)

Remote operations

Marine operations

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Wind farm optimisation WP-4

Nowcasting (2-120 s)

- Possible link to control systems & CFD

Power systems integration

Wind farm modelling

- Couple FLACS-Wind to meteorological mesoscale models and optimizing procedures
- Validate FLACS-Wind for onshore and shallow water wind farms
- Provide guidelines for offshore wind farms

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Common themes WP5

Education
- PhD and Master programs, Nordic research school, Summer schools

Safety
- Shipping lanes, collisions, decision support

Environmental impact assessment
- Effect on bird life and local pelagic and benthic ecosystems

Test facilities and infrastructure
- Pilot testing to support technology development and research

Modelling challenges

Complex physical phenomena
- Anisotropic turbulent flow
- Broad spectrum of ocean waves
- Dynamic system, many degrees of freedom

Large range of length and time scales
- Sea spray and capillary waves
- Tower, nacelle, and turbine blades
- Ocean waves: capillary to ocean swell
- Turbulence structures and wake effects
- Full-scale offshore wind farms

Calculation efficiency!

Appropriate subgrid models!

Joint Industry Project

- Three work packages:
  - Enhanced performance – parallelization, etc.
  - Release and dispersion – modelling and validation
  - Explosion consolidation – modelling and validation
- Three year duration
- Prospective sponsors:
  - StatoilHydro, Total, Exxon Mobile, IRSN, …

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