

# TECHNICAL SPECIFICATIONS



**CougarFlow™**

AHM & Uncertainty Analysis  
for Reservoir Simulations

## Software Presentation

Through a multiple realizations approach based on experimental design and state of the art optimization algorithms, CougarFlow aims at reducing the number of simulation runs to properly explore the possible solutions. CougarFlow is usable for any type of numerical simulation at both basin and reservoir scales. CougarFlow allows:

- A thorough screening of uncertainties on a given range of input parameters and their influence on key simulation outputs;
- Uncertainty analysis for quantifying parameters impact and associated optimization;
- Rapid and robust Assisted History Match offering both a fast converging gradient method (local optimizer) and a thorough Bayesian approach (global optimizer).

## Functionalities and Algorithms

### MANAGEMENT OF UNCERTAINTIES

#### UNCERTAIN PARAMETERS

- Scalars such as end points for KrPc curves, WOC...
- Possibility to group parameters with metaparameter option

#### EXPERIMENTAL DESIGN AND RESPONSE SURFACE APPROACH

- From the simplest to the more complex: Classical, Full, User defined, Latin Hypercube and D-Optimal designs for uncertain domain sampling
- Responses of interest:
  - Direct outputs of the simulator (pressures, rates...)
  - Customized responses: multi-time/multi-property/multi-object functions, interpolated, scalar and multi-objective functions (decomposition well by well, property by property), composite responses (R script language to create user defined responses, NPV...)
- Algorithms to compute Parametric (Least Angle Regression Square) and Non-Parametric Response Surface Models (Kriging)
- QC tools to analyze and validate the Predictivity of Response Surface Model: Spider and Tornado plots, Cross plot and Quality Indicators such as Predictivity Q2 and Predictivity with confirmation runs Q2 conf (blind tests)

#### UNCERTAINTY ANALYSIS

- **Global Sensitivity Analysis:** qualitative and quantitative sensitivity analysis to determine the most influential parameters; automatic calculation of interactions between parameters
- **Risk Quantification:** uncertainty propagation and controllable uncertainty optimization
  - **Field Appraisal:** assess the impact of uncertain uncontrollable parameters on the production uncertainty profile
    - > **Bayesian formalism** to constrain the uncertainty by historical data (posterior sampling using Markov Chain Monte Carlo)

- **Field Development Optimization:** determine the optimal production scheme; optimize controllable production parameters
- **Decision Making:** choose the best production scenario with the full knowledge of geological, modeling and financial uncertainties

### OPTIMIZATION ALGORITHMS

- Objective-function based optimizations:
  - User defined weight definition, standard deviation
  - Possibility to manage every history point and weight
  - Possibility to create composite objective function
  - Possibility to add water breakthrough time to objective function
- Possibility to define constraints between uncertain parameters
- Possibility to optimize both geological and dynamic models
- Three methods for optimization are available:
  - 2 Gradient-based methods<sup>(1)</sup>
  - Bayesian algorithm<sup>(2)</sup>

<sup>(1)</sup> 2 Gradient based methods: Optim (Cougar's historical method) and SQPAL (to avoid non-physical fluid flow models)  
Five algorithms implemented from the simplest to the more complex for local optimizer:

- **Steepest Descent (Optim):** robust, particularly suited for solving non-linear problems, cases where the initial value is far from the optimal solution; may become less and less efficient when it approaches the solution.
- **Gauss-Newton (Optim):** good convergence rate (quadratic), efficient in most cases; less robust for highly non-linear problems and when the initial parameters are too far from the optimal solution
- **Levenberg-Marquardt (Optim and SQPAL):** extension of the Gauss-Newton method; good when the initial point is far from the solution, numerical stability; needs to define a suitable initial value of the Marquardt parameter
- **Powell dog-leg (Optim and SQPAL):** improvement of the previous algorithm; robust and quick; combines the Steepest-Descent and Gauss-Newton solutions according to a trust region in the parameter domain; the radius of the trust region is adjusted with respect to the evolution of the objective function
- **BFGS (SQPAL):** quasi-Newton method of Broyden, Fletcher, Goldfarb, and Shanno; uses the first derivatives only to approximate the Hessian matrix of the used function; good performance for non-smooth optimizations; to use for large datasets only

<sup>(2)</sup> Global optimizer: based on Bayes formula; iterative optimization process based on Response Surface and posterior (parameter distribution that matches the production data); getting a set of matched models.

- Analysis of HM: percentage of matching well by well and property by property, bubble maps

## EXTRAS

- Linked to any reservoir simulator: PumaFlow™, Eclipse™, Petrel-RE™, VIP/Nexus™, CMG IMEX/GEM/STARST™, Powers™
- Seamless link with FracaFlow™
- Link with third-party geo-modelers: Petrel™
- Link with material balance tool: MBAL™
- Flexibility from Uncertainty to AHM workflows
  - Initialize an AHM workflow from the sensitivity analysis results. Only influential parameters can then be optimized to save simulation time
  - Possibility to pursue after an initial optimization adding parameters, modifying the Objective Function
  - Define and analyze several OF before launching the AHM procedure

## Results Analysis

- Many viewers are available: histograms, cross-plots, graphs, logs, maps, cross-sections, 3D inherited histograms OpenFlow platform
- Filters and graphic settings
- Specific plots for uncertainty analysis: cross-plots, tornado plot, spider plot, Pareto plot
- Objective Function Analyzer (OF contributions, percentage of matching)
- Bubble maps

## Data Management

### DATA IMPORT/EXPORT

The following formats are available:

- Well paths and logs in ASCII columned, LAS 2.0 and 3.0
- Well/Trap/Group/Reservoir dynamic data (production/injection history, flowmeter, RFT, well tests, etc.) in ASCII, RSM and OFM (.prd)
- Well pressure and perforation data in ASCII
- 3D grid in GRDECL and EGRID format
- Rescue models in ASCII or binary (version 37) and ResQML 2.0 import
- Reservoir simulation results ASCII or binary format
- Templates, preferences and color scales from OpenFlow
- Groovy scripts & packages
- Data exchange between OpenFlow Suite projects

### DATABASE

- MySQL or Oracle database
- Improved data security and integrity, reduced data storage
- User and project administration

### OTHER FACILITIES

- Unit system management
- Workflow manager: create, delete, configure, start, stop, load, restart, monitor a workflow...; manual and automatic launch/stop/restart/load
- Help through an online reference manual and contextual information
- Search tool
- Perspectives for display
- Workflow tree
- Host & Activity settings

## Extensions and Customization

- Direct link to transfer data between Petrel and OpenFlow using an Ocean plugin
- Scripting facility based upon Groovy language
- Scripting facility based upon Freemarker language for customization of the reservoir-simulation input data
- Generate KrPc tables from Corey coefficients, call different property maps, automatic schedule writing to optimize surfactant/polymer injections, generic cycles

## System Requirements

- **Operating Systems:**
  - Windows Seven 64 bits service Pack 1 and Windows 10
  - Linux RedHat 6.6
- **RAM:** 16 Gb or more recommended, 8Gb minimum
- **Minimum free disk space:** 5 Gb (for installation)
- **CPU:** x86-64 processors (Opteron, CoreDuo, Core2Duo, Xeon & EMT64, Nehalem, Westmere, Sandy Bridge, Core i3, i5, i7)
- **Dualcore or Quadcore:** 2 GHz or more recommended
- **Graphics board:** NVIDIA (except Quadro FX 1000, Quadro FX 3500, Quadro NVS 110 M and Quadro NVS 280 SD) with recent driver (at least OpenGL 3.3 -driver 330 or later)
- Openmotif rpm package must be installed on Linux
- **Database:** MySQL 5.5 or 5.6.X (with X superior to 22) and Oracle 11g or 12c
- FlexLM 11.13.1.3 server for licensing



**Beicip-Franlab Headquarters**  
232, avenue Napoléon Bonaparte  
92500 Rueil-Malmaison - France  
Tel.: 33 1 47 08 80 00  
Email: [info@beicip.com](mailto:info@beicip.com)

**BeicipFranlab**   
An IFP group company