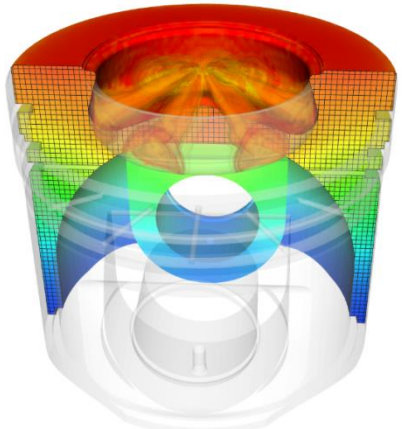
Introduction of new feature of CONVERGE Studio 2.3

Your True Partner for CAE&CFD

IDAJ CAE Solution Conference

ICSC2015

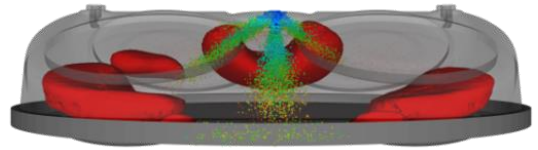
Gallery cooling with VOF



Conjugate heat transfer analysis of Diesel engine

CONVERGE CFD SOFTWARE

Who are we?



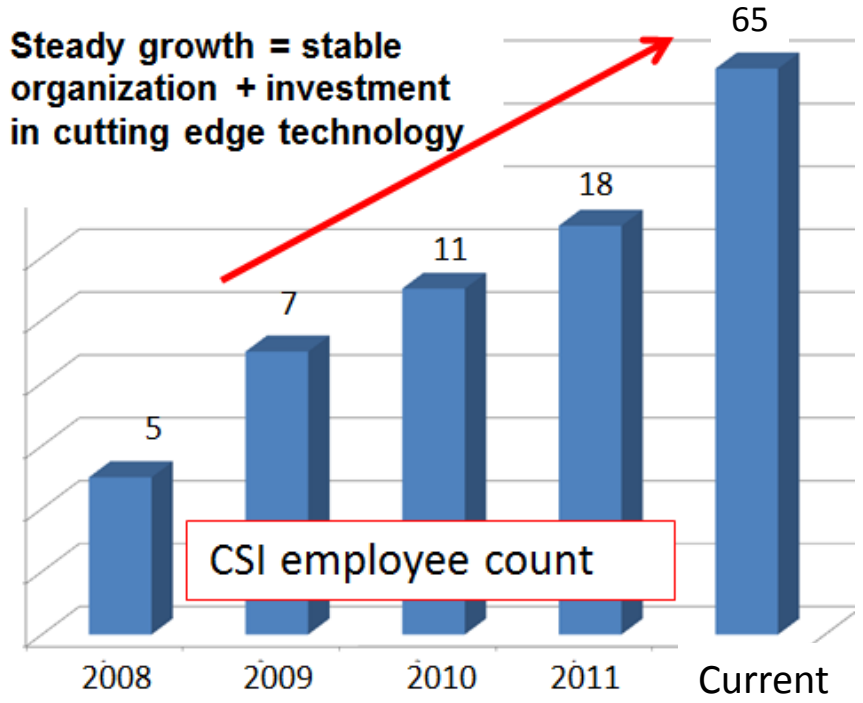
Auto-ignition locations (red) and liquid spray droplets for dual fuel engine. Courtesy Chrysler LLC

- Convergent Science Inc. (CSI) was founded in 1997
- Experts in CFD modeling of turbulent flow, spray, combustion, heat transfer and optimization
- Developers of CONVERGE: commercially available since March 2008
- Extensive academic program
- CSI partners with thought leaders including:
  - US: Argonne National Lab, LLNL, Sandia and Oak Ridge National Lab
  - Europe: IFPEN, CMT

Convergent Science Inc. headquarters in Madison, Wisconsin

- *Long meshing time*
- *Course mesh (grid dependent)*
- *Empirical physical models*
- *Extensive tuning*

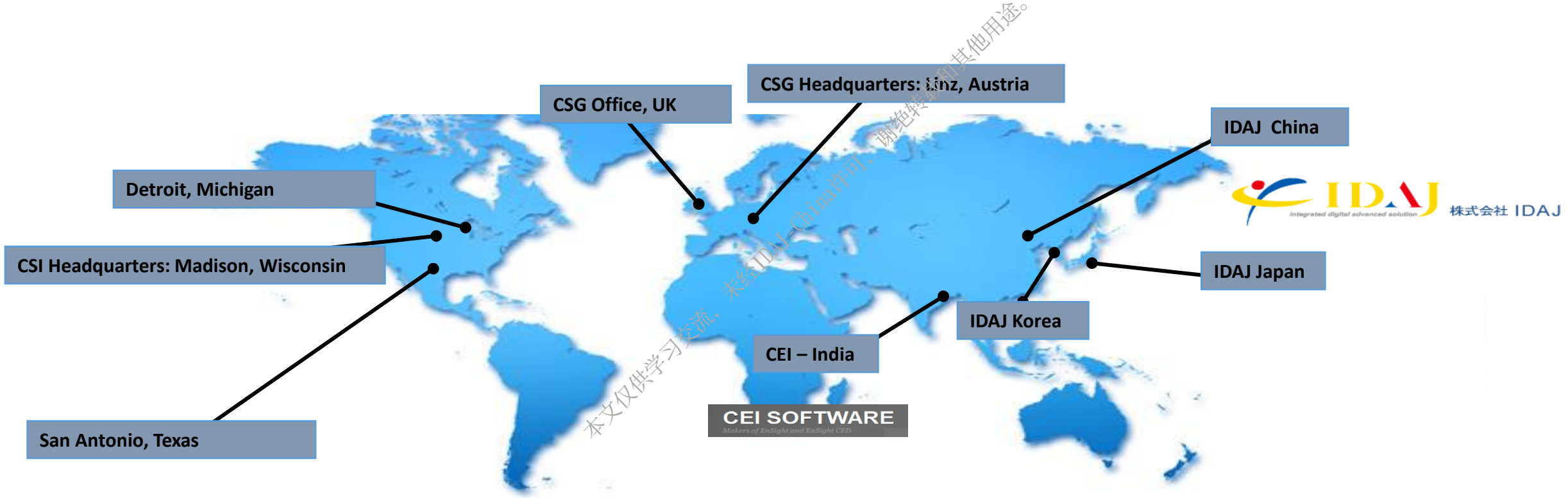
How we used to do CFD



CONVERGE CFD SOFTWARE

Corporate Highlights

- 2013: IDAJ becomes the official distributor of CONVERGE in China, Korea and Japan
- 2014: Convergent Science Gmbh (CSG) formed to sell and support CONVERGE in Europe
- 2015: CSI opens office in Detroit area

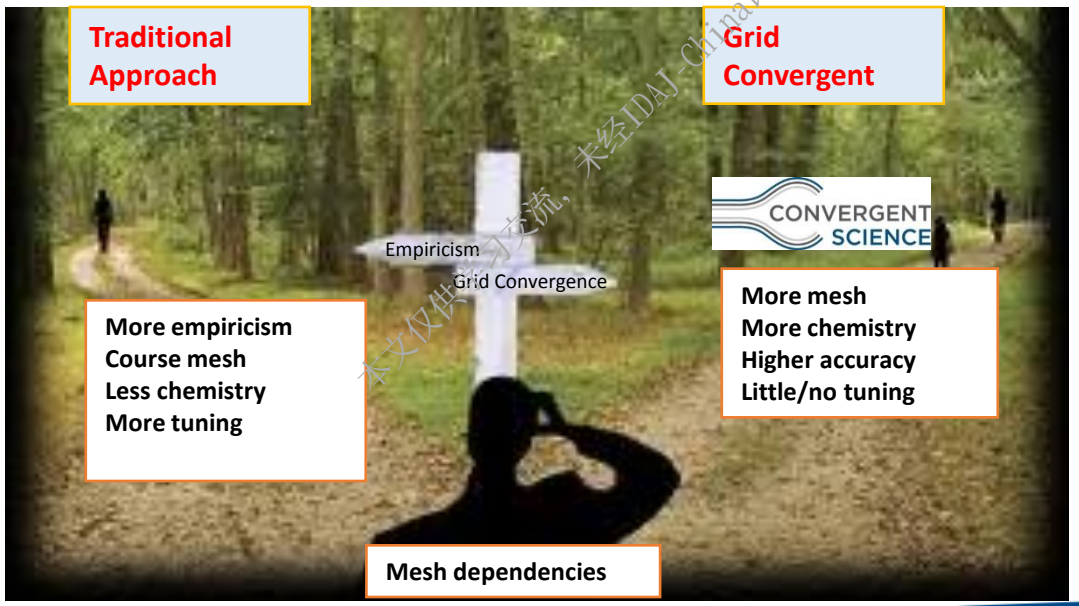


Convergent Science sales and support network

What do we do?

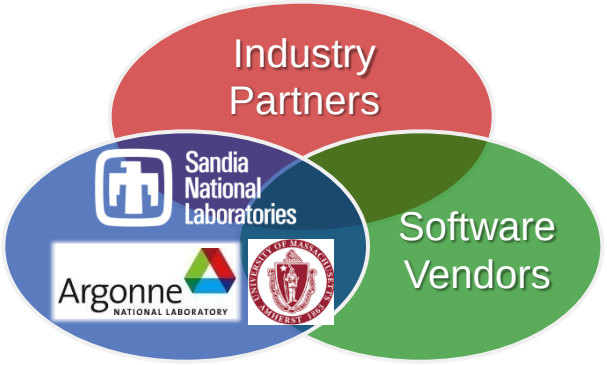
- CONVERGE CFD software was developed with the goal of simultaneously increasing both productivity and accuracy for modeling flow, spray and combustion
  - Generates a high quality mesh automatically at runtime thus eliminating all user meshing
  - Adds mesh refinement when and where it is needed to minimize mesh effects (Grid Convergent Modeling)
  - Has a rich suite of physical models for spray, combustion and turbulence
  - Can readily handle all engine types (Diesel, natural gas, gasoline, two or four stroke, rotary engine or reciprocating)
  - Extensive user defined functions (UDF) allowing user to add physical models and custom output
- Genetic algorithm included which automatically spawns CONVERGE simulations for optimization

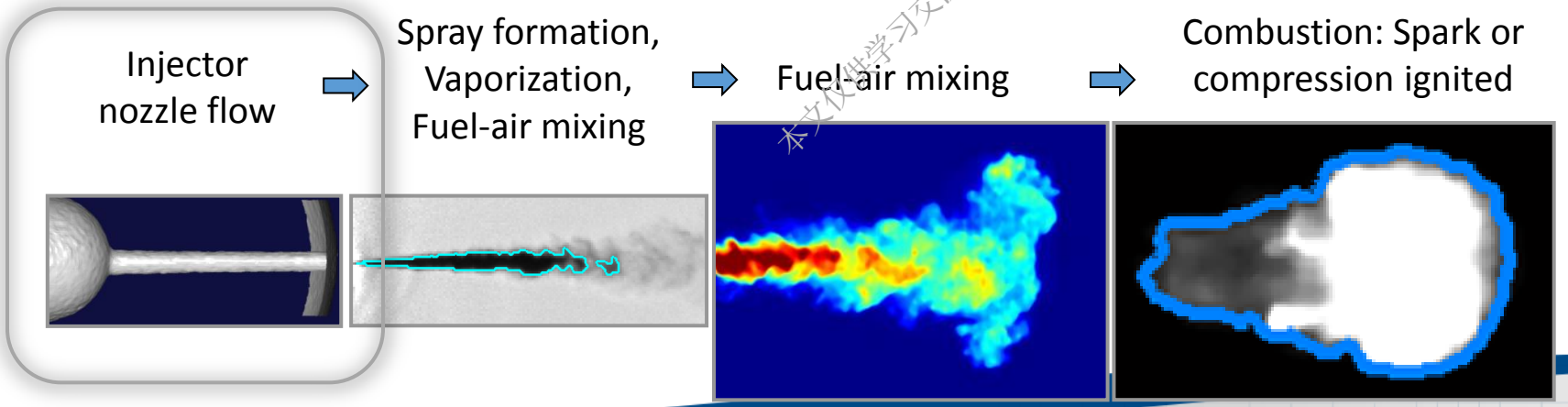
"If you change your mesh, does it change the results?"



Partnership with Sandia National Lab

- Sandia National Laboratory has formed a spray combustion consortium (SCC) which will officially kick off soon
- CSI was thrilled to commit to joining this consortium
- The goal of this consortium is to develop predictive spray models linked to transient internal nozzle flows.
- Supported by OEMs, suppliers, software vendors
- Experiments in real-scale transparent nozzles at realistic conditions.
- High-fidelity and engineering-level simulations to incorporate key physics.
- Coupled spray models released by software vendors for combustion design development.





COMBUSTION RESEARCH FACILITY

CONVERGENT SCIENCE

Collaboration with Argonne National Laboratory

What Virtual Engine Research Institute and Fuels Initiative (VERIFI) Offers:

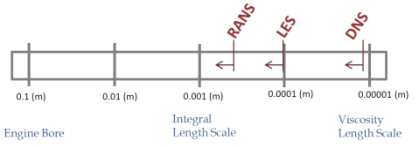
- High-performance computing—enables a paradigm shift in engine CFD
- Uncertainty analysis for engine simulations
- New low-temperature combustion concepts
- Design-optimizing simulations to reduce cost and shorten development cycles
- Argonne's capabilities in combustion chemistry, engine modeling, math/computer science, and facilities for computing/testing

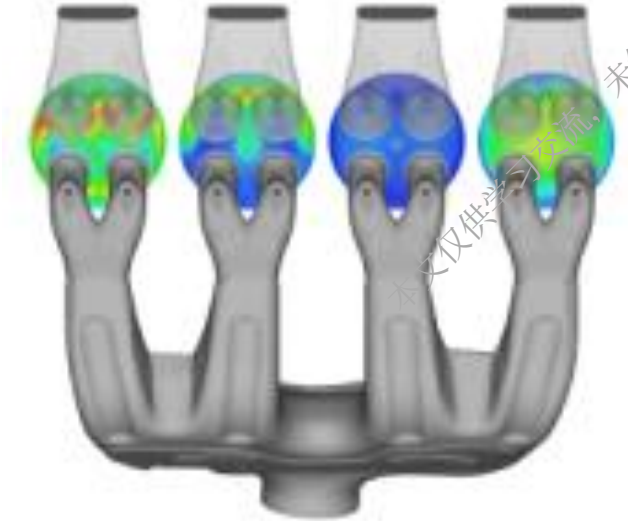
Industry partnerships—to date, with Caterpillar, Cummins, Convergent Science, Navistar, GM R&D, Fiat Chrysler, DENSO, …

Winner: 2015 Federal Laboratory Consortium Award for Excellence in Technology Transfer

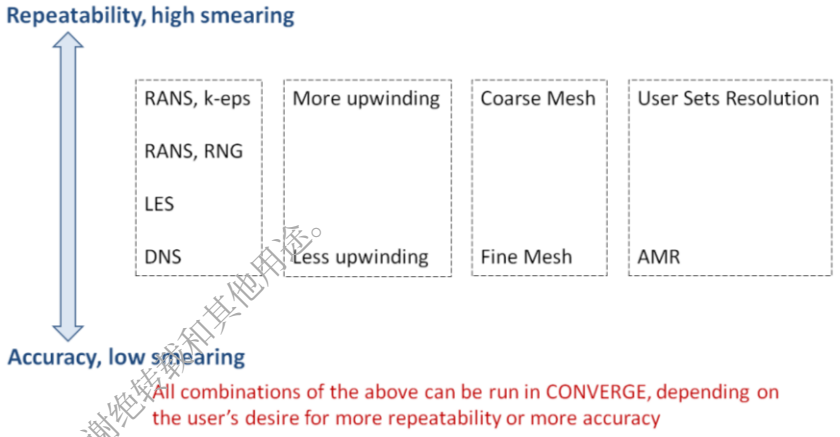
Accuracy vs Repeatability

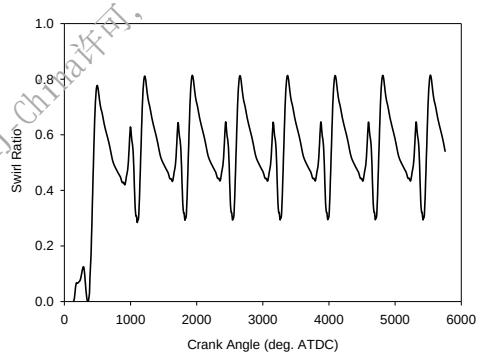
- Running multiple cylinders and multiple cycles to study cycle to cycle variations is becoming very common with CONVERGE
  - Very important for GDI engines
  - Very important for auto-ignition studies
- This brings up an important tradeoff between repeatability and accuracy
  - Repeatable results require fewer cycles, yet missed important phenomena
  - Accurate results require more cycles to be run.
- CONVERGE can be run in either mode: highly accurate (recommended) or repeatable



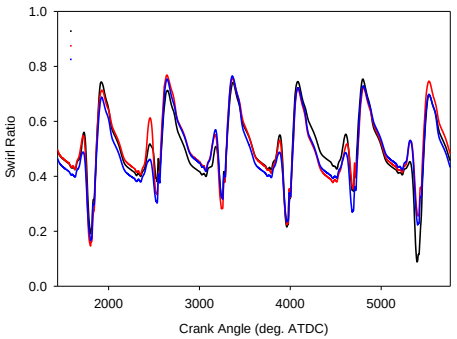


Multiple cylinder simulation
Courtesy Chrysler

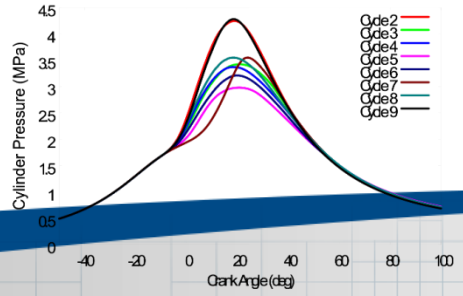




Repeatable solution (no cycle to cycle variations)



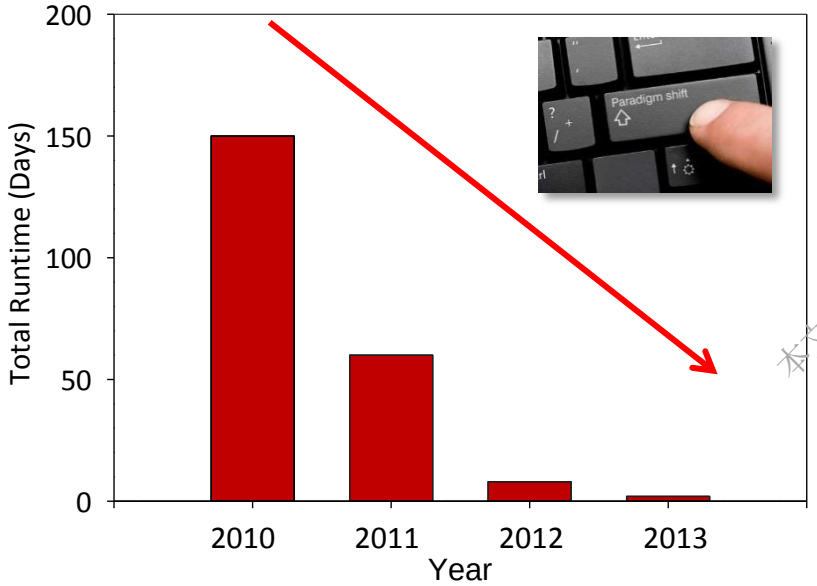
Accurate solution showing cycle variations



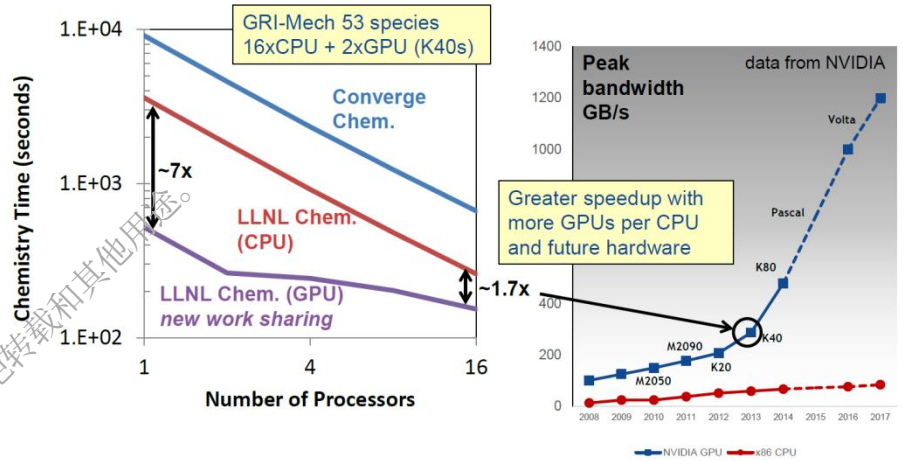
CONVERGE CFD SOFTWARE

Collaboration with LLNL

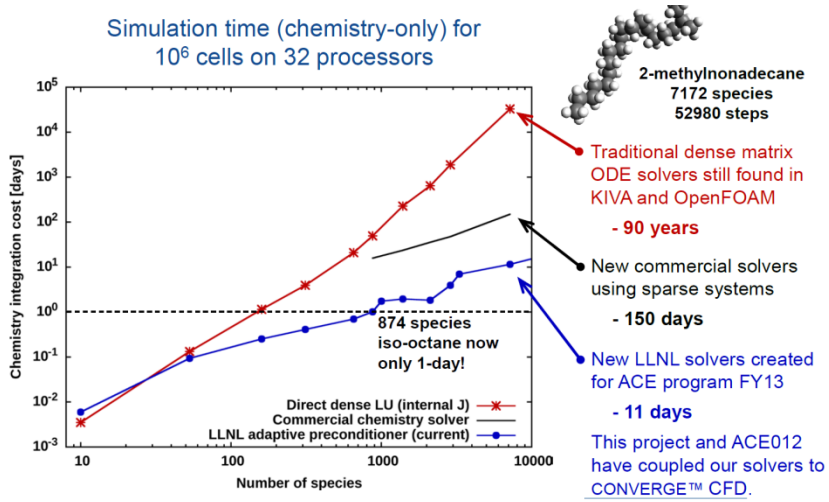
- CSI is thrilled to be partner with LLNL
- Detailed chemistry solver speedup
  - Multi-zone model for chemistry speedup
  - New chemistry solver available in v2.2
  - The goal is for detailed chemistry to be as fast (or faster) than empirically based combustion models
- GPU processing of chemistry (first version available as a UDF in v2.3)



Reduction in run time associated with detailed chemistry



Lawrence Livermore National Laboratory

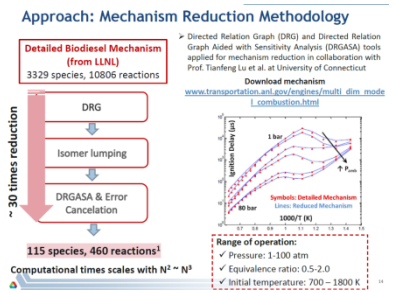


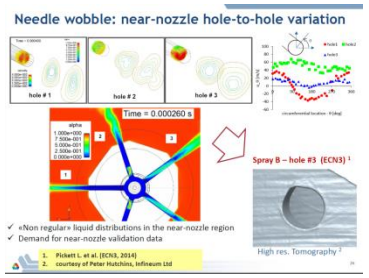
Model Development and Analysisof Clean & Efficient Engine Combustion (ACE012)

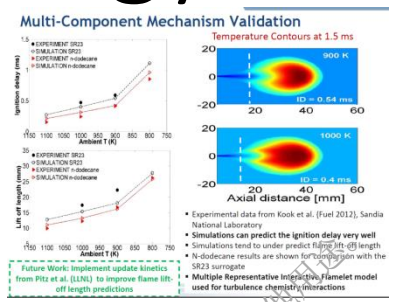
CONVERGE CFD SOFTWARE

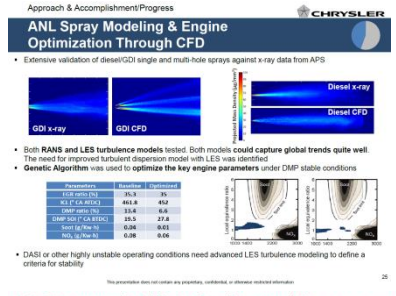
Department of Energy Merit Review

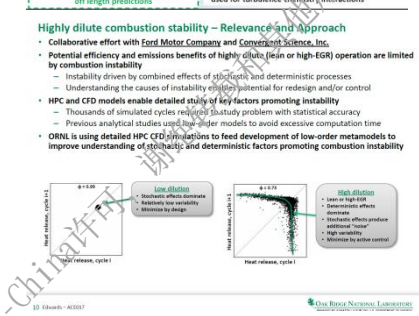
- Topics include: Optimization, spray modeling, nozzle analysis, cyclic variability, mechanism reduction, soot modeling, chemistry speedup, pre-chamber engine, LES, cavitation, GPU processing, Diesel engine, Gasoline engine

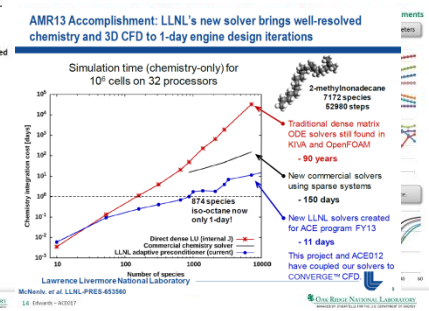


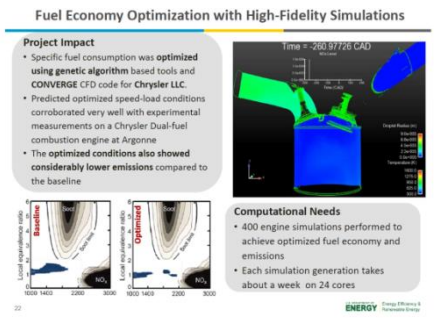


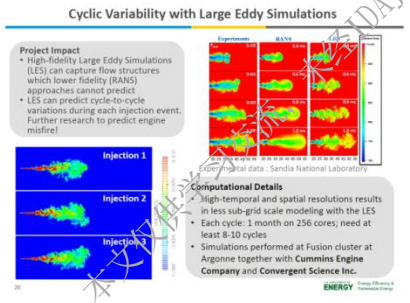


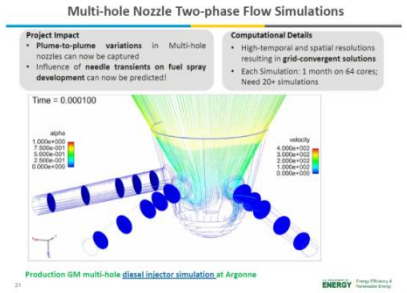


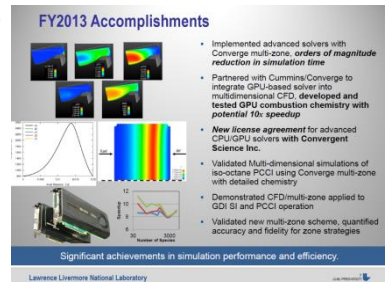


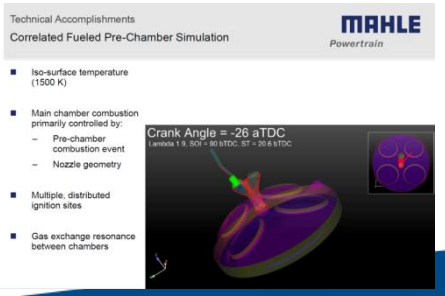


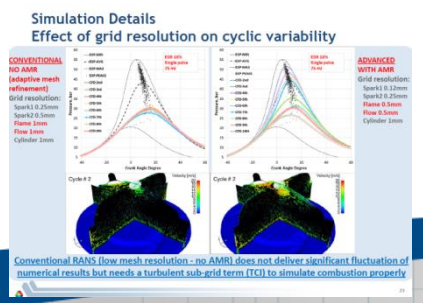


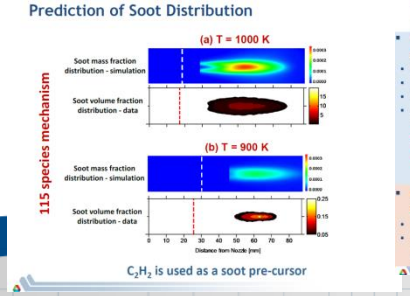


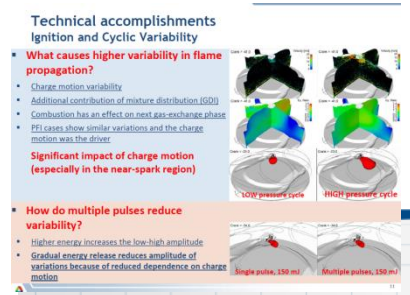










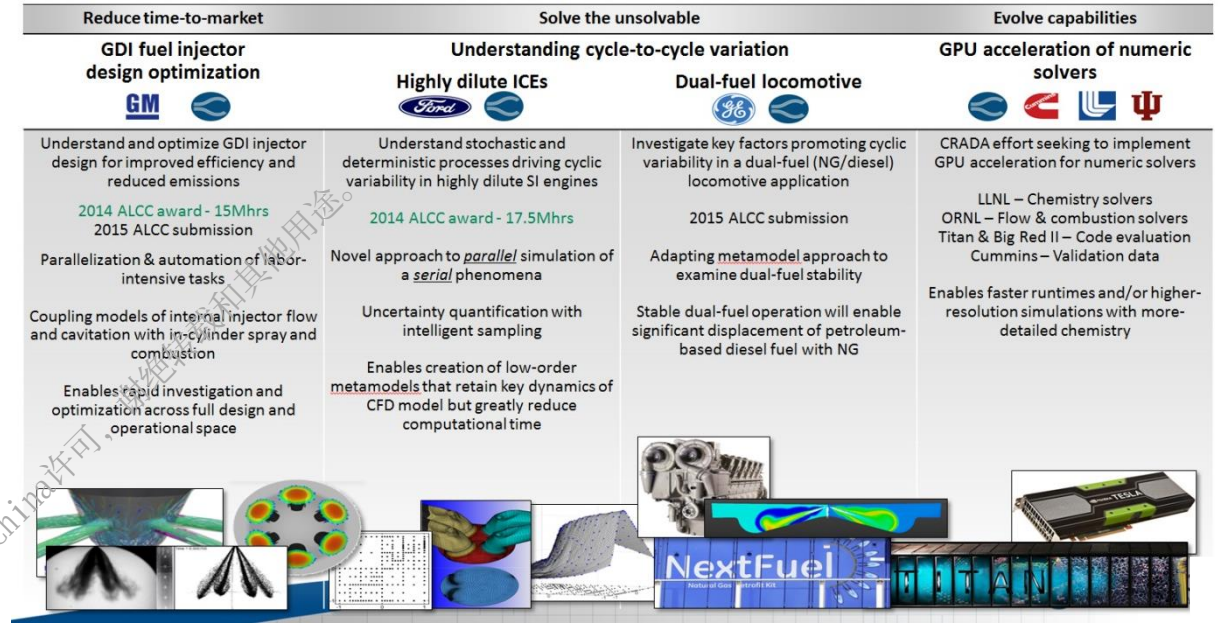


http://energy.gov/eere/vehicles/vehicle-technologies-office-annual-merit-review-and-peer-evaluation

CONVERGE CFD SOFTWARE

Collaboration with ORNL

- CSI is thrilled to be partner with Oak Ridge National Laboratory
- Various multi-year DOE funded projects are underway with the goals of:
- Convergent Science collaborates with:
  - GM (fuel injector optimization)
  - Ford (Highly dilute spark ignited engines)
  - GE (Dual fuel locomotive engines)
  - Cummins (Reduced runtime for chemistry)



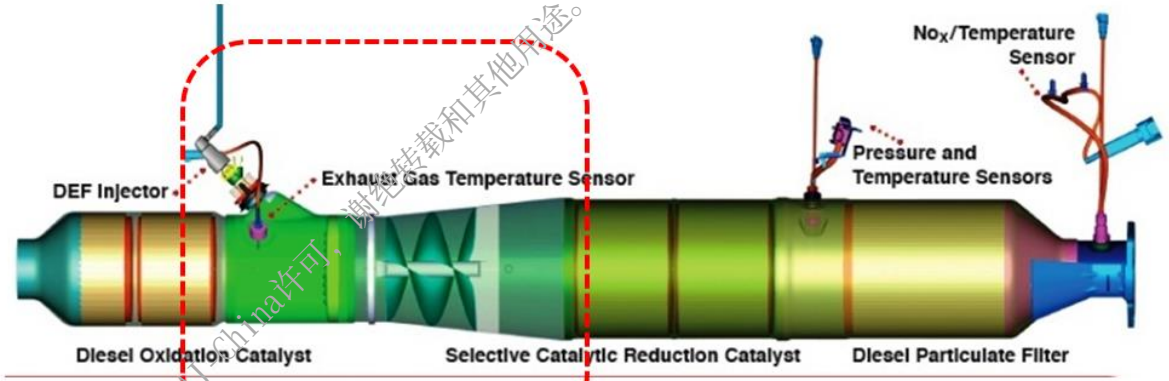
Accelerating predictive simulation of IC engines with high performance computing (ACE017)

IFPEN Development Partnership

- Convergent Science recently formed a development partnership with IFPEN in Paris
- IFPEN will assist in implementing their physical models into CONVERGE
  - IFPEN ECFM combustion models available in early 2016
  - Urea chemistry and deposit formation (2016)
- IFPEN will use CONVERGE exclusively for RANS engine calculations
- Utilize IFPEN's extensive experimental database for validation work

After-Treatment (SCR/Urea) Modeling

- Complicated geometries
  - No-User Meshing and AMR
- Detailed chemistry
- Turbulence models
  - RANS and LES
- Atomization models
  - Liquid breakup
  - Spray-Wall Interactions
  - Liquid filming/evaporation
  - Urea wall deposition ← Collaboration with IFPEN
- Catalyst simulation



Urea modeling is an important topic for CSI

Birkhold Spray-Wall Interaction Urea Test Case

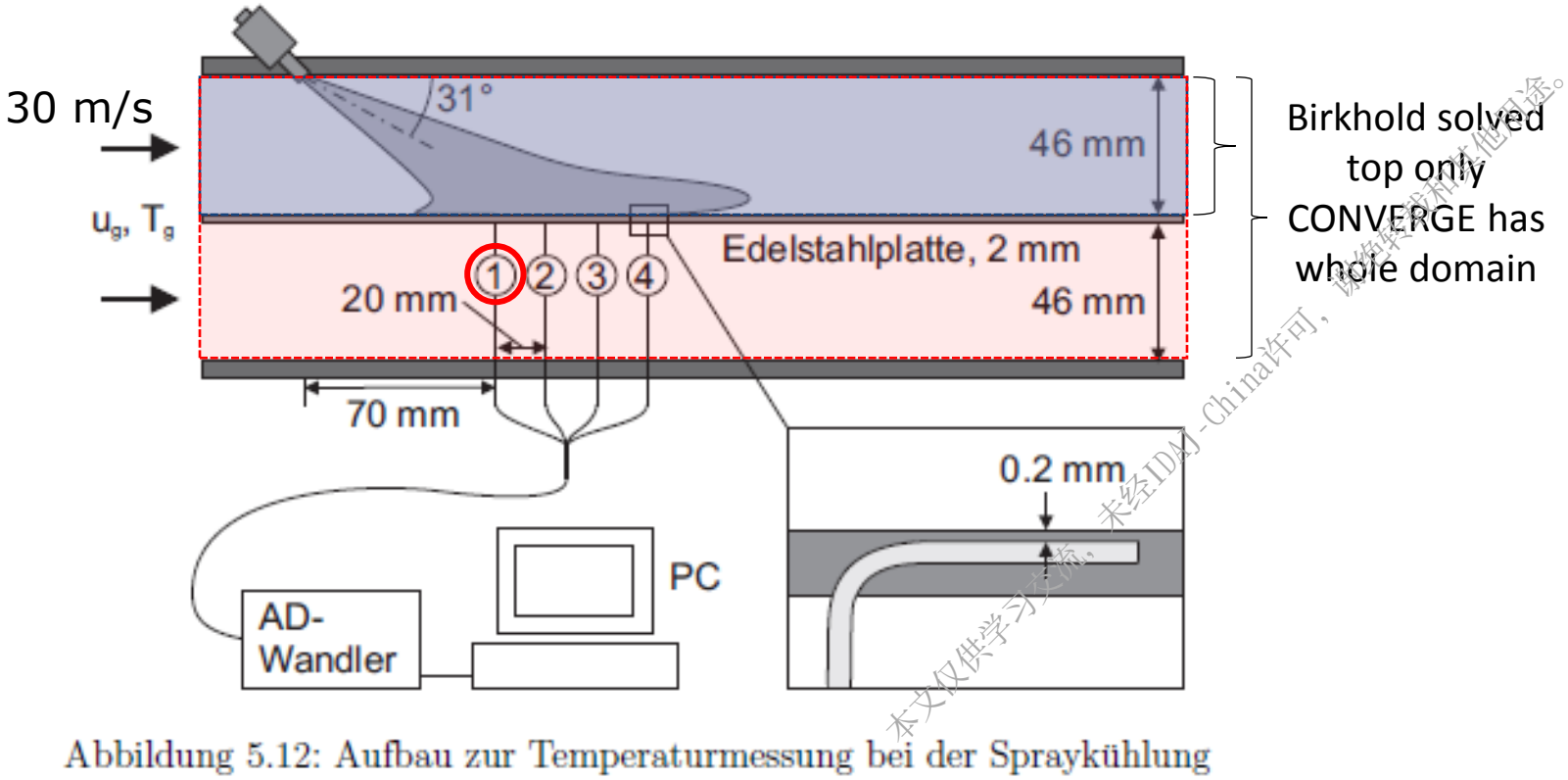


Abbildung 5.12: Aufbau zur Temperaturmessung bei der Spraykühlung

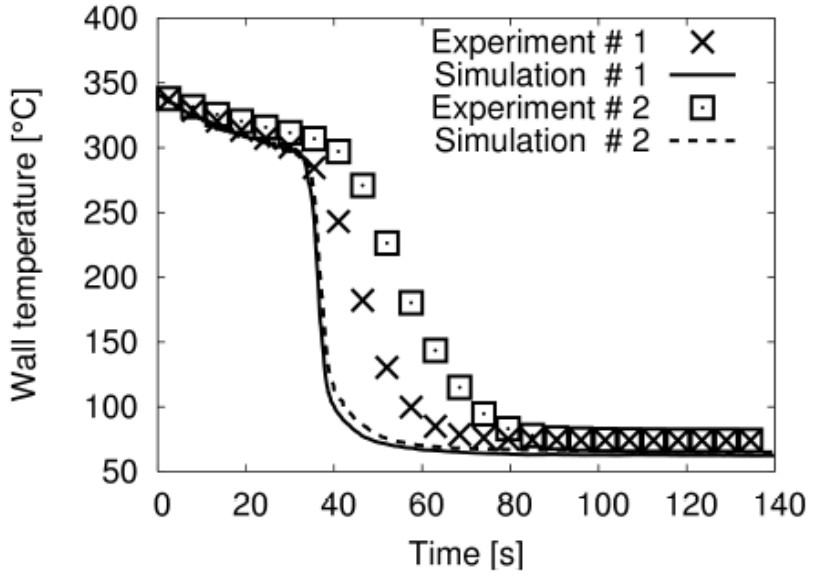
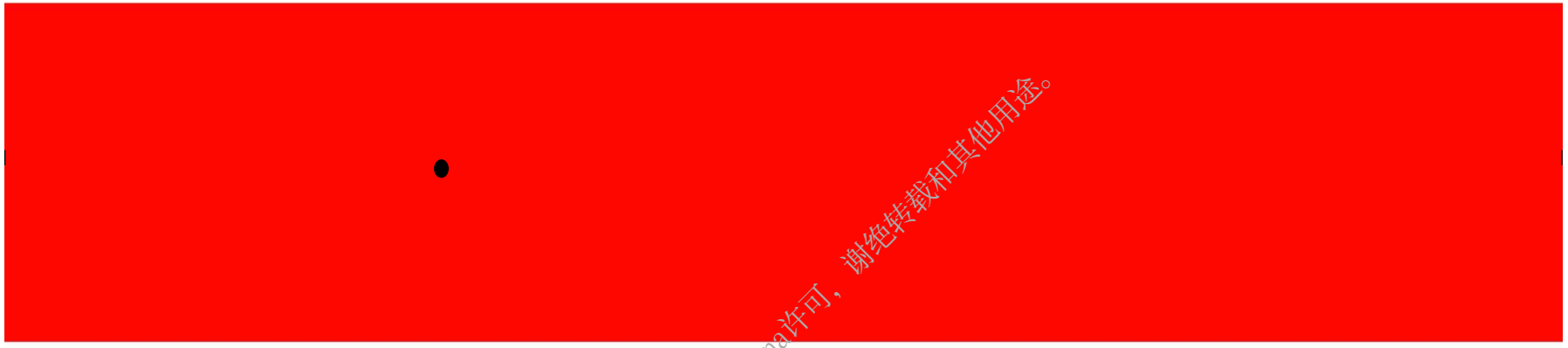
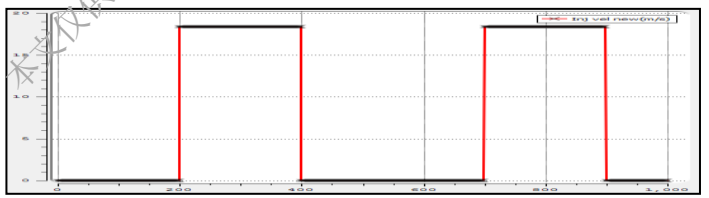


Figure 11: Measured and simulated evolution of wall temperature with wall film formation for positions # 1 and # 2, $\dot{m}_{inj} = 3.72\ kg/h$, $T_g = 340°C$.

Birkhold Spray Wall-Interaction Results



Pulse spray profile



Experimental wall temperature = 345 K
Multi-component model used (same results found for molten solid)

Comparable Film Height Predictions

FIRE (Birkhold 2006)

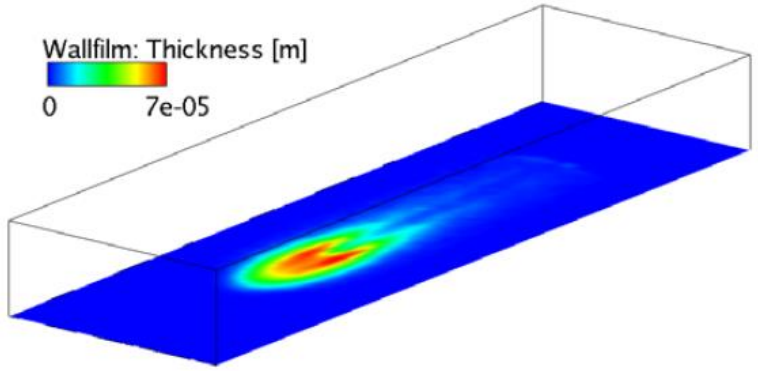
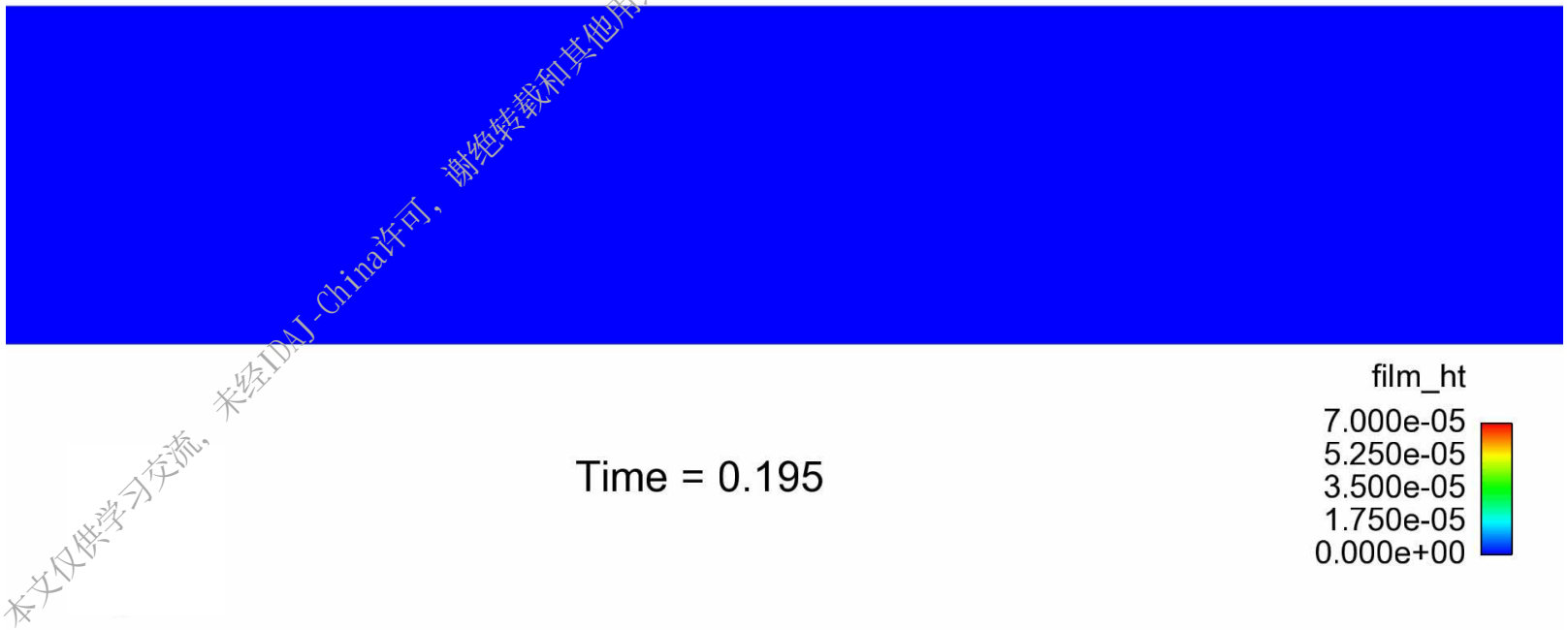
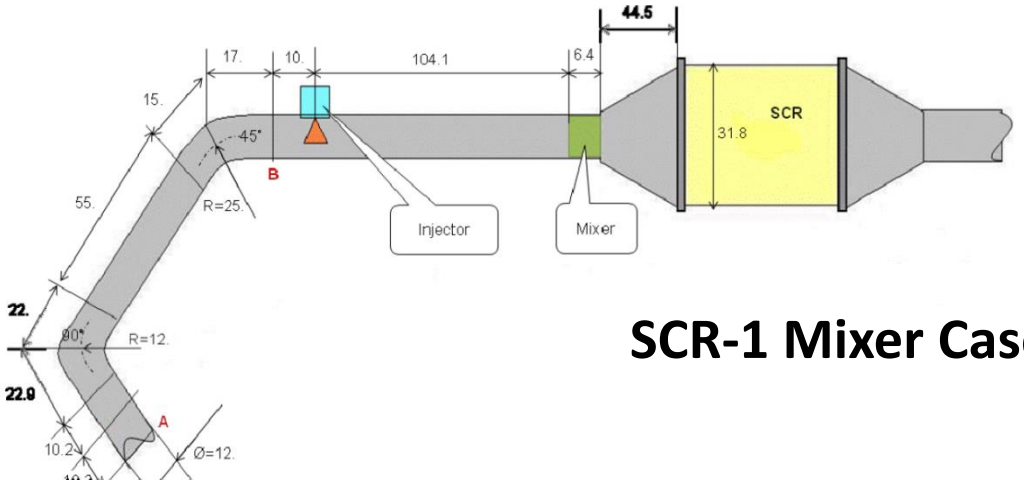


Figure 13: Predicted wall film thickness, $m_{inj} = 0.83\ g$, $T_g = 340°C$.

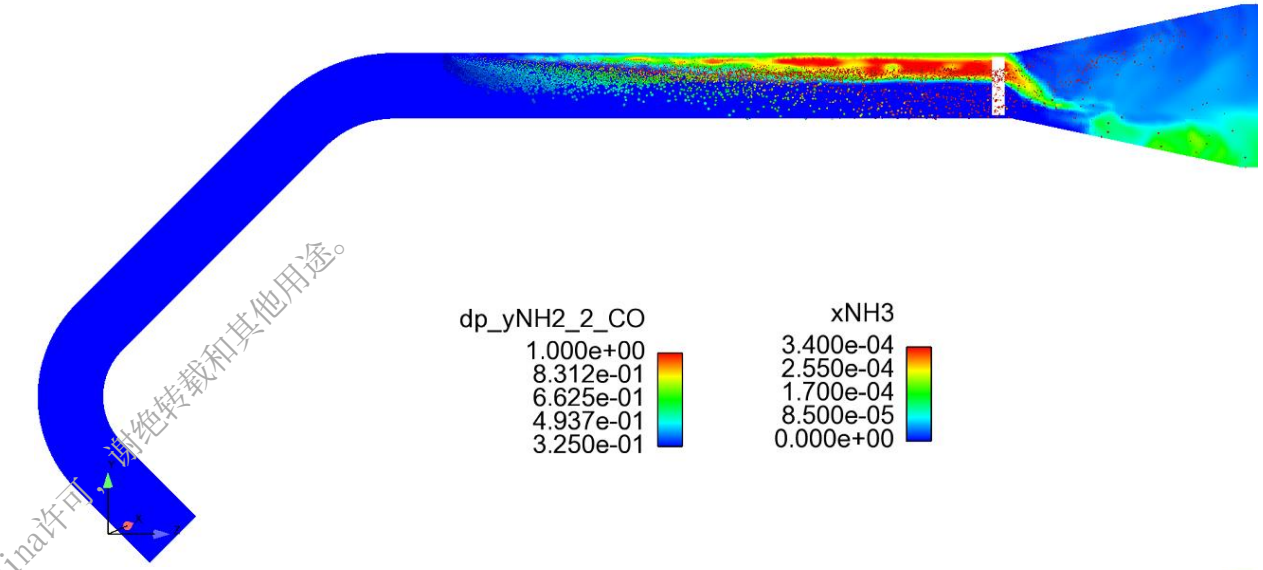
CONVERGE

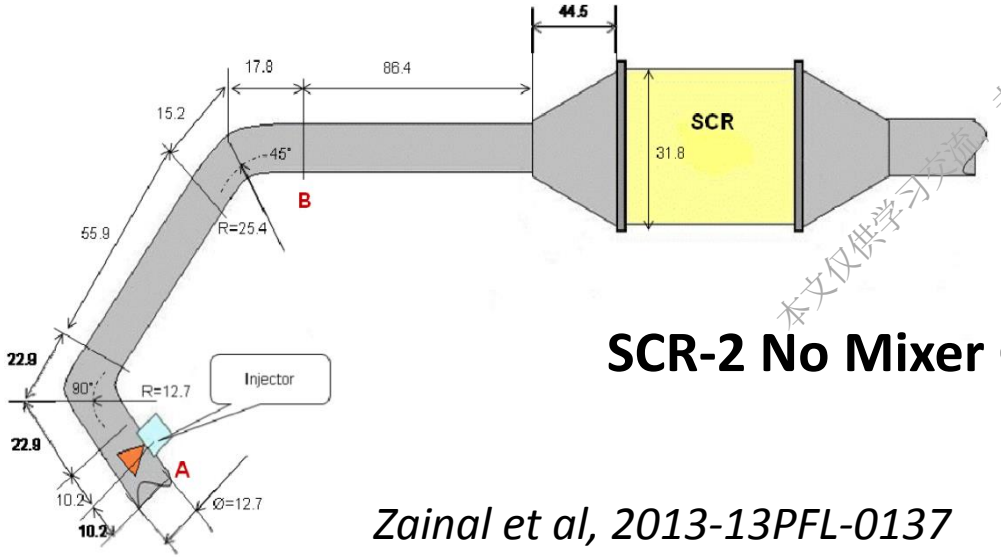


SwRI Validation Case

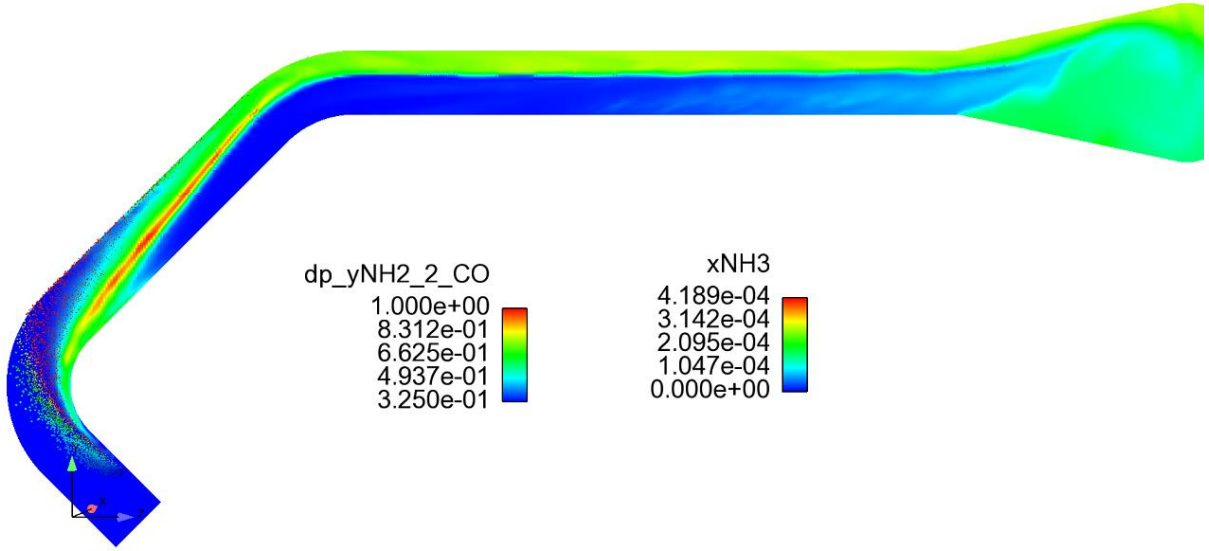


SCR-1 Mixer Case





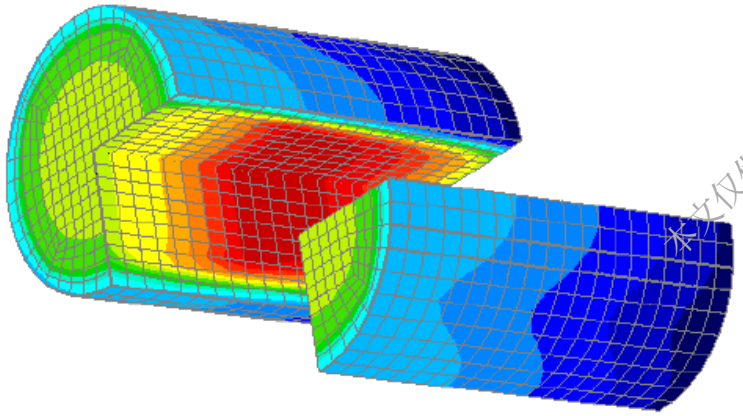
SCR-2 No Mixer Case

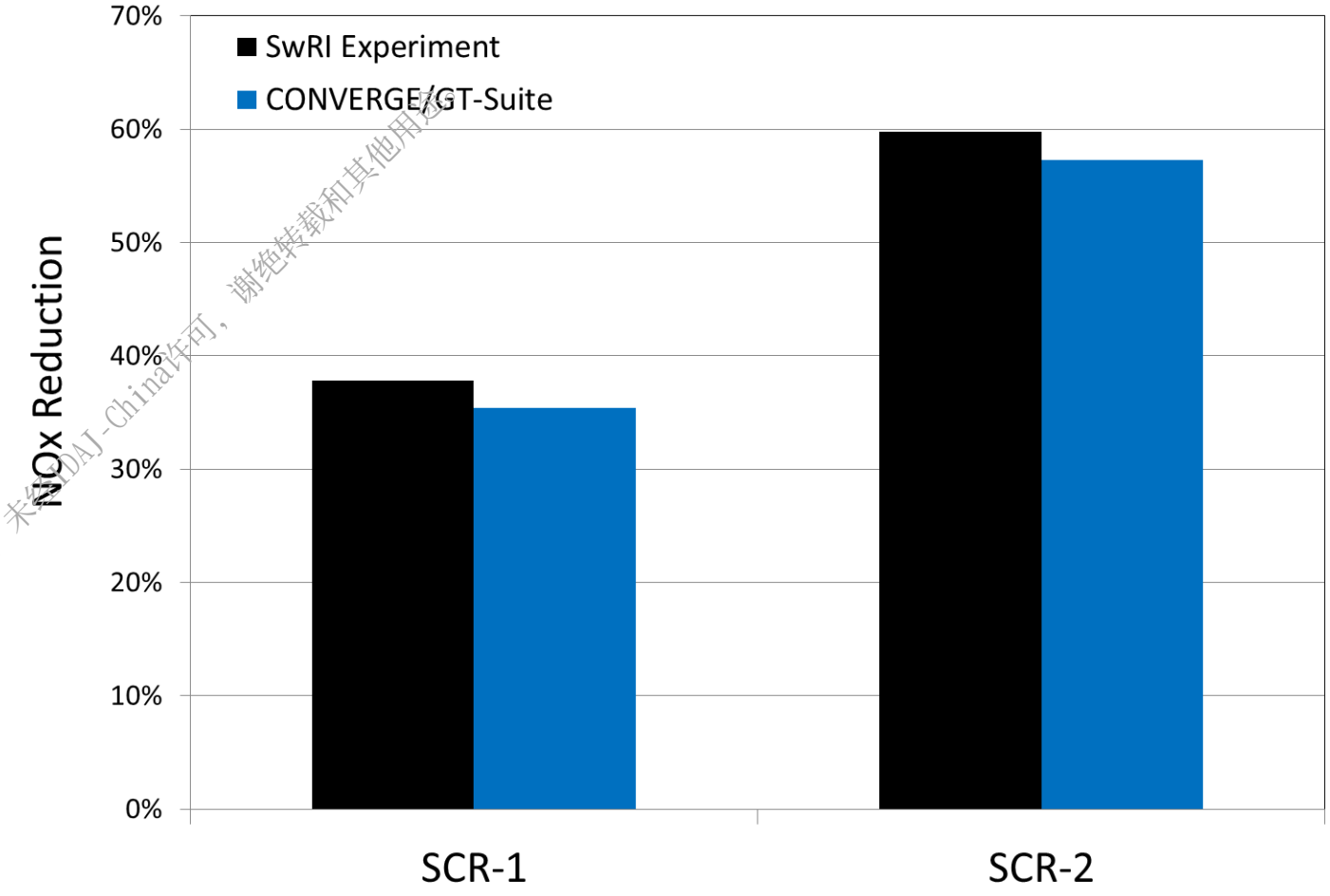


Zainal et al, 2013-13PFL-0137

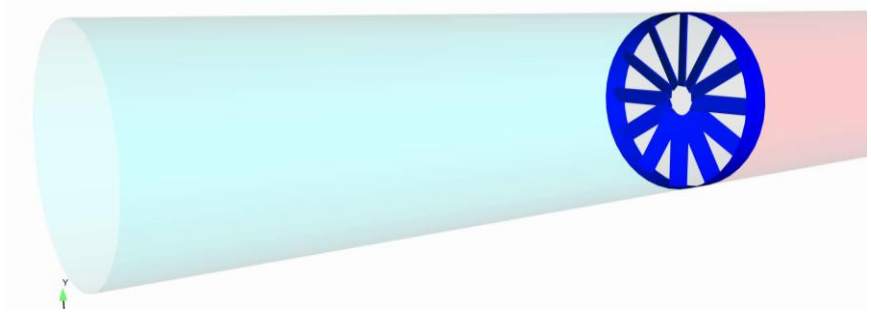
SwRI SCR Coupled 1-Way Results

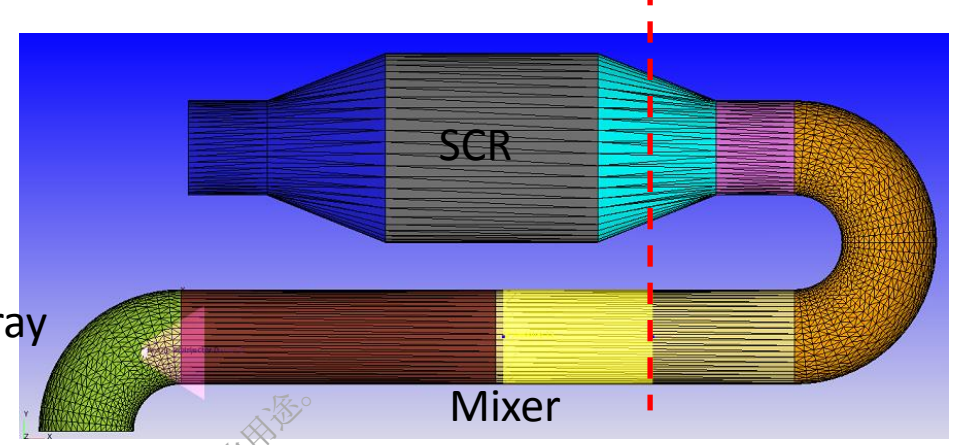
- CONVERGE to GT-Suite Link
  - New Post capability
- Validated GT-Suite SCR model
  - Olssen 2008
  - 10 x 10 x 8 = 800 reactors



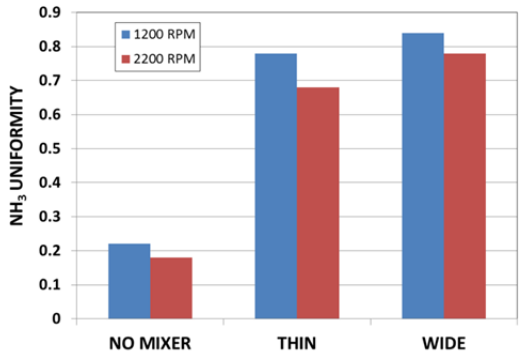


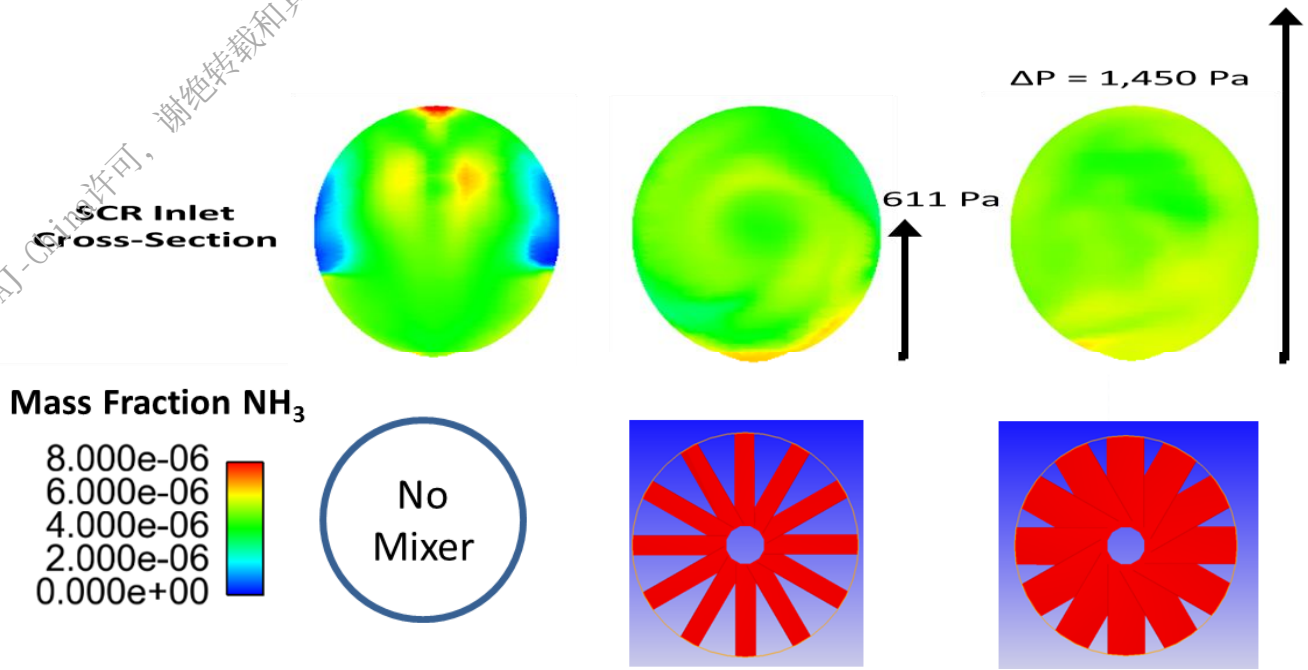
Modern Urea/SCR System





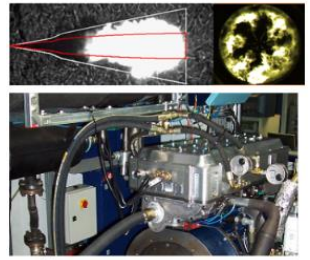
- *Urea film locations are likely areas of deposit formation*
- *Collaboration with IFPEN will allow CONVERGE to model urea deposits*

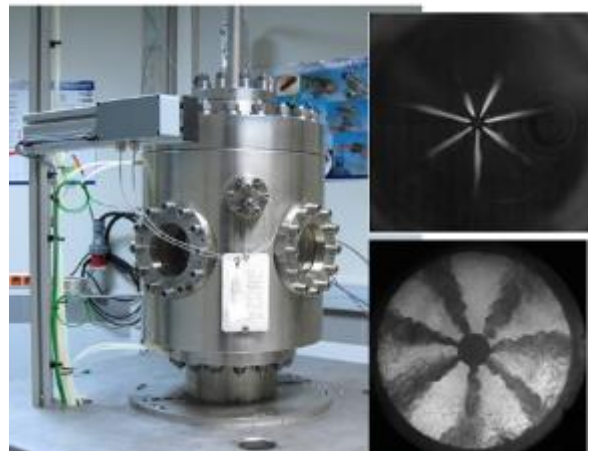


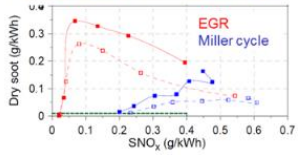


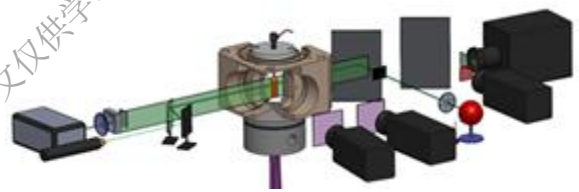
CMT Collaboration

- Convergent Science is collaborating with CMT-Motores Térmicos (Thermal Engines) of the Universidad Politécnica of Valencia, Spain
  - CMT is a world leader in engine research
- Topics of the collaboration include modeling spray, combustion, mixing, emissions and experimental data
- Extensive model validation is a goal of this partnership, taking advantage of CMT's experimental database
- Publications co-authored by CSI and CMT are expected in 2016
- CMT will have researchers and students using CONVERGE









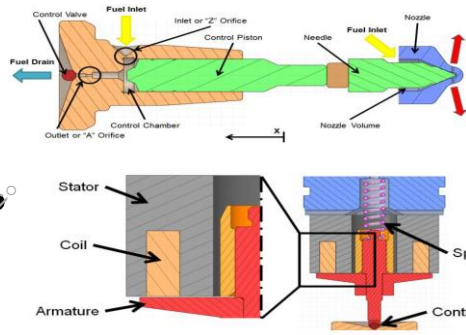
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

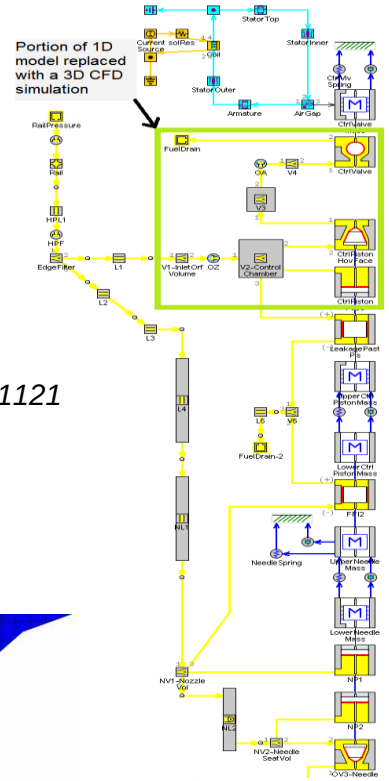
motores térmicos

CONVERGE CFD SOFTWARE

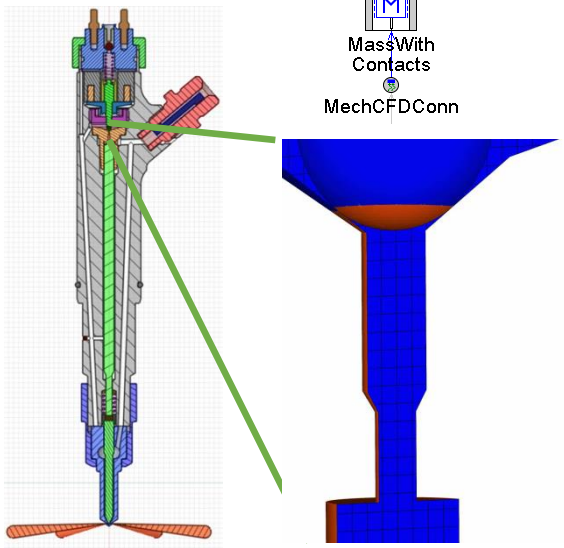
Partnership with Gamma Technologies

- Convergent Science works closely with Gamma Technologies
  - CONVERGE and GT-Suite are complimentary tools
- CONVERGE-Lite - A fully embedded version of CONVERGE linked into GT-SUITE
- Cylinder Coupling – Multiple Cylinders
- Hydro-Mechanical coupling (FSI) - (NEW)
  - GT solves 1D fluid mechanics and 1D/2D/3D mechanical motions
  - GT sends mechanical position (ball valve, needle, etc.) to CONVERGE
  - CONVERGE solves 3D flow, passes fluid forces and moments acting on mechanical element
- After treatment Modeling (Urea surface chemistry) – (NEW)
  - CONVERGE predicts flow, urea spray, ammonia conversion and mixer
  - Couple with GT-Power to predict NO reduction in catalyst brick

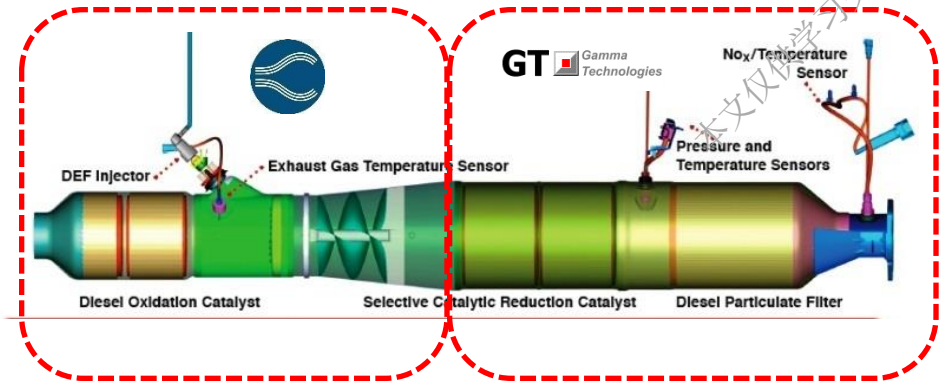


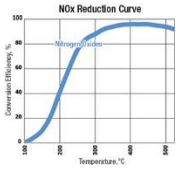


ASME technical paper ICEF2015-1121



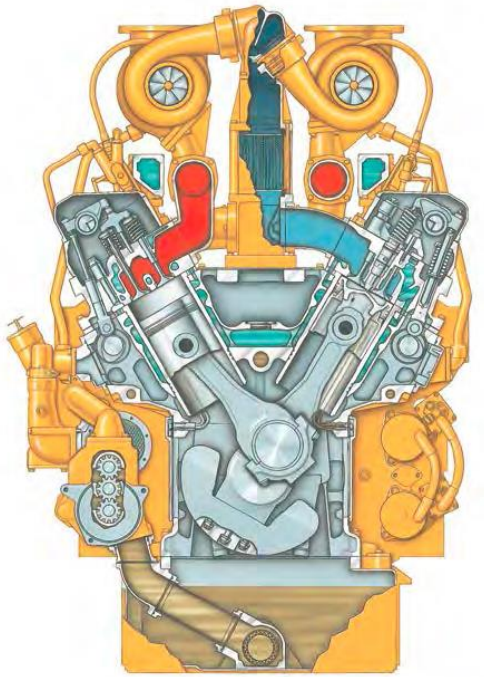
Hydro-mechanical coupling between CONVERGE and GT-Suite



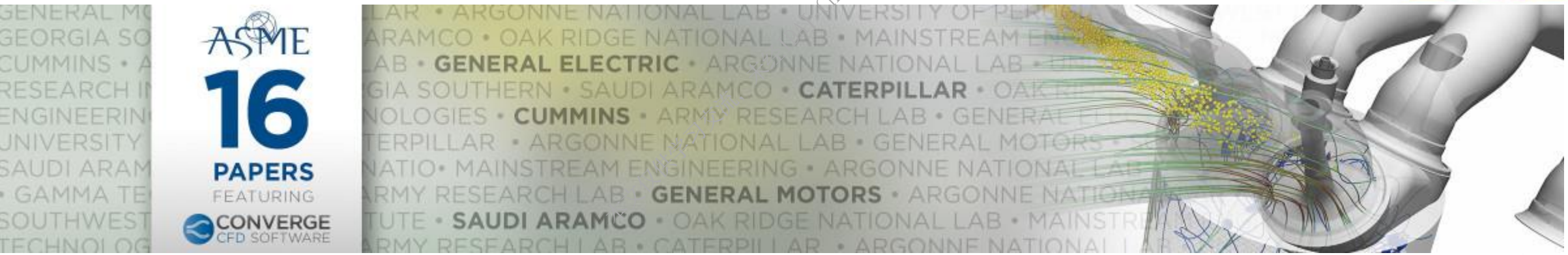


CONVERGE CFD SOFTWARE

ASME ICE Conference



- The ASME Internal Combustion Engine Division Fall Technical Conference conference was held October 9-11 in Houston, Texas
- There were 16 papers which used CONVERGE presented
- Both of the lunchtime talks showed CONVERGE results as well



CONVERGE
CFD SOFTWARE

Computational Chemistry Consortium

Convergent Science is planning to start a chemistry consortium:

- Consortium money will be used to fund universities, national labs, consortium members, and potentially non-consortium members to conduct R&D
- Convergent Science is not looking to profit off of this consortium
- Our motivation is to provide better chemistry, combustion, and emissions modeling capabilities to our customers.

How is this different from past consortia?

- Open format will be used for all mechanisms
- The format will be published such that all mechanisms can be used by any engineering software
- The mechanisms and the formatting will eventually be released to the general public. This will allow for more extensive validation and development by the combustion community.
- Board of directors and voting (not clear if this is different or not)

Convergent Science is eager to begin this consortium – please let us know if you are interested in joining

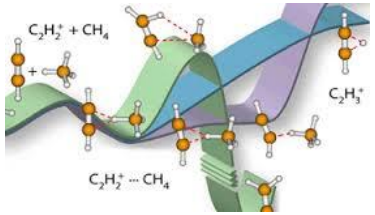
Industrial Members

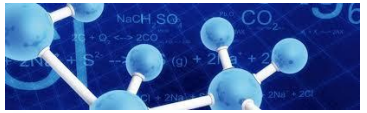
generic logo company

generic logo company

generic logo company

University Partners





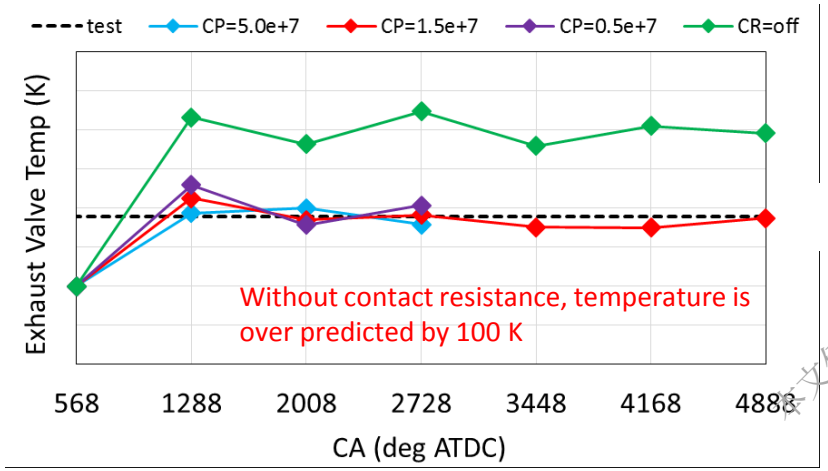
User Conference

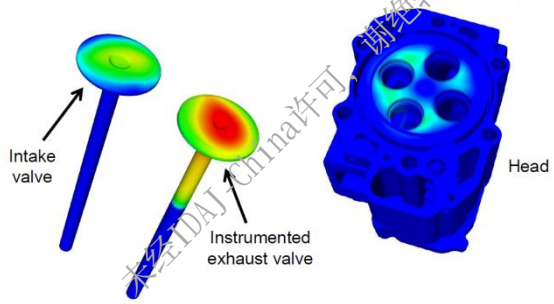
- CSI had a very productive user conference in October, 2015
- Presentations showing CONVERGE work at PSA, Cummins, GM, Ford, CAT, Chrysler, Red Bull and Renault
- User presentations on new applications including urea modeling and conjugate heat transfer

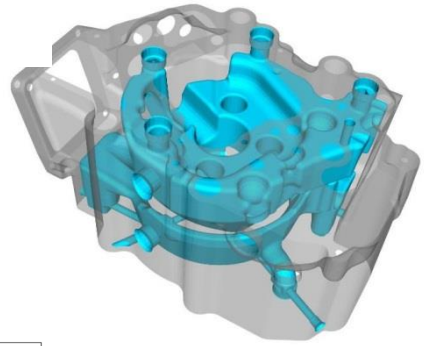
CONVERGE
2015 USER CONFERENCE
OCTOBER 5-9 RICHARD CHILDRESS RACING WELCOME, NC

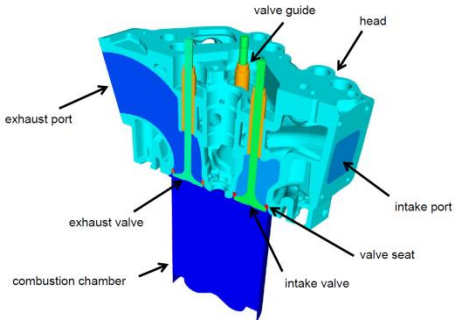
User Conference - CAT

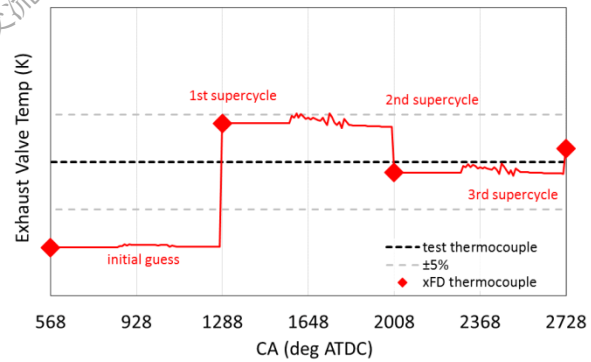
- Caterpillar presented “Engine Valve Temperature Prediction using CONVERGE”
- This study utilized CONVERGE conjugate heat transfer to predict spatially resolved exhaust valve temperature in a large bore production Cat® Diesel Engine
- Super-cycling was utilized to reduce computational cost
- Contact resistance was found to be very important for accurate metal temperature predictions

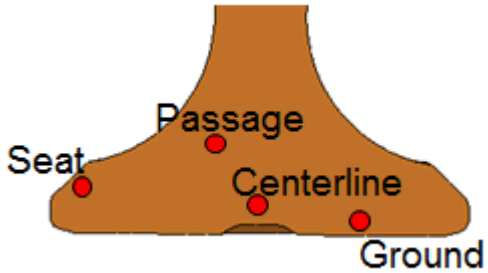






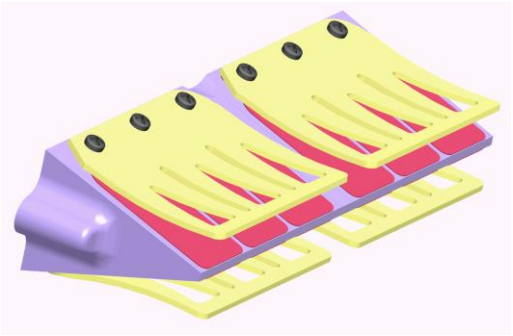




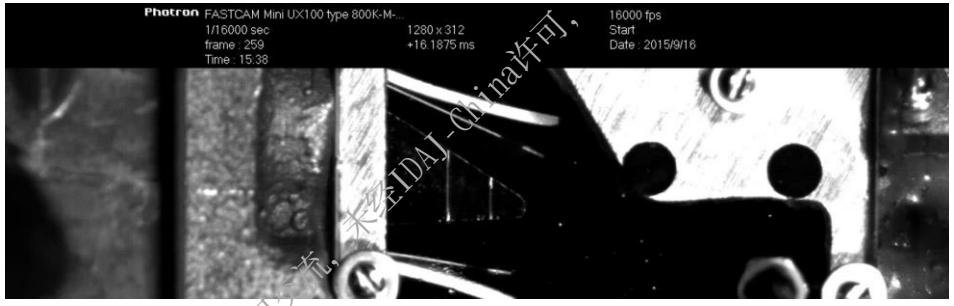


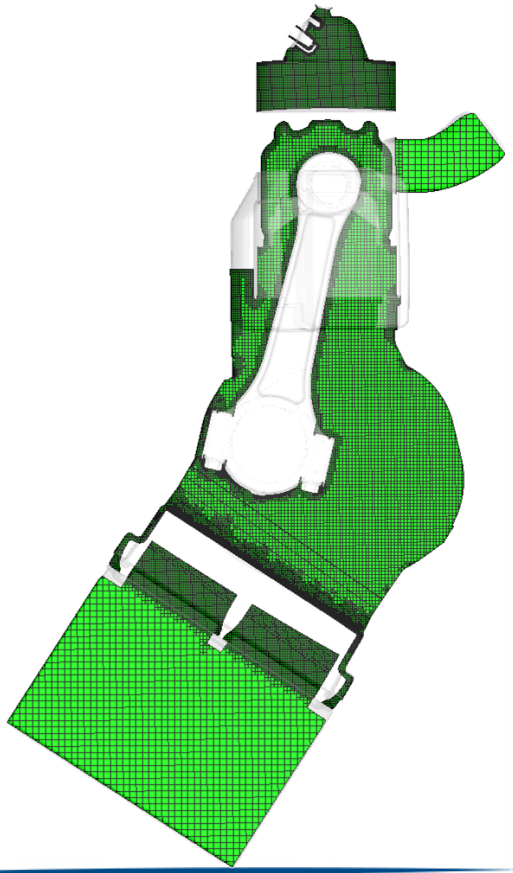
User Conference - BRP

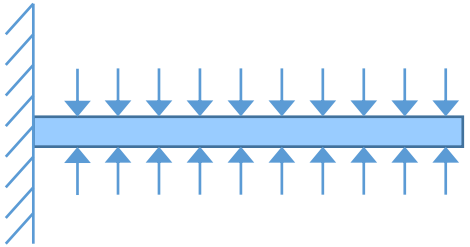
- BRP Presented “Two-Stroke Reed FSI Modeling and Validation”
- Reed pedals were modeled as free vibration of cantilevered beam
- Good agreement for crankcase pressure and reed motion achieved



Reed Assembly



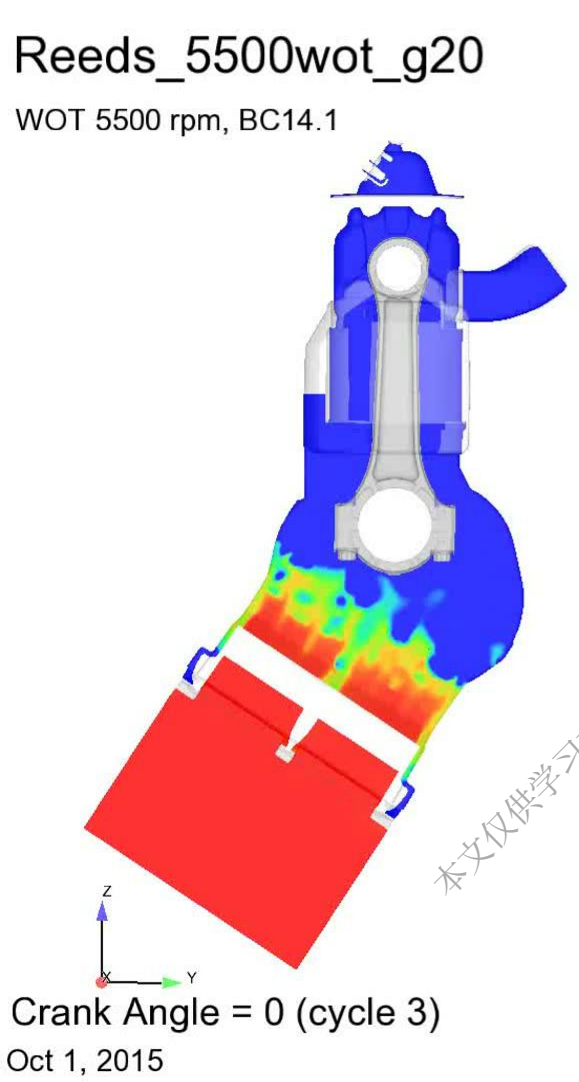


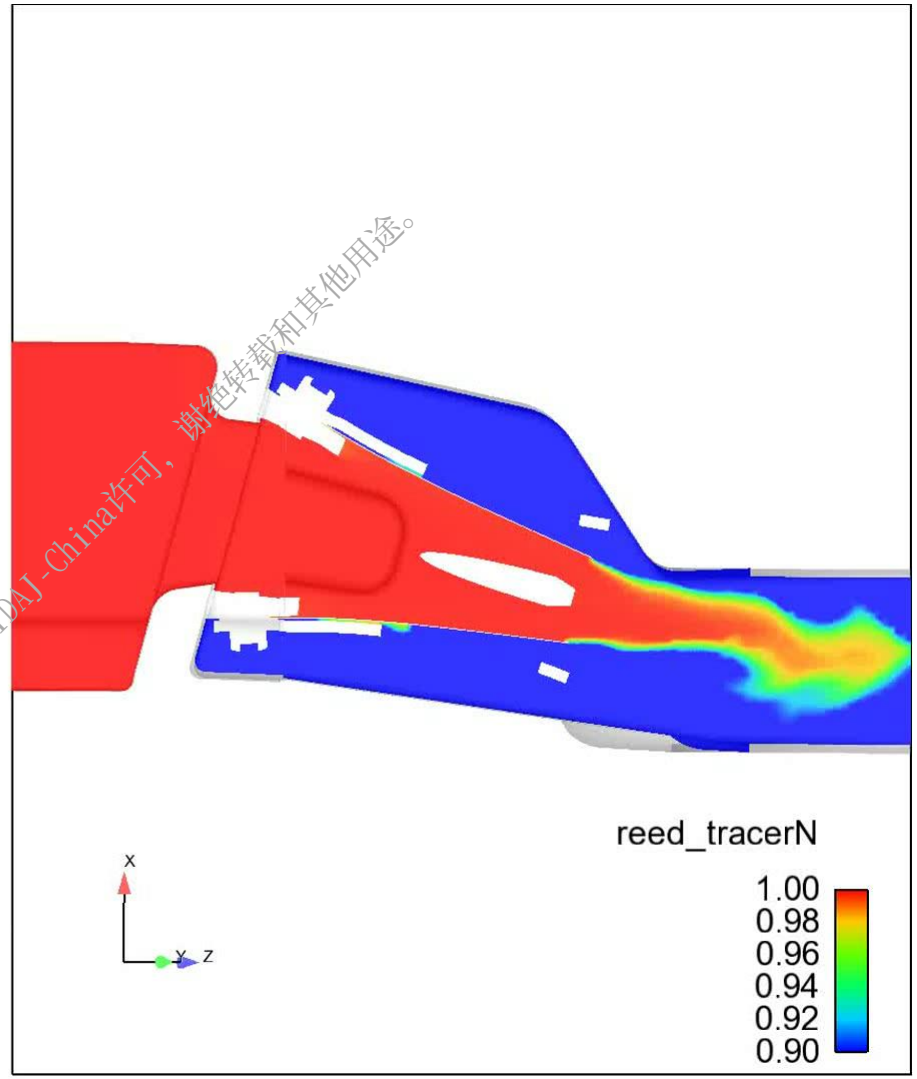


$$\frac{d^2 z_i}{dt^2} + 2\zeta_i \omega_i \frac{dz_i}{dt} + \omega_i^2 z_i = F_i \qquad EI\frac{\partial^4 y}{\partial x^4} + \rho A \frac{\partial^2 y}{\partial t^2} = 0$$

Courtesy of BRP

User Conference - BRP





Courtesy of BRP

User Conference - Renault

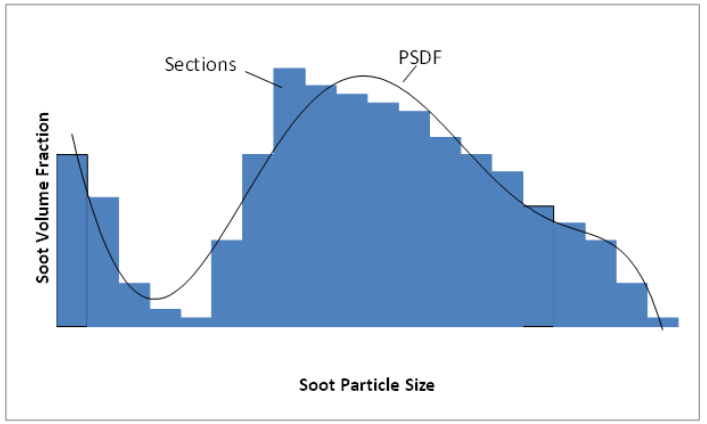
Advanced soot modeling for Diesel application
PSM model in CONVERGE

CHANGE UP!

ENGINEERING MECANICAL ALLIANCE – MECHANICAL DESGN –FUNCTION AND SYSTEM ENGINEERING - F.RAVET | 7th October 2015 | 1 | RENAULT

Compared accuracy of PSM (new) and Hiroyasu (historical) soot models

PSM also allows for soot size distribution



CONVERGE CFD SOFTWARE

Introducing Version 2.3

- CONVERGE v2.3 offers you more user-friendly, powerful, and flexible tools that allow you to gain insight into complex physical problems
  - Advanced new surface preparation tools
  - Additional models and more user-controlled options
  - A more efficient and robust solver
  - Enhanced post-processing tools
  - Urea modeling
  - Conjugate heat transfer improvements

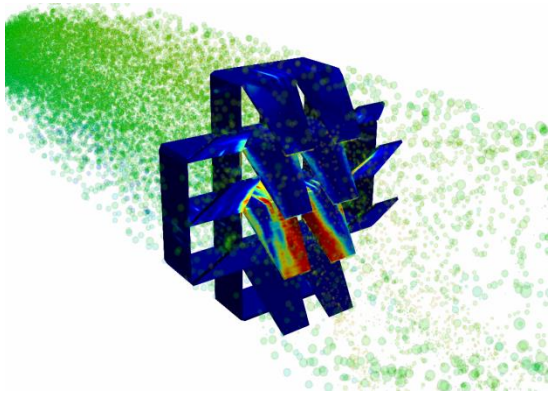
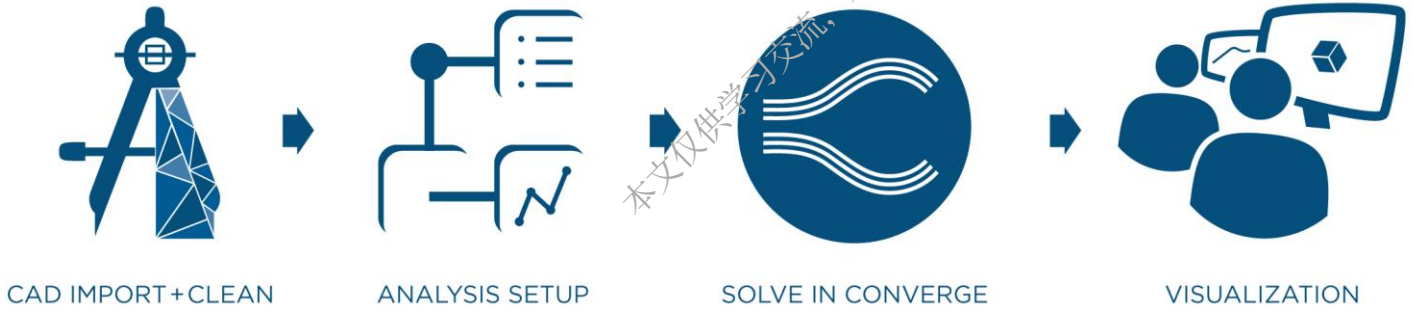
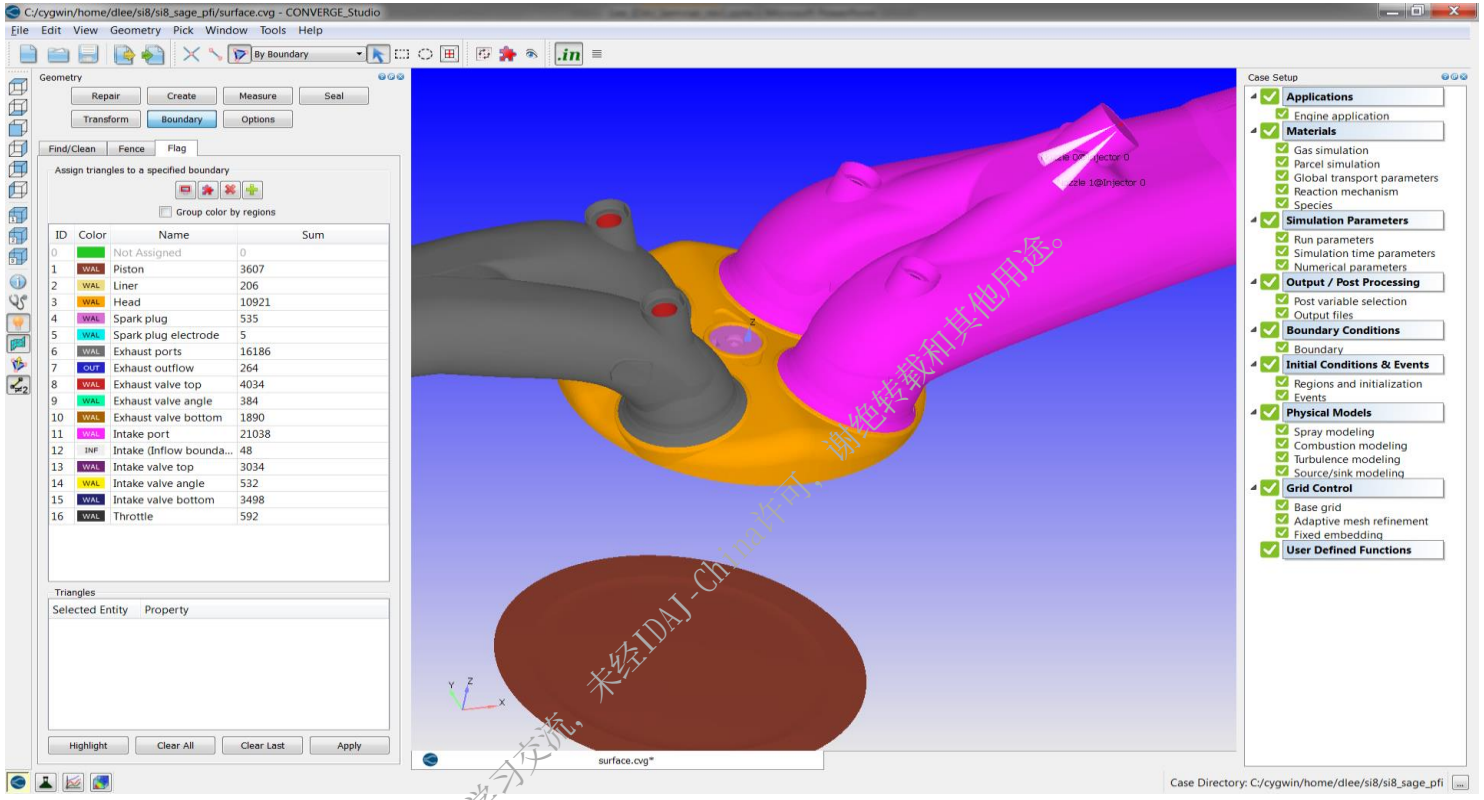
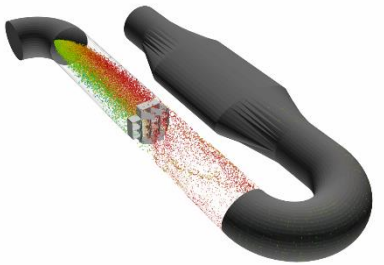


Image courtesy of SWRI



CONVERGE Studio v2.3





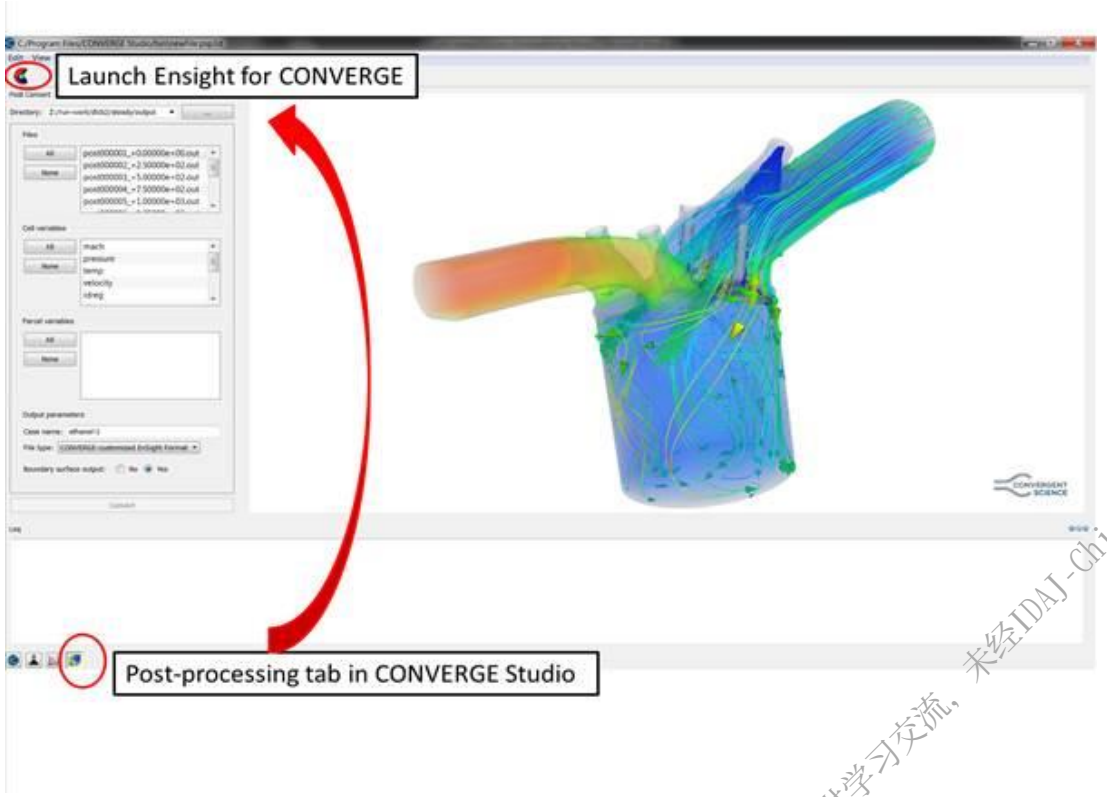
Urea System Model

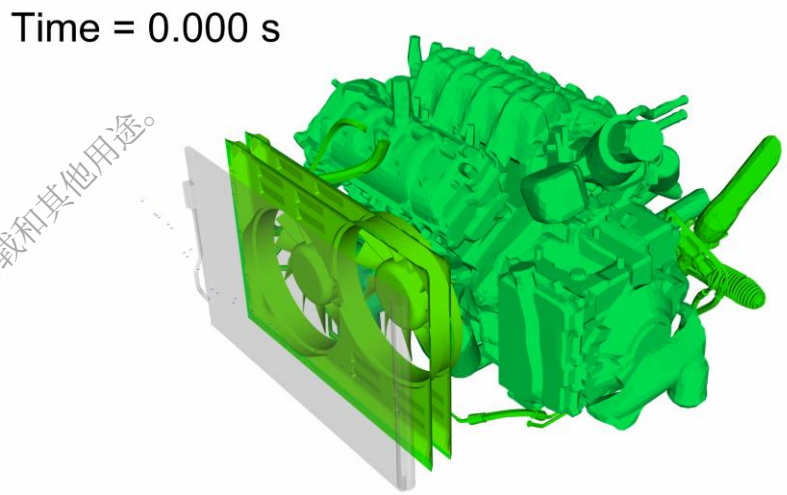
- Full case setup (mesh inputs, spray, combustion etc.) with error checking
- Chemistry reduction environment
- Templates (pre-defined and user generated)
- V2.3 is packed with new features, making case setup quicker and easier than ever
  - Surface wrapper
  - Polygonnica cleanup tools

With Studio, the user only works with surface mesh as the volume mesh is made automatically at runtime.

CONVERGE CFD SOFTWARE

Ensight Desktop for CONVERGE





Underhood thermal analysis

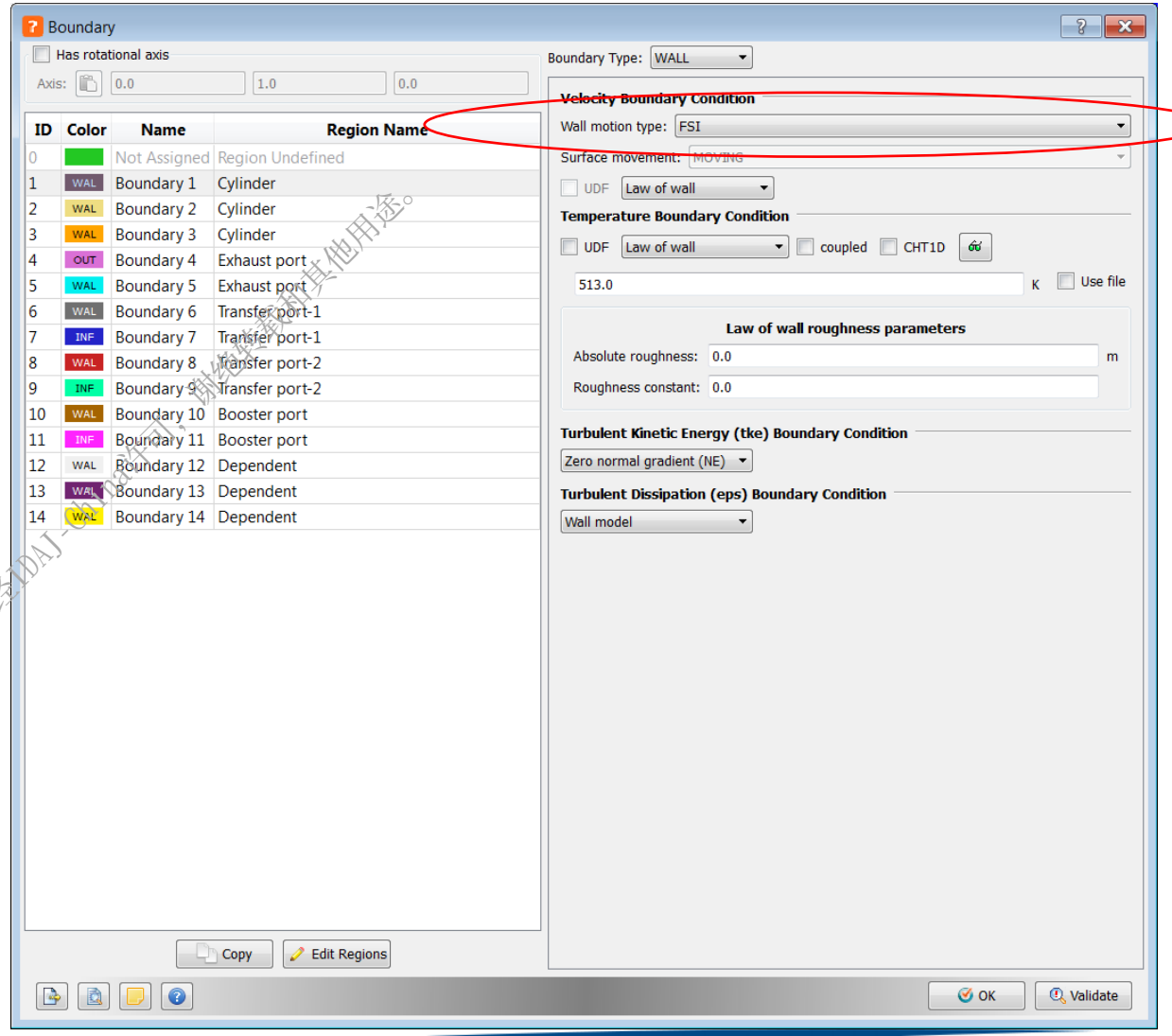
- Ensight Desktop comes bundled as a standard feature of CONVERGE
- Other post-processor formats can be readily exported

Fluid Structure Interaction (FSI)

- The boundaries motion can be calculated by CONVERGE during the simulation
- A 6 degree of freedom (6-DOF) solver integrates the fluid forces (spring force can be included)
- New mesh created automatically each timestep as always
- Applications include wastegate, reciprocating compressors, valves, etc

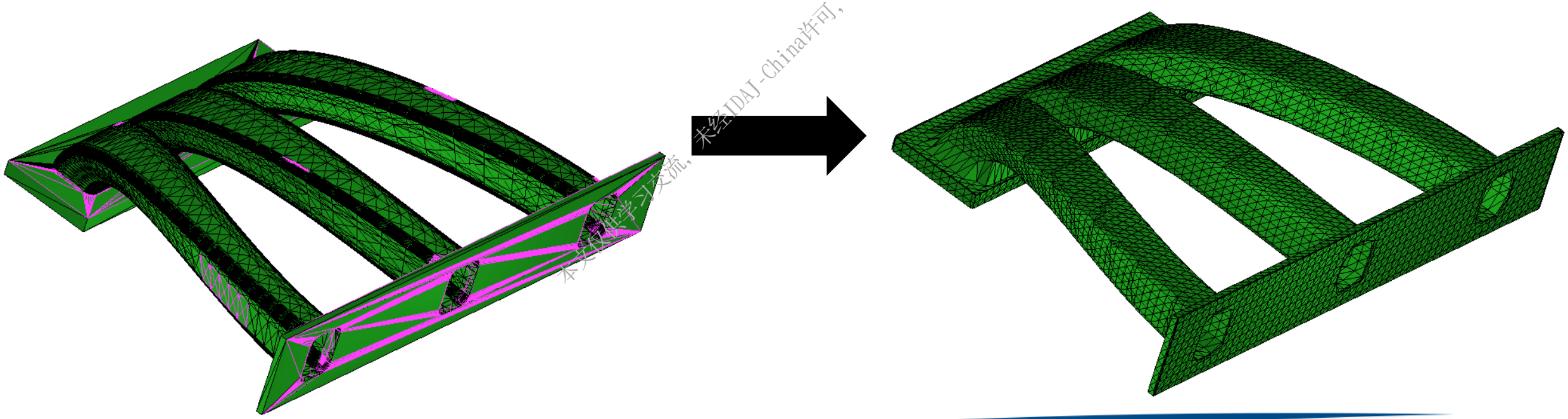
$$\dot{\vec{v}}_G = \frac{1}{m}\sum \vec{f}_G$$

$$\dot{\vec{\omega}}_B = \mathbf{L}^{-1}\left(\sum \vec{M}_B - \vec{\omega}_B \times \mathbf{L}\vec{\omega}_B\right)$$



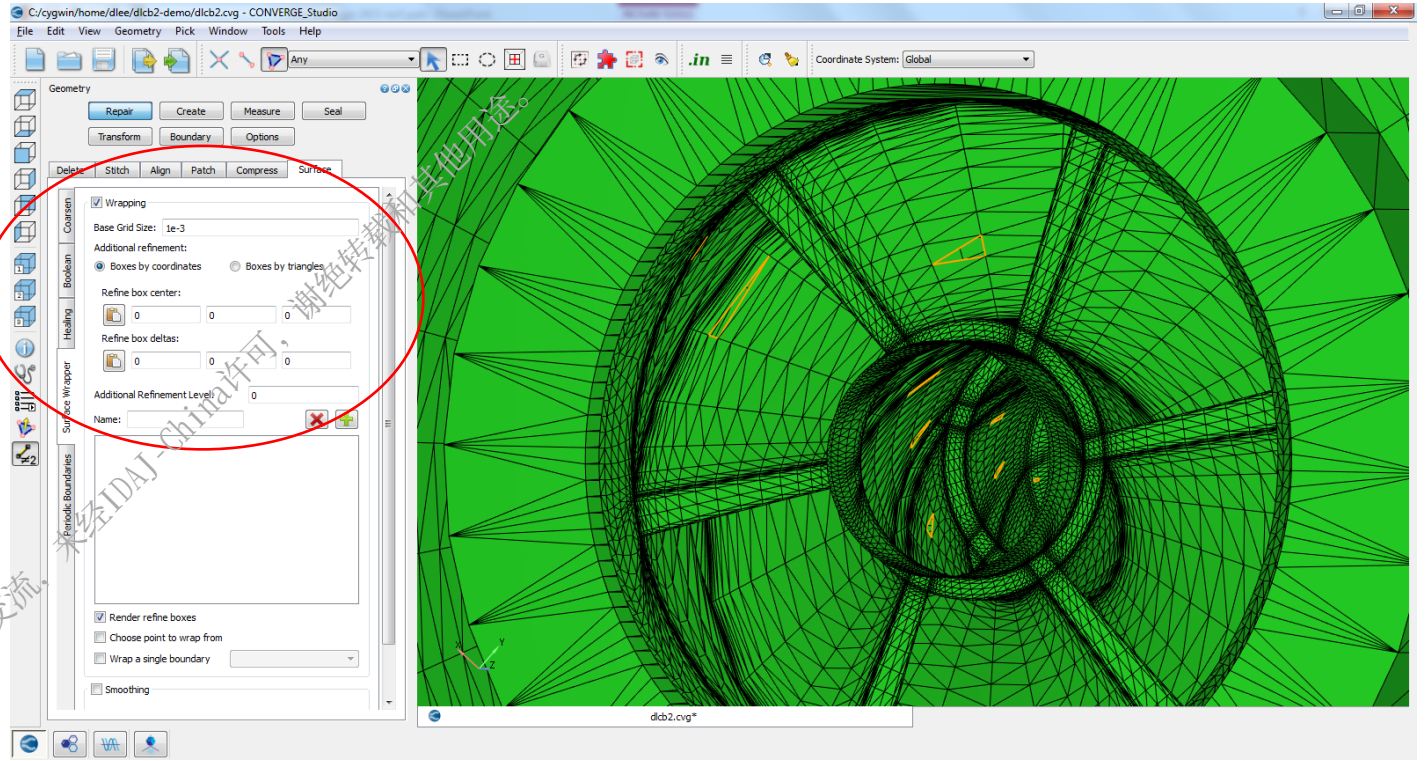
CONVERGE Studio: Surface Wrapper

- **Surface wrapper**: Repair geometries with significant surface defects
  - After wrapping the geometry, apply various smoothing functions to ensure an error-free geometry



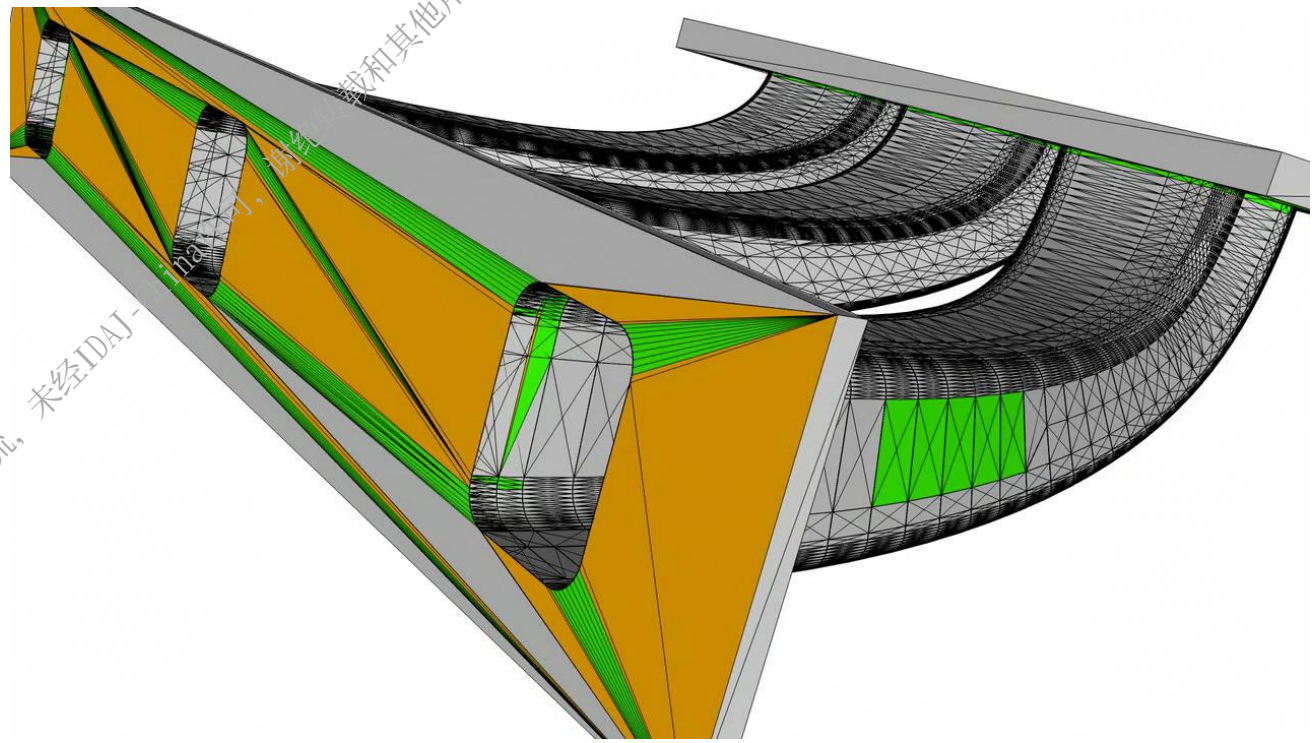
What is a Surface Wrapper?

- The new surface wrapper in Studio can drastically reduce the cleanup time for dirty geometries.
- A surface wrapper wraps a **new surface** around the given geometry
- Since the tool creates a new surface, problems in the old surface do not carry over
- The wrapping procedure should **ideally** be free from intersections and non-manifold edges

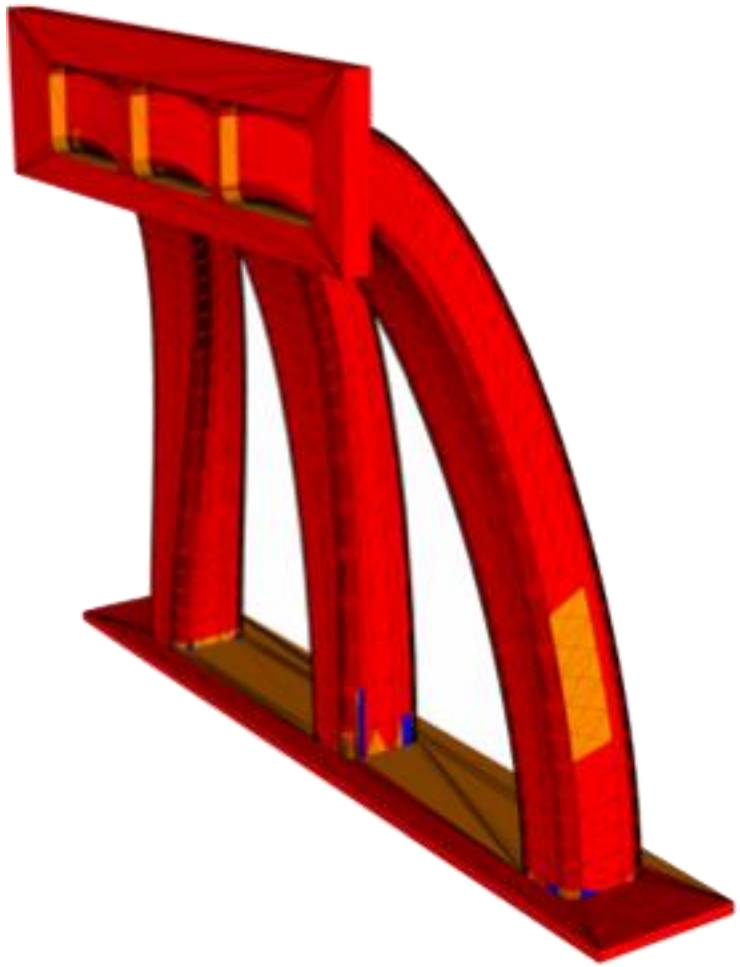


Summary of Problems in the Model

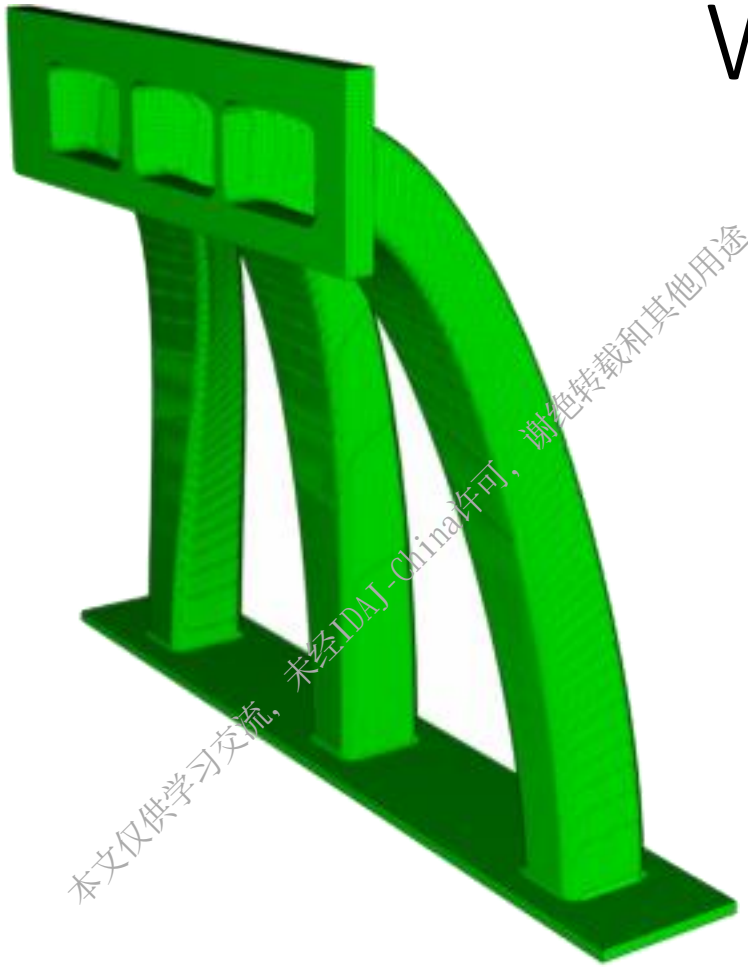
- Intersection **3268**
- Non-manifold edges **253**



Wrapping Results



Original 35K



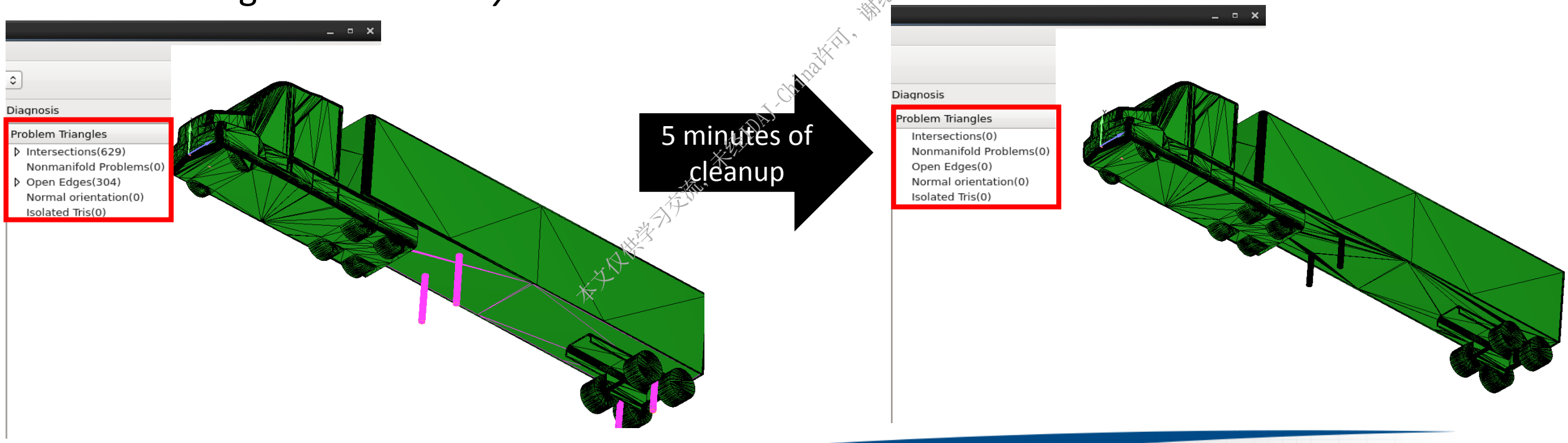
Wrapped 270K

13 seconds

Wrapped models have **0** errors

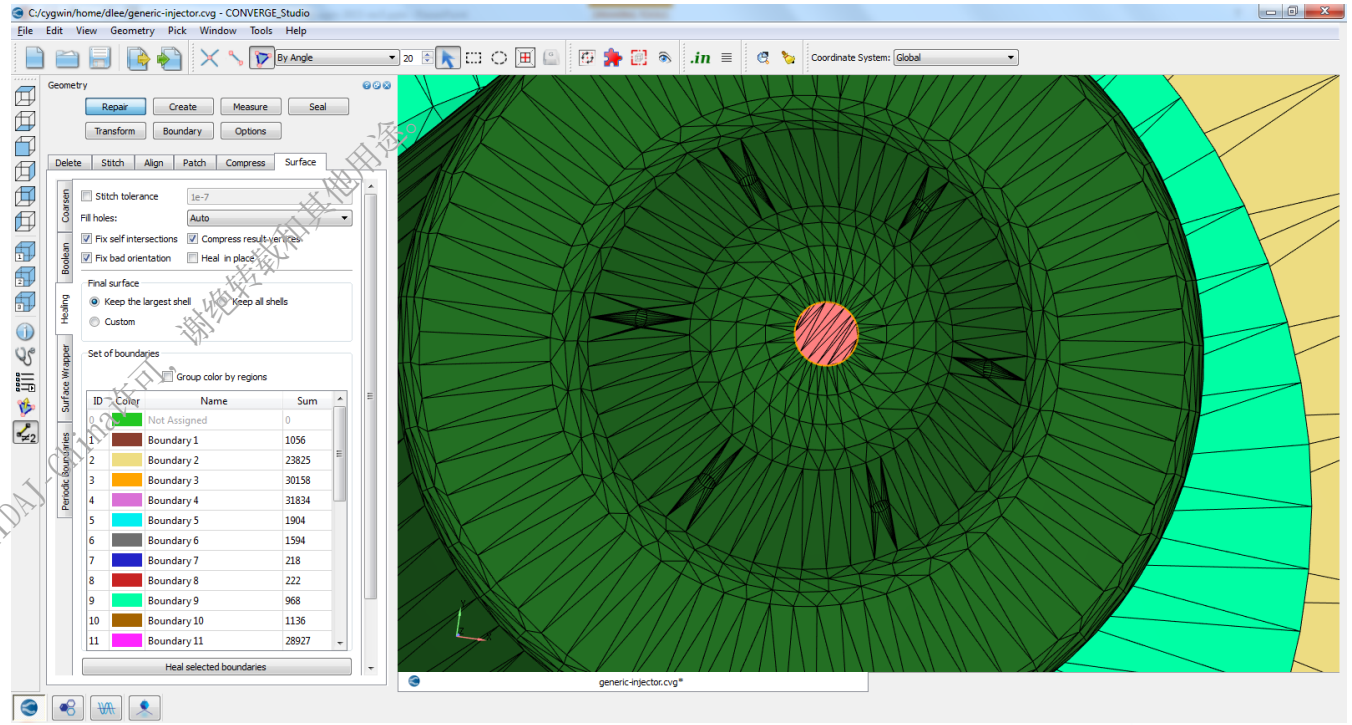
CONVERGE Studio: Polygonica

- **Polygonica toolkit**: With the appropriate Polygonica add-on, you can access Polygonica geometry tools such as coarsening, Boolean operations, and healing through the *Geometry* dock in CONVERGE Studio



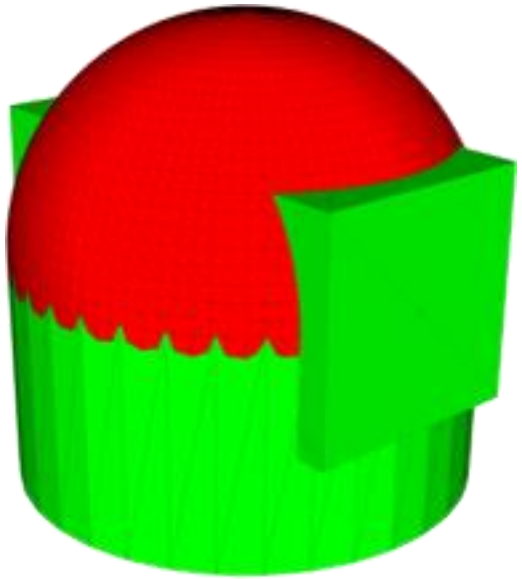
What is Polygonica ?

- Polygonica is a solid modelling toolkit which provides the user powerful tools for surface cleanup and preparation
- Solid healing — automatically close and repair solid models
- Fast boolean operations
- Solid simplifications — simplify very large geometries
- The Polygonica toolkit requires a separate license

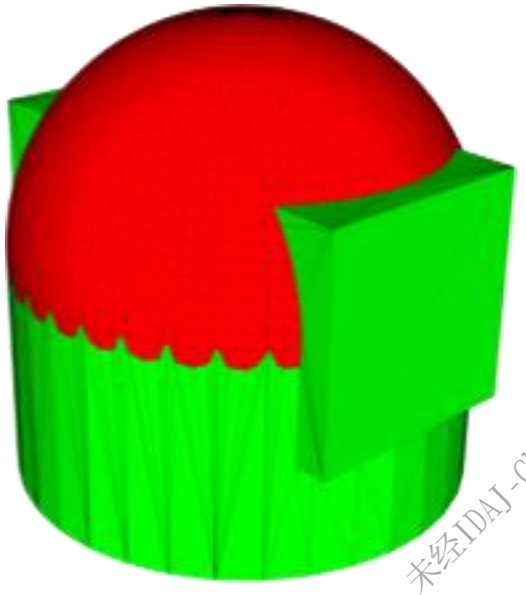


CONVERGE CFD SOFTWARE

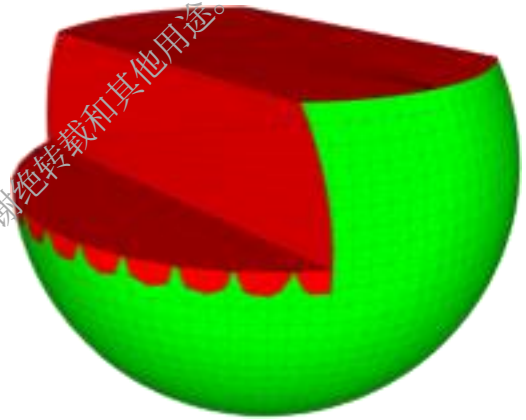
Boolean Tools



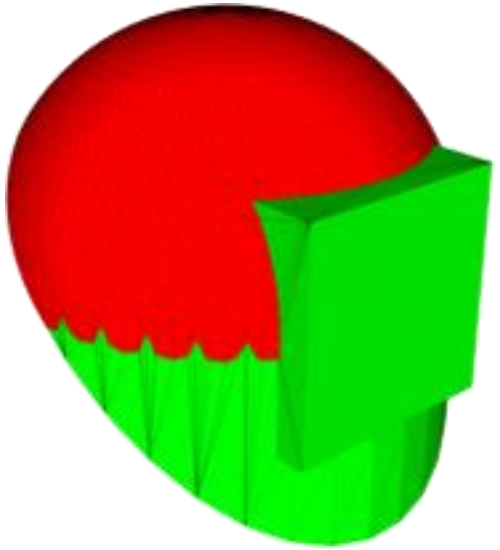
Original



Union



Intersection



Section-cut

~ 2 seconds

Resulting models have **0** errors

Summary of Problems in the Model

- Intersections **638**
- Open edges **649**

Original

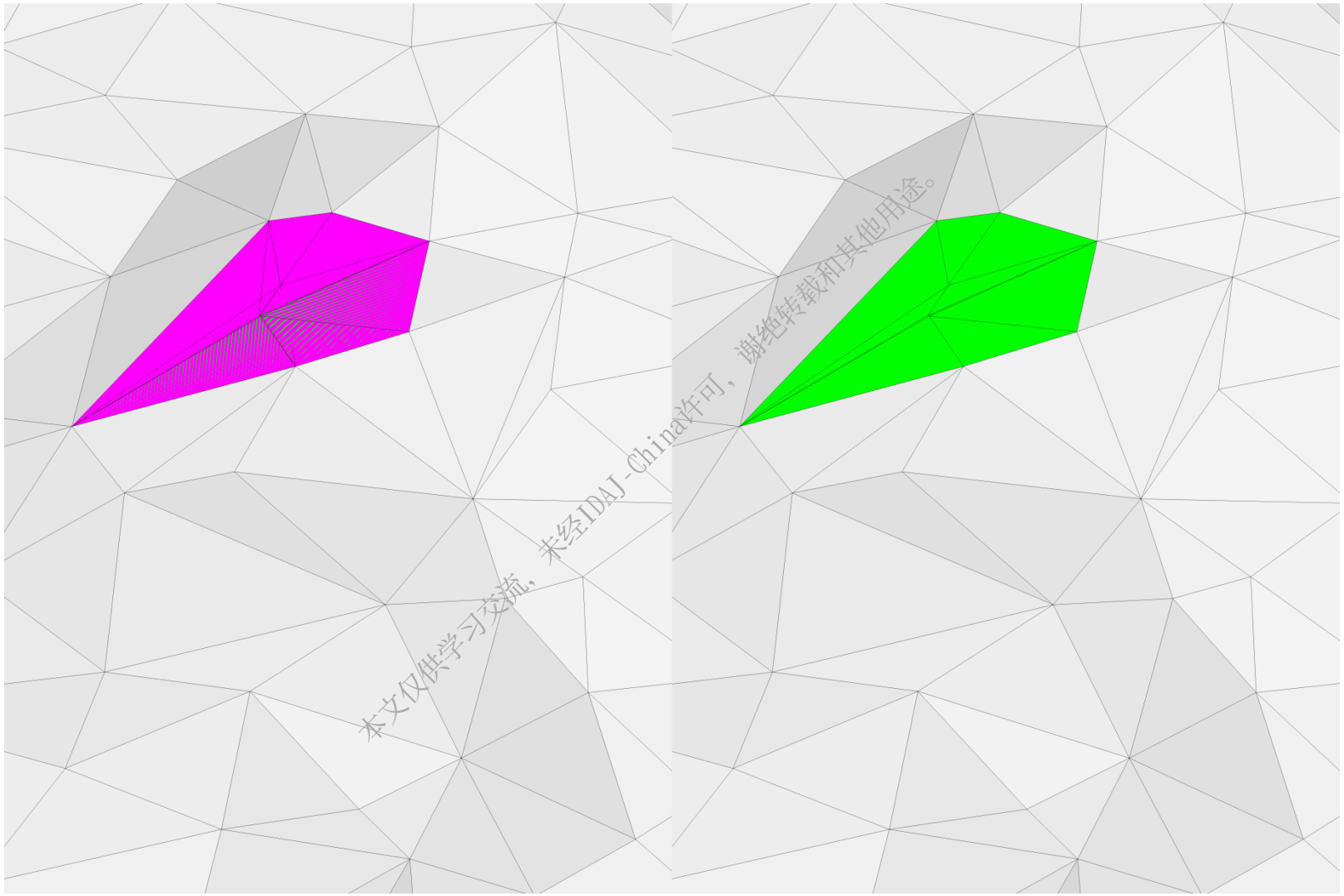
Fixed/Healed

~ 2 seconds

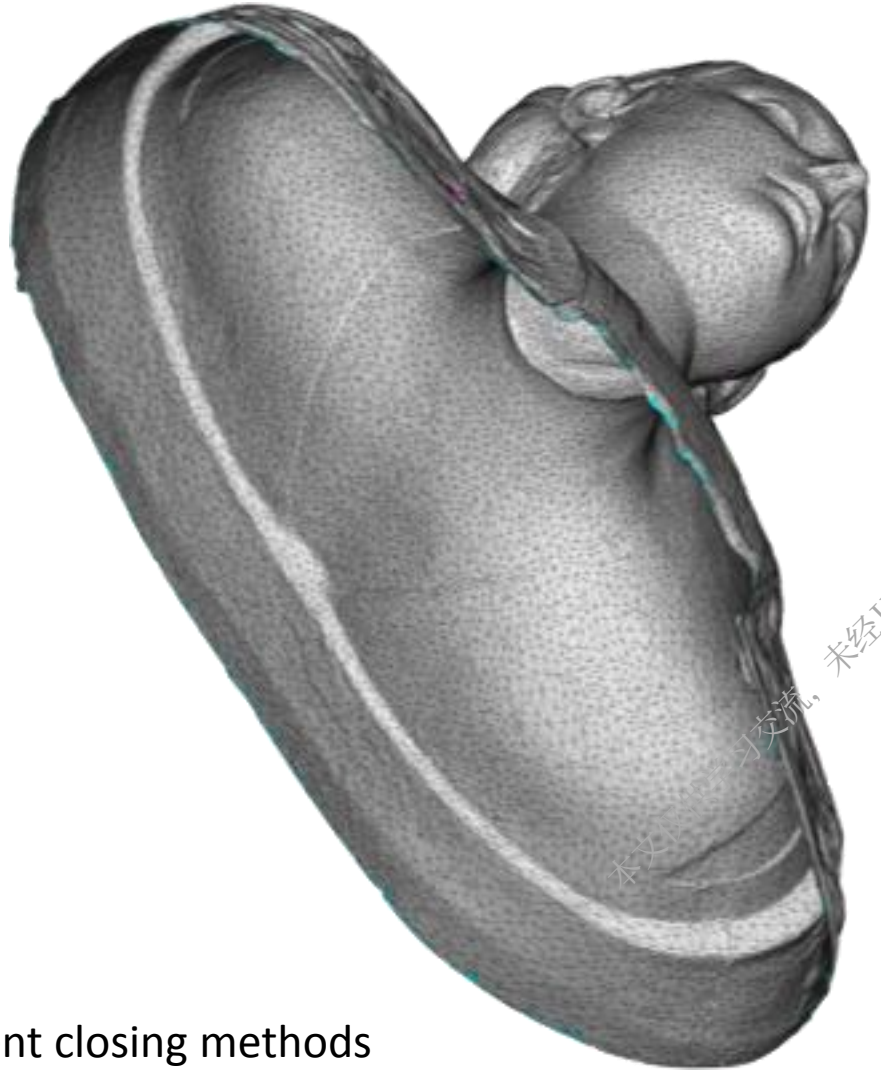
Resulting model has **0** errors

Original

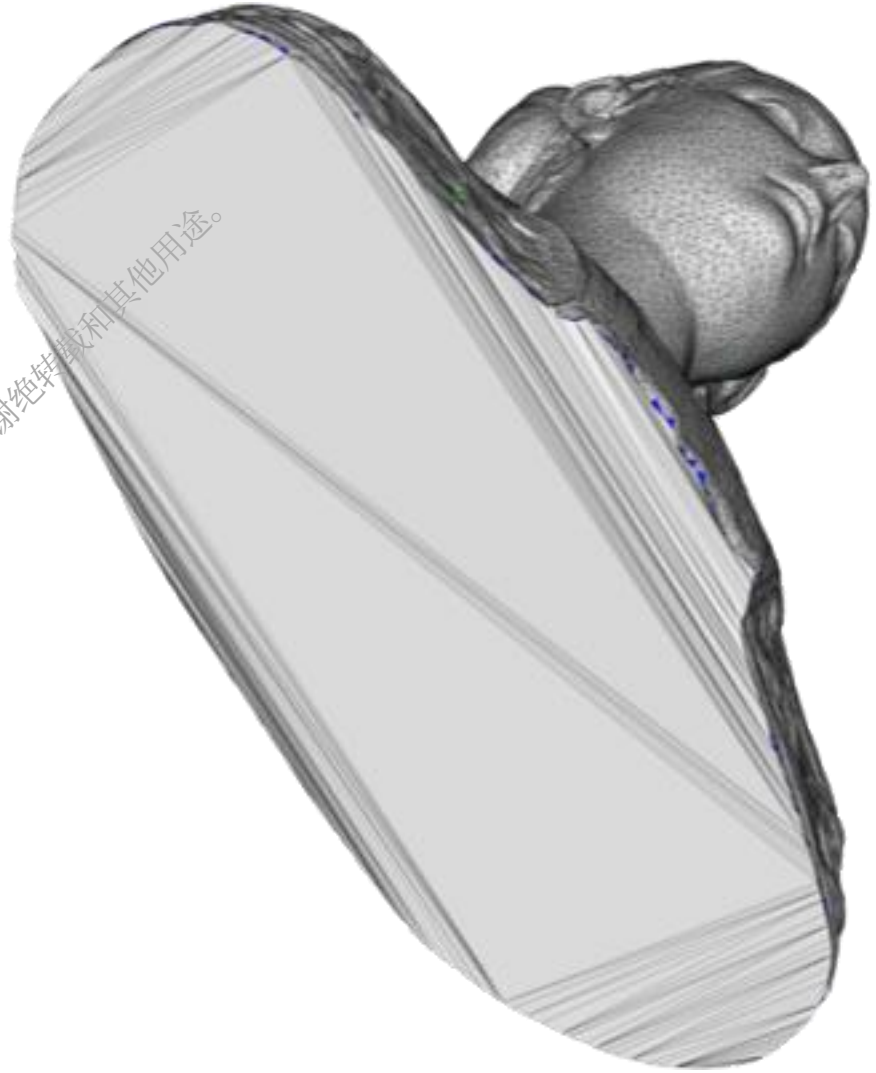
Fixed/Healed



Original



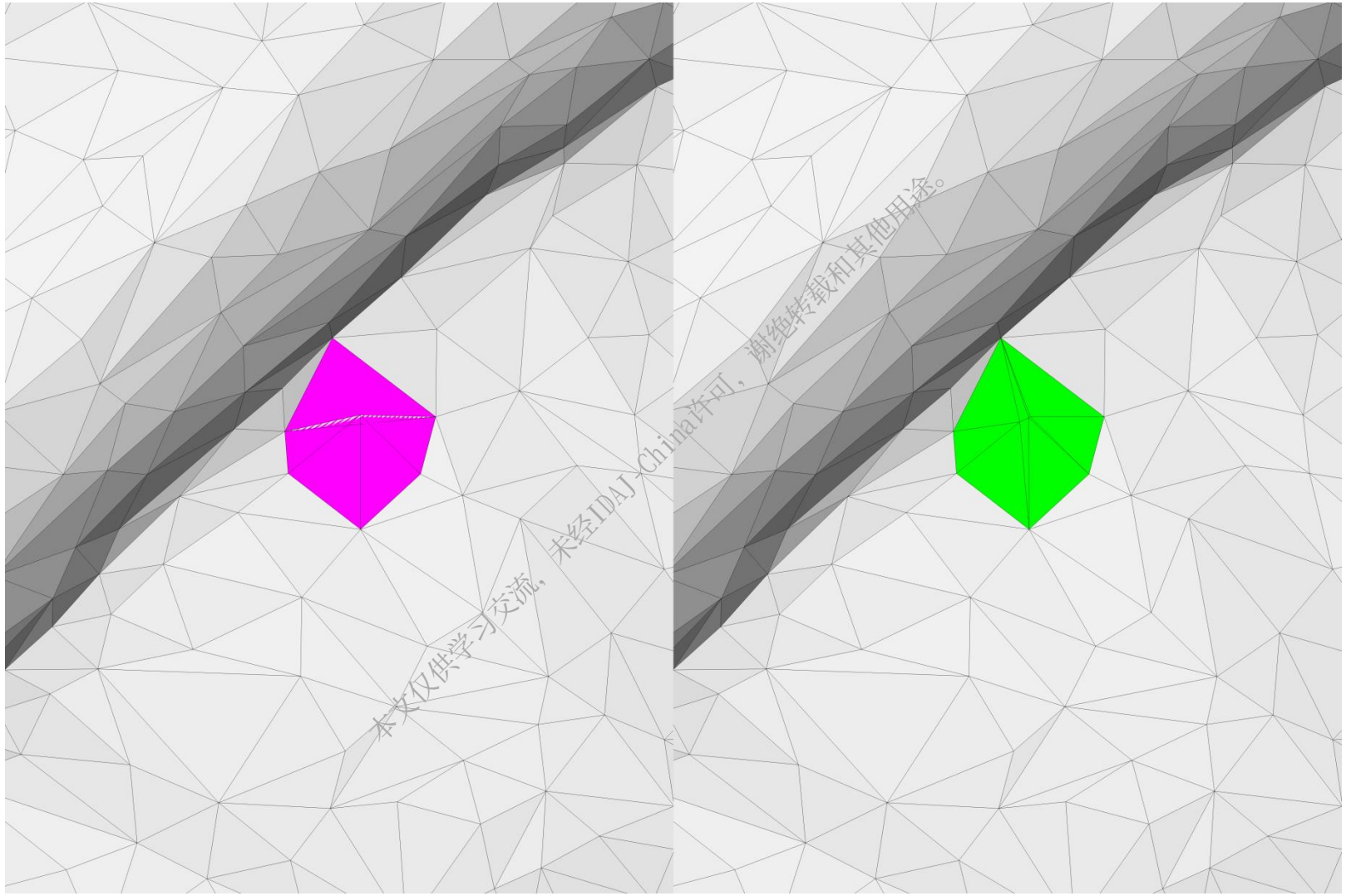
Fixed/Healed



4 Different closing methods are available

Original

Fixed/Healed



Polygonica: Coarsening

- Reduces the number of triangles to reduce runtime and RAM requirements
- Automatically closes the solid and **tries to produce an error-free model**
- Additional options:
  - Coarsen by *Maximum number of triangles*
  - Coarsen by *Maximum error*

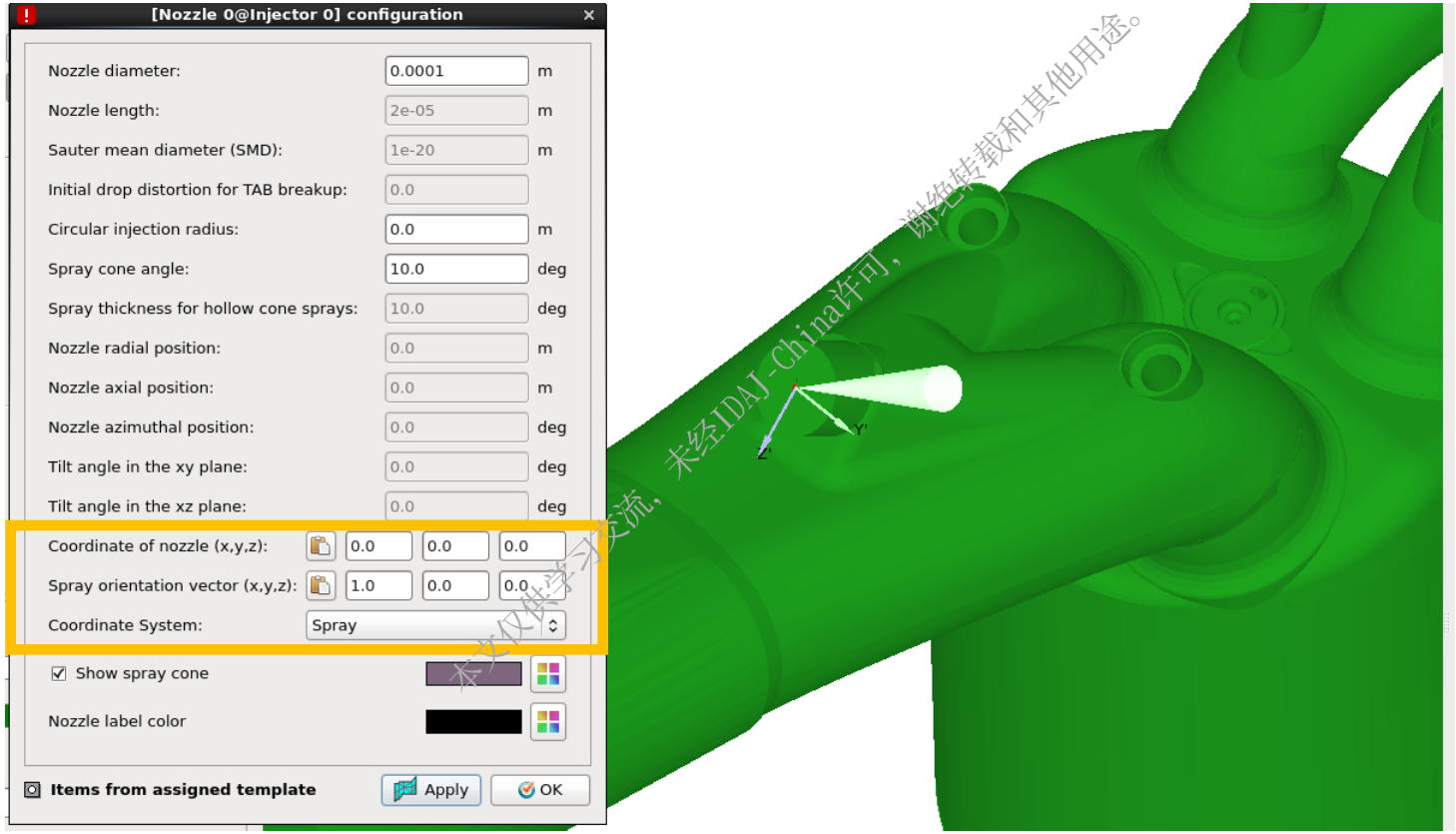
Polygonica Healing and Coarsening

- These tools are very easy to use and produce high quality results
- They do not increase the triangle count like the surface wrapper
- Example: a gas turbine combustion client provided a dirty stl file with ~25 million surface triangles
  - This would take a long time to repair manually
  - The large triangle count would slow down Studio and use a lot of solver memory
- Polygonica healing and coarsening quickly repaired the geometry and reduced the triangle count to ~500,000
  - The case was running within a day
  - The client was extremely impressed (~month to mesh in other tools)

Wrapping vs Polygonnica - Which Tool to Choose?

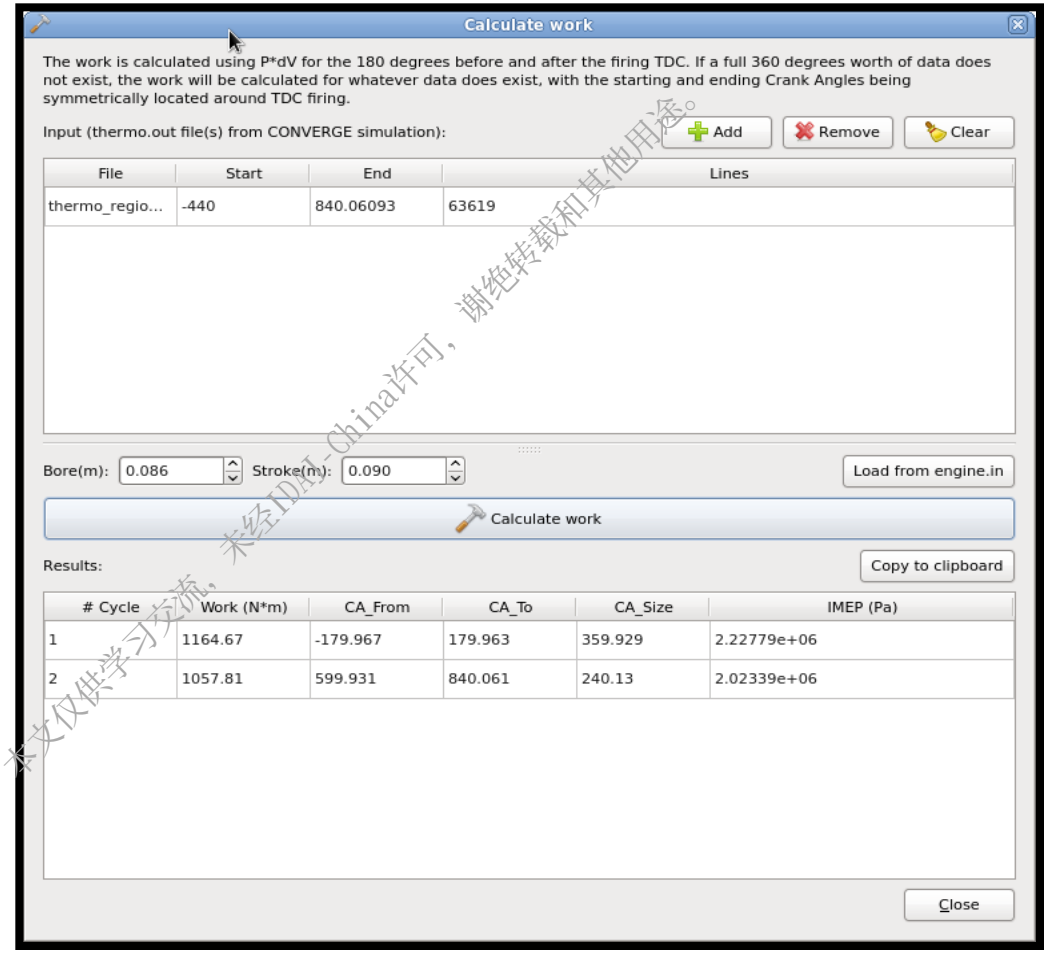
- The healing tool removes problems accurately without modifying the shape of the geometry
- Also, the healing tool maintains small features. This is a problem if the small features are a result of a user error.
- Wrapping can be a viable solution if the end goal is to run the simulation without a lot of manual cleanup

Creating local co-ordinates for easy spray alignment



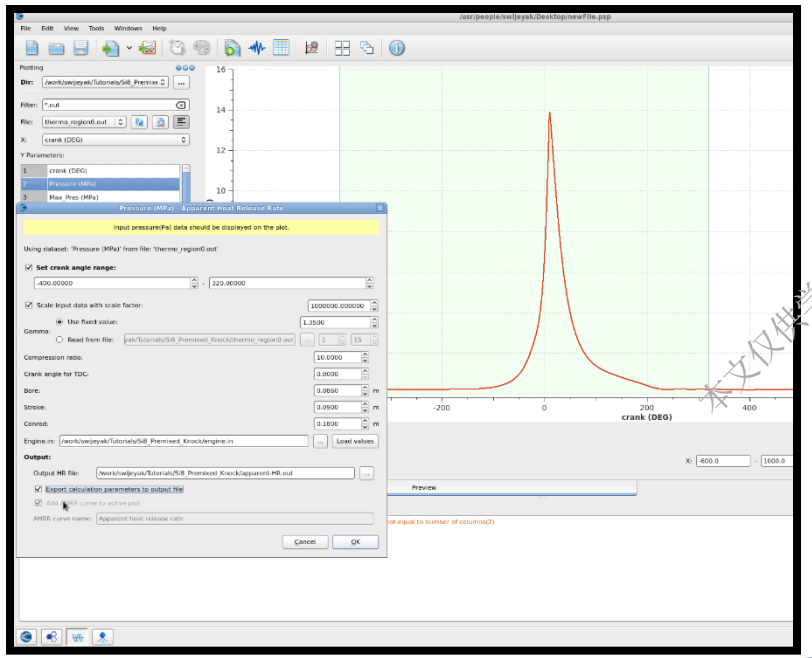
CONVERGE Studio: Line Plotting (1/3)

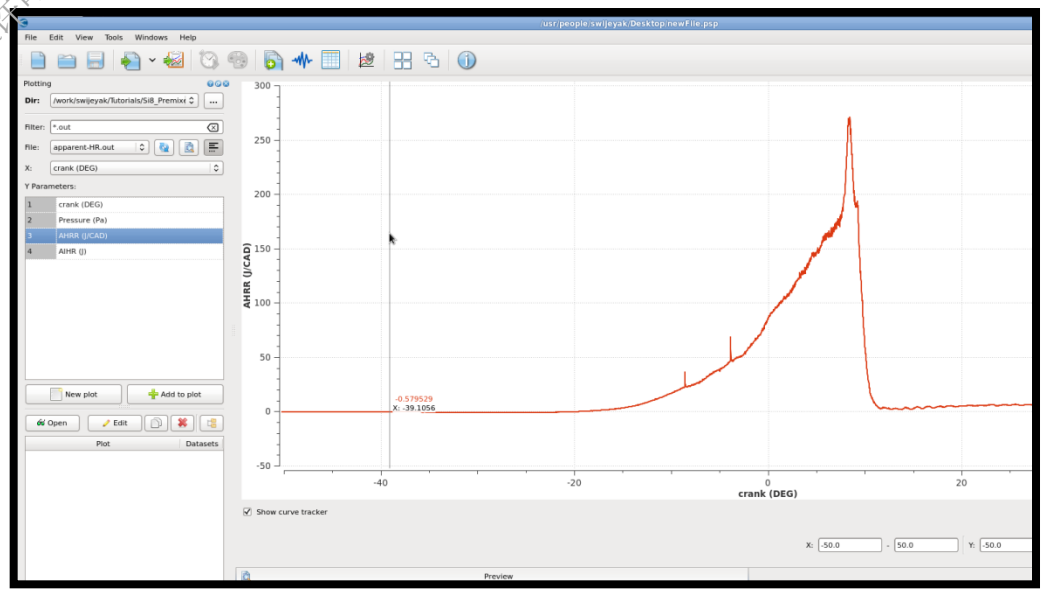
- **Engine work calculator**: Calculate engine work and indicated mean effective pressure (IMEP) for engine simulations

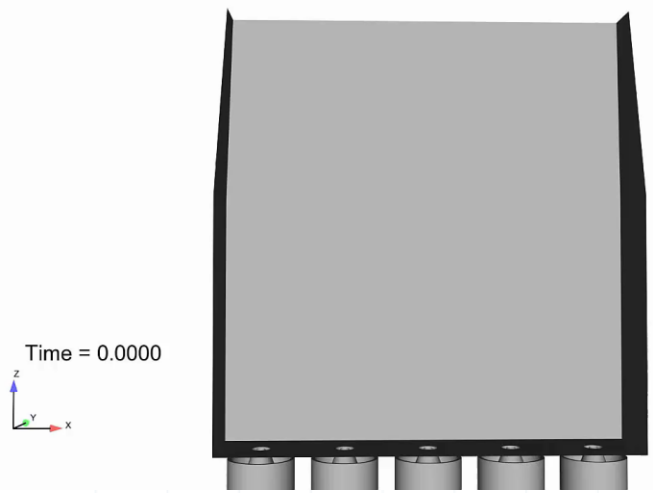


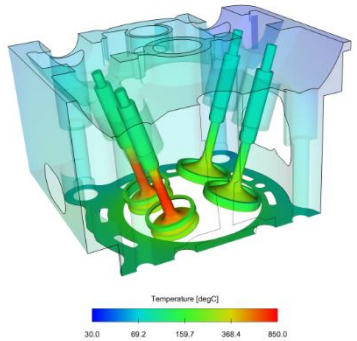
CONVERGE Studio: Line Plotting (3/3)

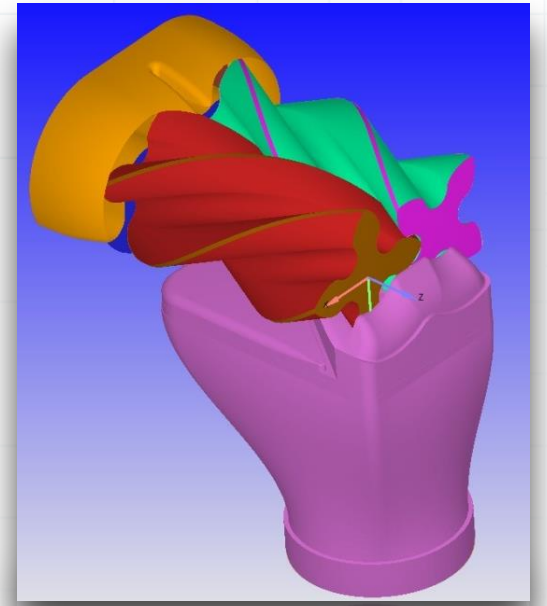
- **Apparent heat release rate (AHRR) calculator**: Calculator updates allow you to read pressure data from a specific range of crank angles, read gamma from a specified file and column, and interpolate gamma and pressure between the available data











THANK YOU!

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