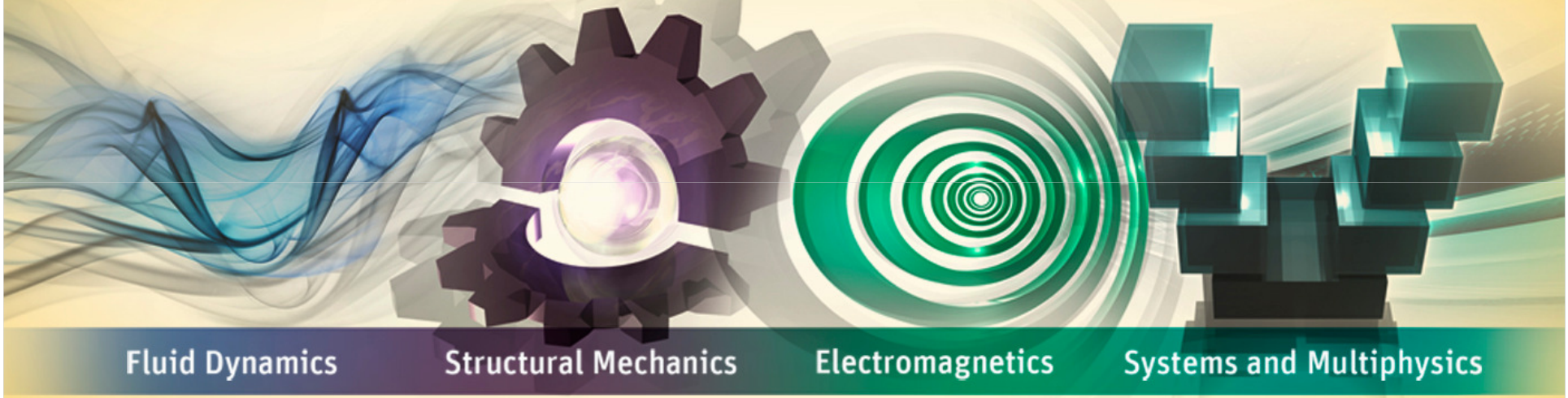
ANSYS

Realize Your Product Promise™

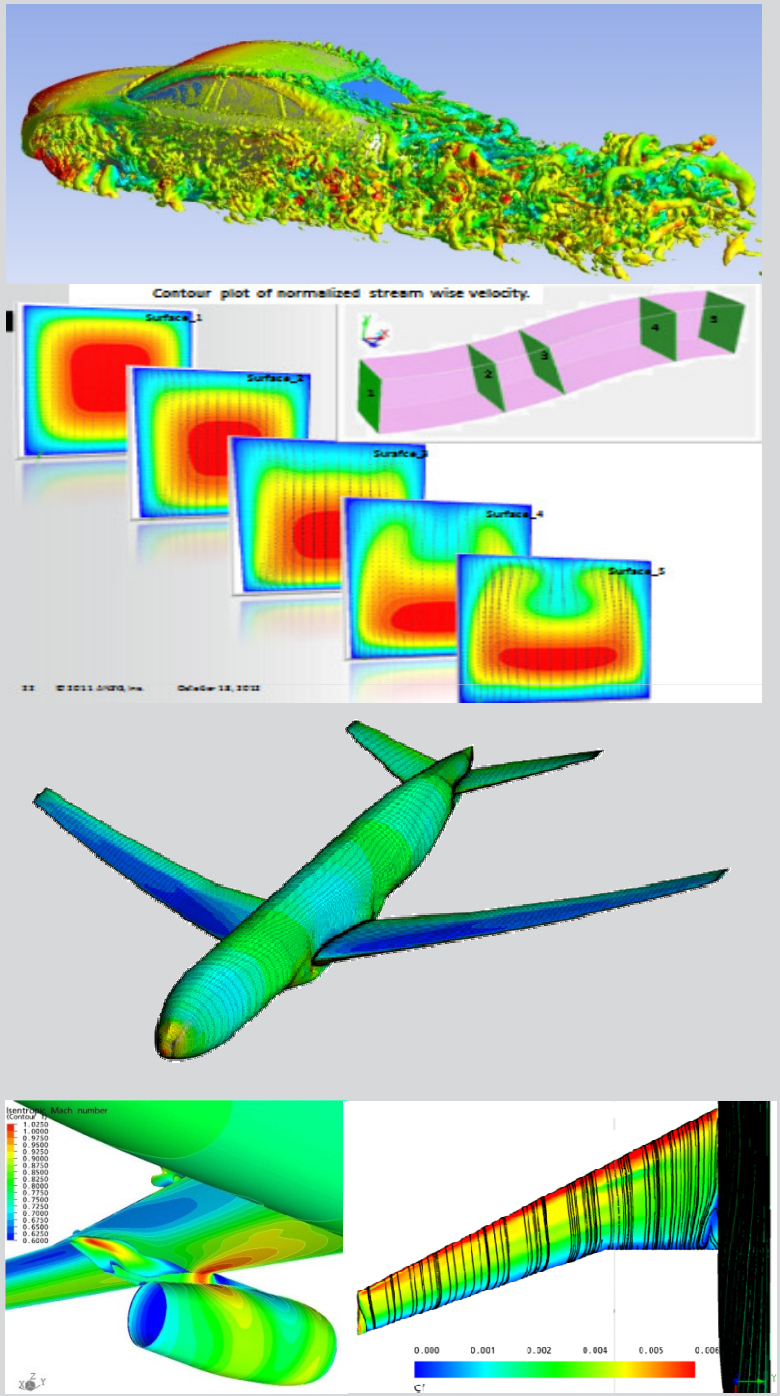
A Database of ANSYS Fluid Solver Verification & Validation Tests based on ANSYS EKM



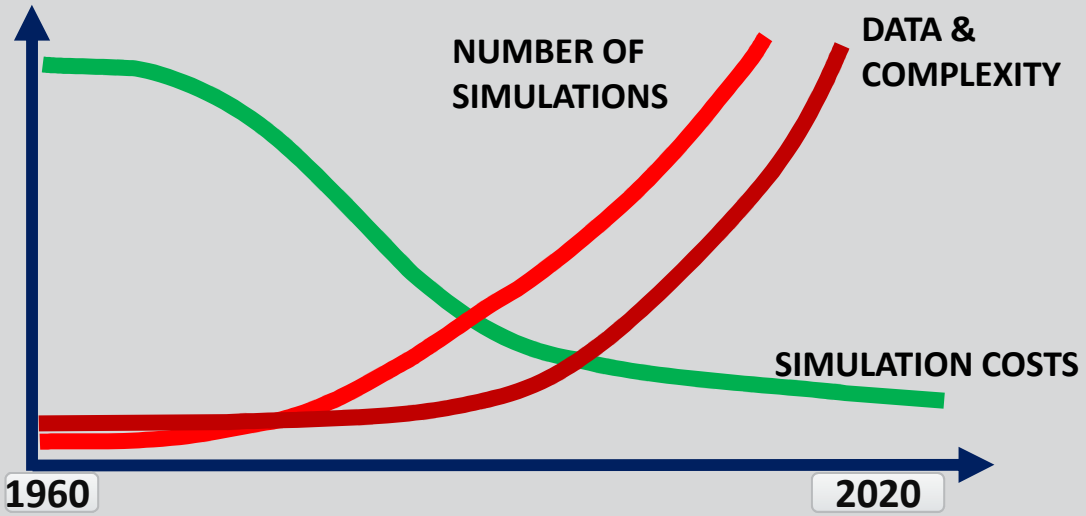
Thomas Frank
ANSYS Fluids Validation Manager
ANSYS Germany, Otterfing
Thomas.Frank@ansys.com

Outline

- Introduction
- The target of a centralized ANSYS CFD V&V test case database
- The solution – ANSYS EKM
  - The technical infrastructure
  - The database structure
  - The ANSYS EKM implementation
  - EKM V&V database usage scenarios
  - The V&V database content
- Future outlook on ANSYS CFD V&V



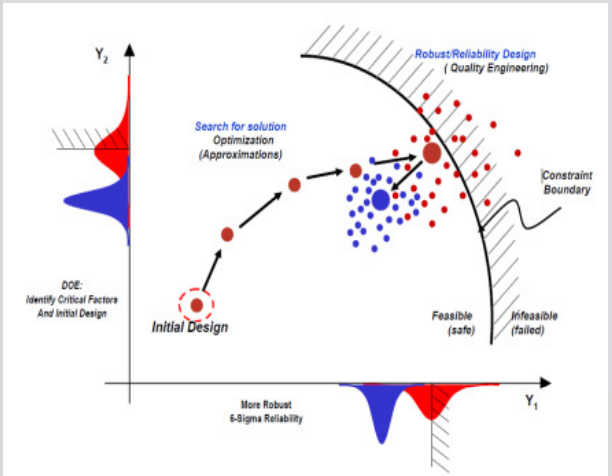
Introduction: CAE Trends



Traditional Growth – Linear
Robust Design & Parametric Studies – Exponential

- *Reduced costs & increased CFD capabilities drive the increased use of CFD in industrial design processes*
- *CFD use for efficiency optimization of designs*
  - → *CFD based design decisions*
  - → *increased importance of thoroughly validated CFD model capabilities & CFD Best Practice*

Network Speed
Computer Speed
Hardware Parallel Computing



SIMULATION MATURITY

Component | Subsystem | System

TECHNOLOGY DRIVES SYSTEMS SIMULATION & ROBUST DESIGN

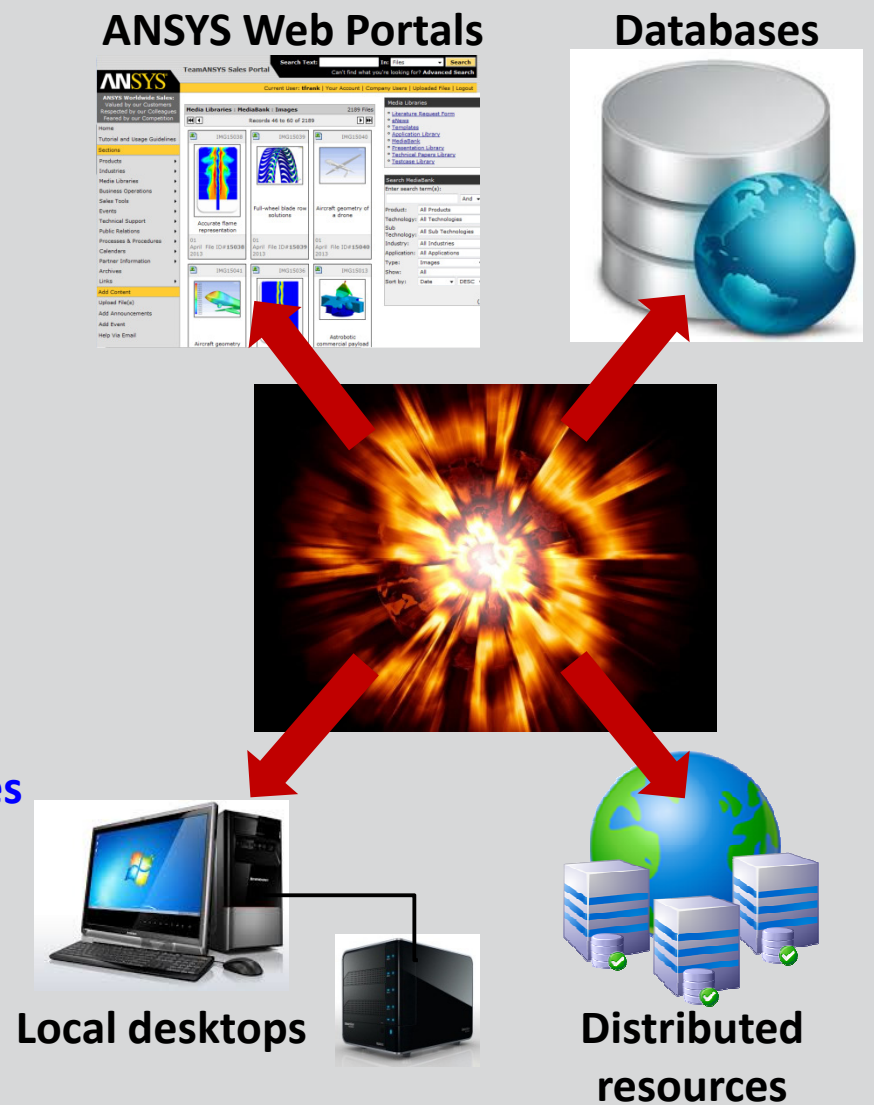
Introduction – CFD Solver V&V

- Verification & validation has long tradition in CFD solver development
- 2000-2004 : QNET-CFD
  EU Network on Quality and Trust in the Industrial Application of CFD
  → ERCOFTAC CFD BPG's
- OECD/NEA WGAMA
  (Working Groups on Management of Accidents)
  → CFD V&V related activities since ~1998
  → ISP's (Intl. Standard Problems)
  → CFD Validation Benchmarks
- ASME V&V 10-2006 - Guide for V&V in Computational Solid Mechanics
- ASME V&V 20-2009 - Standard for V&V in CFD and Heat Transfer
- ASME V&V conferences since 2012

The Historical ANSYS Picture

ANSYS CFD Solver V&V had historically several issues:

- Distributed & loosely coordinated CFD solver V&V activities
- Many different repositories and sources for CFD solver V&V material
  - 2000-2007 the technical infrastructure has not yet allowed to centralize repositories of large CFD data
  - Islands of validation data & studies
    - Global web portals & intranet sites
    - Databases & local desktop repositories
  - Data duplication
  - "Reinventing" solution strategies / cases
    - Customer support and CFD solver development repositories
    - World-wide ANSYS offices & Channel partners



ANSYS CFD Solver V&V Initiative

The Target:

- Collect and store all investigated V&V test case material for ANSYS CFD solver products in a single place in a unified format
- Establish unified V&V procedures based on the ERCOFTAC CFD Best Practice Guidelines (2000) and the ASME V&V 20 Standard (2009)
- Establish a quality assurance and test case reviewing process
- Providing ANSYS customers with high quality CFD solver validation material
- Establish permanent improvement of our CFD solver products as integral part of software development process by investigating validation cases alongside code implementation
- Enable for world-wide ANSYS staff:
  - Easy access to the V&V test case database (doc, search, retrieval)
  - Knowledge sharing and leveraging
  - Team collaboration on ANSYS CFD solver V&V and model development
  - Support for sales & marketing teams

The Solution for V&V Database – ANSYS EKM

DATA MANAGEMENT

File Repository

Meta-Data Extraction

Advanced Search

Data Mining

Report Generation

PROCESS MANAGEMENT

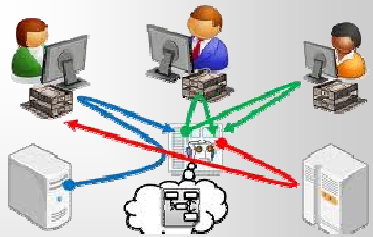
Automate Processes

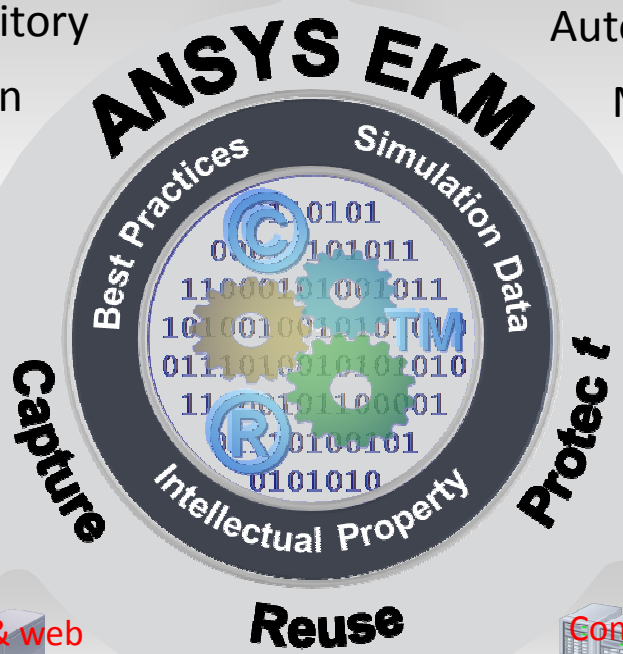
Manage Workflows

Design Systems

E-mail Notification

Track Progress





File & web servers

Compute server

End user

Enterprise Access

Web Enabled

Application Portal

Job Submission

ACCESS MANAGEMENT

The Solution for V&V Database – ANSYS EKM

DATA MANAGEMENT

File Repository

Meta-Data Extraction

Advanced Search

PROCESS MANAGEMENT

Automate Processes

Manage Workflows

Design Systems

- **EKM provides more than a web portal or a plain file server**
- **Ability to easily store & retrieve simulation data**
- **Automated metadata extraction on upload**
- **Compatible with all ANSYS products and other CAE data**
- **Efficient team collaboration platform**
- **Advanced meta-data based search, test case property, Quality Assurance & workflow management**

Enterprise Access

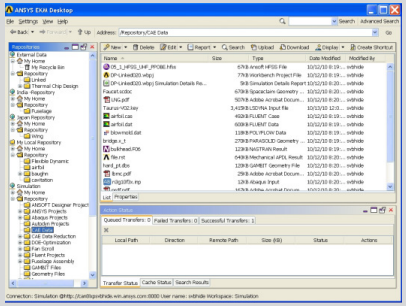
Web Enabled

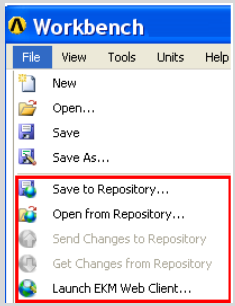
Application Portal

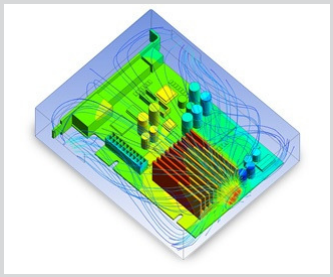
Job Submission

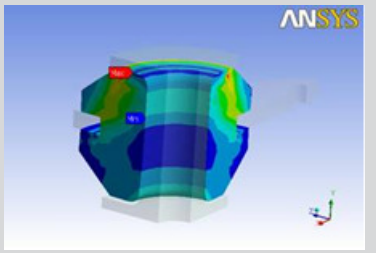
ACCESS MANAGEMENT

Easy Access to ANSYS EKM







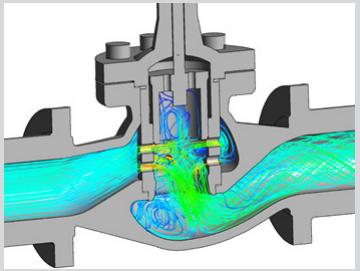


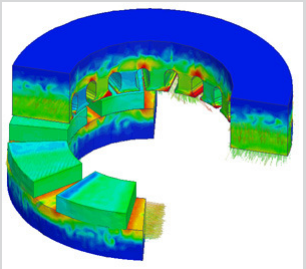
ANSYS WB or EKM Desktop

Installed by default with ANSYS WB

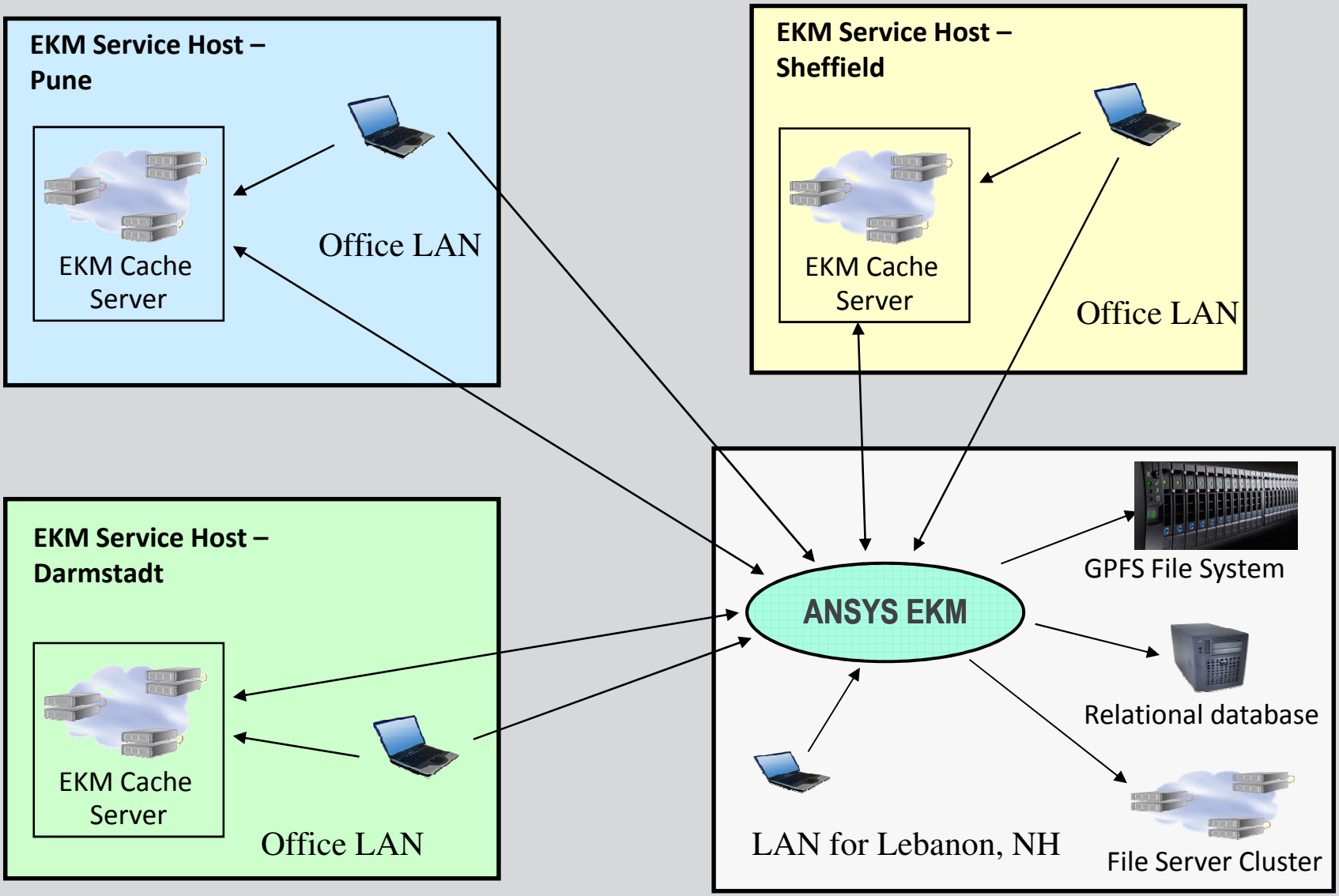
WEB UI

Doesn't need any installation!!

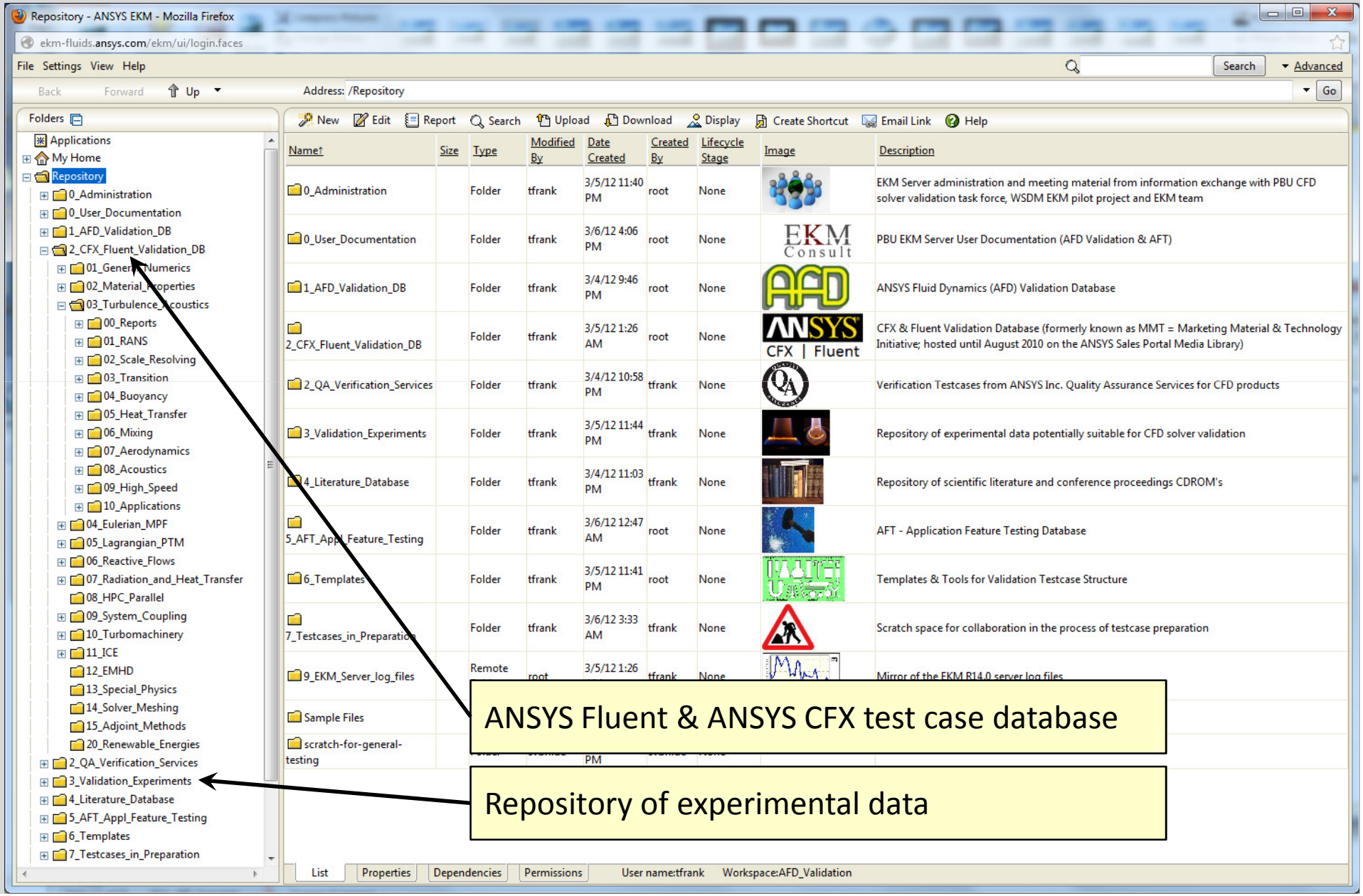




World-wide distributed EKM Infrastructure



Fluid Solver V&V Database EKM Server



V&V Database Structure

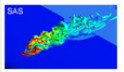
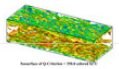
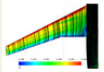
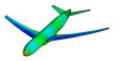
Database asset = Validation Test Case
= EKM Customized Type
= folder structure + EKM properties + lifecycle management workflow

File Settings View Help — Search — Advanced

Back — Forward — Up — Address: Search Results — Go

Folders — Clear Results — Edit Query — Save As — Search Reports

- Applications
- My Home
- Repository
  - 0_Administration
  - 0_User_Documentation
  - 1_AFD_Validation_DB
  - 2_CFX_Fluent_Validation_DB
    - 01_General_Numerics
    - 02_Material_Properties
    - 03_Turbulence_Acoustics
      - 00_Reports
      - 01_RANS
      - 02_Scale_Resolving
      - 03_Transition
      - 04_Buoyancy
      - 05_Heat_Transfer
      - 06_Mixing
      - 07_Aerodynamics
      - 08_Acoustics
      - 09_High_Speed
      - 10_Applications
    - 04_Eulerian_MPF
    - 05_Lagrangian_PTM
    - 06_Reactive_Flows
    - 07_Radiation_and_Heat_Transfer
    - 08_HPC_Parallel
    - 09_System_Coupling
    - 10_Turbomachinery
    - 11_ICE
    - 12_EMHD
    - 13_Special_Physics
    - 14_Solver_Meshing
    - 15_Adjoint_Methods
    - 20_Renewable_Energies

/03_Turbulence_Acoustics/02_Scale_Resolving /Val_med_Trailing_Edge_Separation_WMLES		03 TC Template Folder	10:52 AM	Public	13.0	1) Unrestricted	2_Validation		WMLES of Trailing Edge Separation
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/02_Scale_Resolving /Val_xtrm_Hot_Jet_in_Crossflow		03 TC Template Folder	1/29/13 10:52 AM	Released	13.0	3) Restricted	2_Validation		Investigation of hot jet in cross-flow by applying scale-resolving turbulence models (SAS, DDES, ELES) and by investigating hexahedral, hybrid tetrahedral and hybrid cartesian meshes
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/02_Scale_Resolving /Ver_med_Periodic_Channel_WMLES		03 TC Template Folder	1/29/13 10:52 AM	Public	13.0	1) Unrestricted	2_Validation		Wall Modeled LES (WMLES) of periodic channel for different Reynolds numbers
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/04_Buoyancy/Saline_Mixing_Layer		03 TC Template Folder	2/19/13 3:58 PM	Public	12.0	1) Unrestricted	2_Validation		Turbulent mixing and buoyancy in a stable stratification layer of fresh water and salt water (experiment by Uittenbogaard, 1995)
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/04_Buoyancy /Val_low_Differentially_Heated_Cavity		03 TC Template Folder	1/29/13 10:52 AM	Public	11.0 and earlier	1) Unrestricted	2_Validation		Natural convection in a differentially heated cavity
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/04_Buoyancy /Val_low_Natural_Convection_BL		03 TC Template Folder	1/29/13 10:52 AM	Public	13.0	1) Unrestricted	2_Validation		Natural convection boundary layer with laminar-turbulent transition; 1-equation intermittency transition model
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/04_Buoyancy /Val_xtrm_Inclined_Pipe_Buoyancy		03 TC Template Folder	1/29/13 10:52 AM	Public	13.0	2) Acknowledgement Required	2_Validation		Bouyancy-driven natural convection flow of refrigerant R125 in supercritical state in an inclined pipe with differentially heated/cooled copper plates at both ends of the pipe (HySIM project testcase)
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/07_Aerodynamics/Val_med_RAE-2822-Transonic-Airfoil		03 TC Template Folder	1/29/13 10:52 AM	Public	12.0	1) Unrestricted	2_Validation		RAE-2822 Transonic Airfoil Testcase
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/07_Aerodynamics/Val_xtrm_DPW-01_DLR-F6_Engine_Airframe		03 TC Template Folder	1/29/13 10:52 AM	Public	12.0	1) Unrestricted	2_Validation		1st AIAA Drag Prediction WS - Drag Prediction of Engine-Airframe Interference Effects
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/07_Aerodynamics/Val_xtrm_DPW-03_DLR-F6_Wing_Body		03 TC Template Folder	1/29/13 10:52 AM	Public	11.0 and earlier	1) Unrestricted	2_Validation		3rd AIAA Drag Prediction Workshop - Investigation of Wing-Body Configuration
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/07_Aerodynamics/Val_xtrm_DPW-04_Wing_Body_Stabilizer		03 TC Template Folder	1/29/13 10:52 AM	Public	12.0	1) Unrestricted	2_Validation		4th AIAA Drag Prediction Workshop - Simulation of Airplane with Horizontal Stabilizer
/Repository/2_CFX_Fluent_Validation_DB /03_Turbulence_Acoustics/07_Aerodynamics /Val_xtrm_High_Lift_Prediction_WS-1		03 TC Template Folder	1/29/13 10:52 AM	Public	13.0	1) Unrestricted	2_Validation		1st AIAA CFD High Lift Prediction Workshop (HiLiftPW-1)

V&V Database – Test Case Structure

Basic asset – the V&V test case:

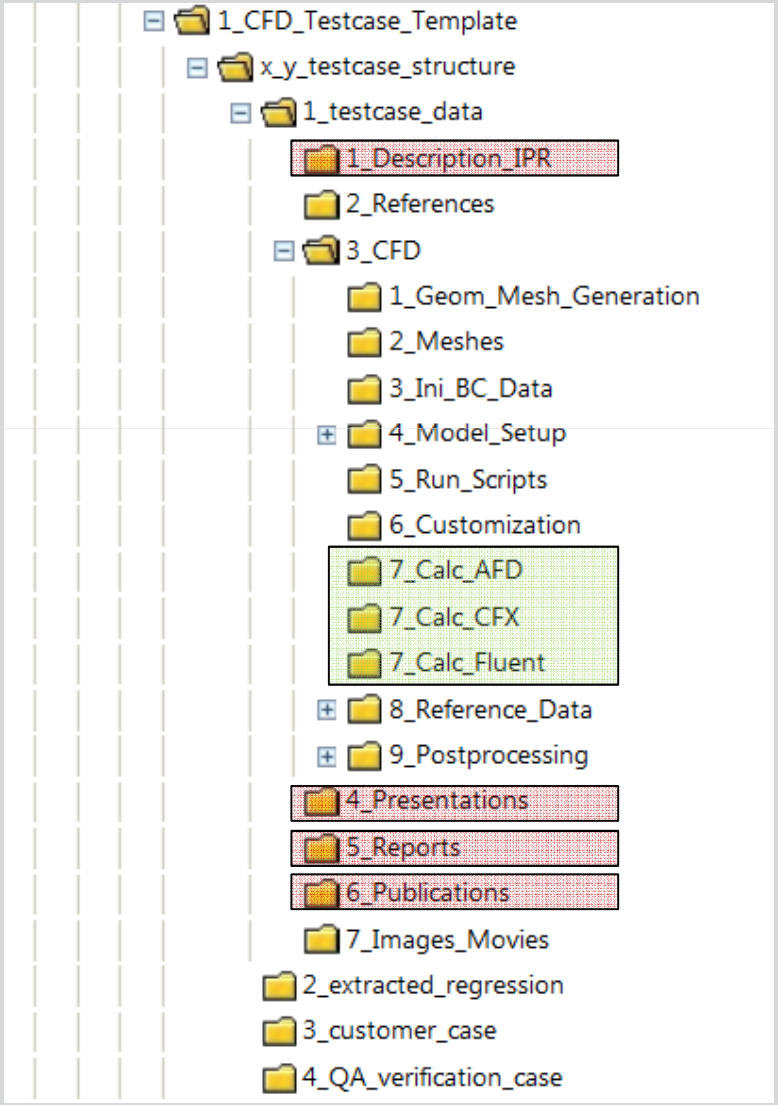
- Legal matter
- References
- Experimental data
- CFD Investigation
- Documentation
- Marketing material
- Classification & keywords

⇒ Unified folder structure

⇒ Assigned EKM properties

⇒ Connected quality assurance process

⇒ Connected access control



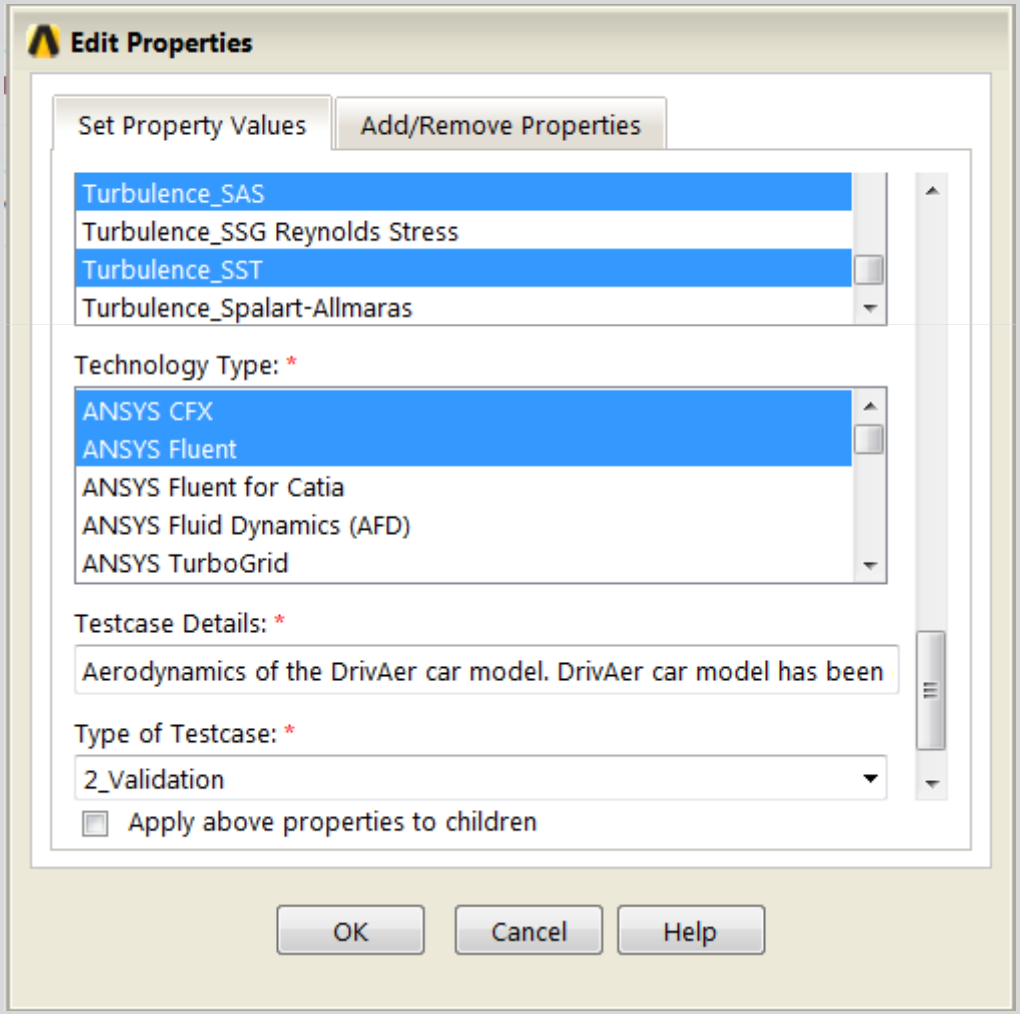
V&V Database – Test Case EKM Properties

Assignment of collateral information to test cases:

- EKM properties for basic assets
  - Type of test case
  - Short description
  - ANSYS Release
  - IPR status
  - Status of investigation
  - Man hours & comp. effort
  - Technology area / CFD solvers
  - Keywords

⇒ Defined in EKM customized folder type (the basic asset type)

⇒ Basis for property based search



V&V Database – Lifecycle Management

Quality assurance and reviewing process:

- EKM LCM defines workflow for review and approval
- LCM stage automatically changes access permissions for database assets

Team leader, EKM server / validation manager

Test case creators

TC uploaded to EKM
Author access / Manager notification for TC approval

TC approved and made visible for Development Teams

TC approved and made visible for ANSYS-wide use

TC archived
Access restricted to author & dev. team

Defined V&V Processes: CFD Best Practice

Quantification of the simulation error

Thoroughly documentation of the test case

Numerical error

- Iteration error → depth of convergence, residual level
- Round-off (computer) error → single vs. double precision
- Discretization error → mesh resolution & time step independence

Model error

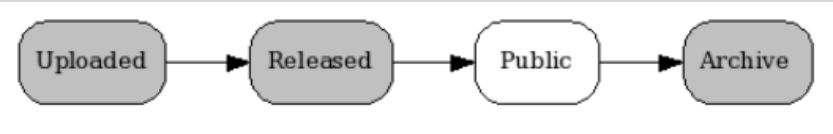
- Sensitivity to physical model(s) involved
- How empiricism affects simulation accuracy

Systematic error

- Remaining reason(s) simulation & reality do not match
- Uncertainties in experimental setup & data
- Simplified geometry, simplified flow physics (?), fluid properties, boundary conditions, steady vs. unsteady, modeled vs. resolved physics (e.g. RANS vs. LES), etc.

Usage Scenarios – Accessing Information (I)

- **Metadata are automatically extracted from all uploaded files**
- **Extraction of simulation details report from ANSYS CAE files**
- **Protocol of lifecycle stage changes → traceability**

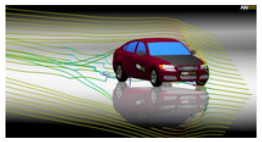


9/24/12 2:54 PM	jsanyal	State change proposed from Uploaded to Released	files uploaded
9/24/12 2:54 PM		Signoff started	
9/24/12 3:44 PM	sjain	Review started	
9/24/12 8:29 PM	sjain	Approved	promoted by sj
9/24/12 8:29 PM		Signoff completed	
9/24/12 8:29 PM		State change completed from Uploaded to Released	
9/24/12 8:30 PM	sjain	State change proposed from Released to Public	promote to public
9/24/12 8:30 PM		Signoff started	
9/24/12 8:30 PM	sjain	Review started	
9/24/12 8:31 PM	sjain	Approved	reviewed and promoted to public by sj.
9/24/12 8:31 PM		Signoff completed	
9/24/12 8:31 PM		State change completed from Released to Public	
3/20/13 9:39 PM	sjain	State change completed from Public to Uploaded	
4/3/13 9:17 PM	jsanyal	State change proposed from Uploaded to Released	
4/3/13 9:17 PM		Signoff started	
4/3/13 9:28 PM	sjain	Review started	
4/3/13 9:43 PM	sjain	Approved	sj uploaded files with Jay.
4/3/13 9:43 PM		Signoff completed	
4/3/13 9:43 PM		State change completed from Uploaded to Released	
4/3/13 9:44 PM	sjain	State change proposed from Released to Public	
4/3/13 9:44 PM		Signoff started	
4/3/13 9:45 PM	sjain	Review started	
4/3/13 9:45 PM	sjain	Approved	Reviewed and promoted to public.
4/3/13 9:45 PM		Signoff completed	

TC Template Folder Properties:

ANSYS Release:	14.5
Completion Status:	1) Finalized
Computational Effort:	XL (more than 2 weeks)
IPR Status:	3) Restricted
Included in AFD Validation Manual:	No
Included in Fluids QA Verification Services:	No
Included in Regression Testing:	1) None
Industry Type:	Automotive, Generic for all Industries
Investment in Man Hours:	640.0
Keywords:	Turbulence_LES, Turbulence_RANS, Turbulence_SAS, Turbulence_SST, Turbulence_aerodynamics
Technology Type:	ANSYS CFX, ANSYS Fluent, Turbulence
Testcase Details:	Aerodynamics of the DrivAer car model. DrivAer car model has been created by TU Munich, Germany in collaboration with BMW and Audi as a blend of BMW 3 and Audi A4 car geometries. The simplified estate and two different fastback car models have been investigated.
Type of Testcase:	2_Validation

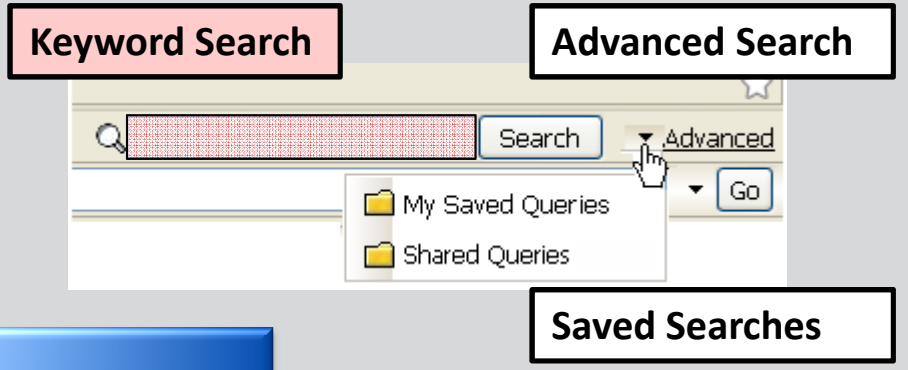
EKM Object Properties:

Checked Out By:	
Checkin Policy:	Checkin Disabled
Created By:	tfrank
Date Created:	12/19/12 10:30 AM
Date Modified:	4/10/13 8:20 AM
Description:	Aerodynamics of the DrivAer car model. DrivAer car model has been created by TU Munich, Germany in collaboration with BMW and Audi as a blend of BMW 3 and Audi A4 car geometries. The simplified estate and two different fastback car models have been investigated.
Expiration Date:	1/4/13 10:17 AM
Image:	
Lifecycle Stage:	Public

Usage Scenarios – Accessing Information (II)

EKM Plain Search:

- **Metadata can be used for plain search for database content**



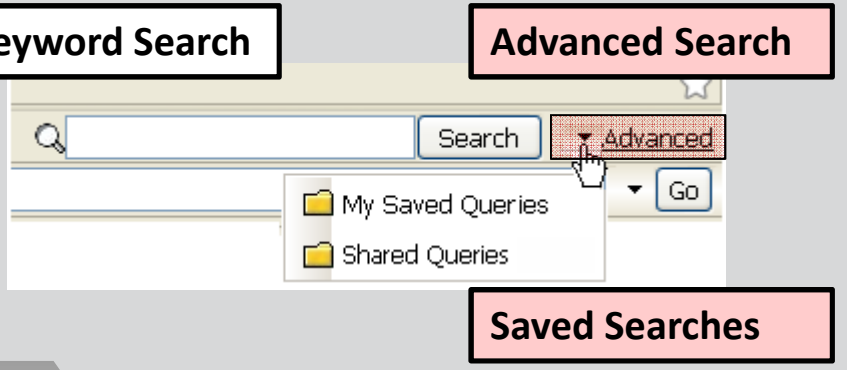
Search in Contents !

/Repository/1_AFD_Validation_DB/06_Reactive_Flows/01_Non_Premixed/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/0_Description/DLR_Combustion_Chamber_sm.png	122 KB	Image	8/10/12 2:41 PM
/Repository/1_AFD_Validation_DB/06_Reactive_Flows/01_Non_Premixed/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/0_Description/DLR_Combustion_Chamber.png	644 KB	Image	8/10/12 2:41 PM
/Repository/1_AFD_Validation_DB/06_Reactive_Flows/01_Non_Premixed/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/4_Presentations/120720_DLR_combustion_presentation_final.pptx	5,249 KB	Microsoft PowerPoint Presentation	8/10/12 2:41 PM
/Repository/1_AFD_Validation_DB/06_Reactive_Flows/01_Non_Premixed/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/7_Images_Movies/DLR_Combustion_Chamber.png	31 KB	Image	8/10/12 2:41 PM
/Repository/1_AFD_Validation_DB/06_Reactive_Flows/01_Non_Premixed/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/7_Images_Movies/DLR_Combustion_Chamber_schematic.PNG	129 KB	Image	8/10/12 2:41 PM
/Repository/3_Validation_Experiments/06_Reactive_Flows/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/3_CFD/7_Calc_Fluent/DDES_combustion_Fluent		Folder	3/7/12 1:27 AM
/Repository/3_Validation_Experiments/06_Reactive_Flows/Val_xtrm_DLR_Combustion_Chamber/1_testcase_data/7_Images_Movies/DLR_Combustion_Chamber.png	31 KB	Image	3/7/12 1:27 AM
/Repository/2_CFX_Fluent_Validation_DB/06_Reactive_Flows/06_Real_Gas/Val_med_RCM-1		Shortcut	7/3/12 4:35 PM
/Repository/4_Literature_Database/ANSYS_iacc_easc_ASWC/2012_ASCW_Detroit/1_Powertrain/validation-verification-internal-combustion-ansys.pdf	6,848 KB	Adobe Acrobat Document	2/4/13 11:45 AM
/Repository/4_Literature_Database/ANSYS_iacc_easc_ASWC/2009_easc_Frankfurt/fscommand/Simulating Internal Combustion Engines (Bauer).pdf	4,278 KB	Adobe Acrobat Document	2/1/13 3:44 PM

Usage Scenarios – Accessing Information (III)

EKM Advanced Search:

- Based on self-assigned EKM properties and automatically extracted metadata
- Logical combinations (and/or/not)
- Queries can be saved & re-used

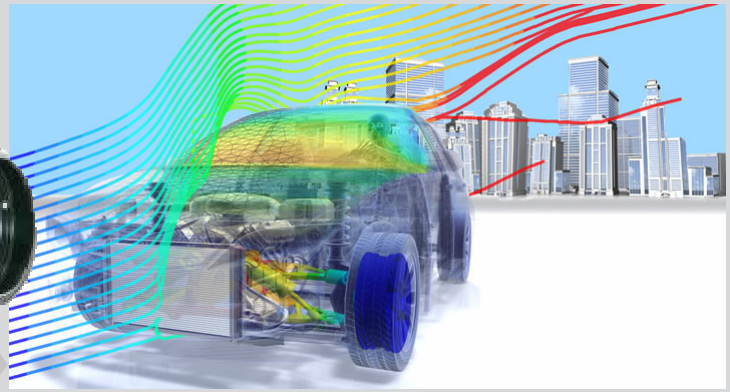


CFX Definition Properties:

Boundaries:	Housing Default, InletSide Side 2, OutletSide Side 2, Inlet, InletSide Side 1, Outlet, OutletSide Side 1, Pipes Default
CFX Version:	13.0
Combustion Model:	None
Domains:	Housing, Pipes
Heat Transfer Model:	Thermal Energy
Materials:	Air Ideal Gas, Steel
Radiation Model:	None
Time:	Steady State
Turbulence Model:	K Epsilon

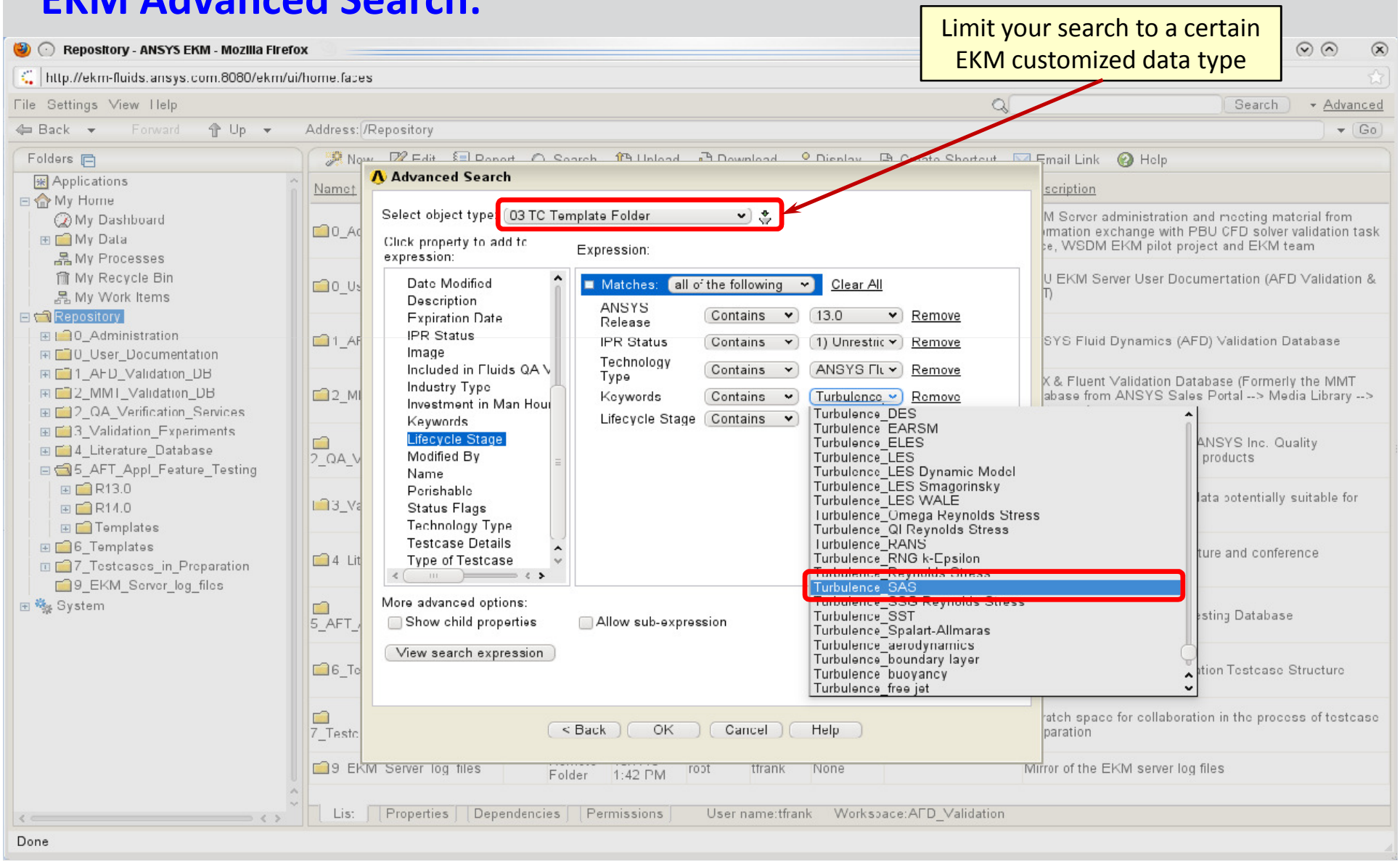
TC Template Folder Properties:

ANSYS Release:	14.5
Completion Status:	1) Finalized
Computational Effort:	XL (more than 2 weeks)
IPR Status:	1) Unrestricted
Included in AFD Validation Manual:	No
Included in Fluids QA Verification Services:	No
Included in Regression Testing:	1) None
Industry Type:	Chemical and Petrochemical, Environmental, Generic for all Industries, Oil and Gas, Power Generation, Process Technology
Investment in Man Hours:	200.0
Keywords:	EulerianMPF_fluidized bed, EulerianMPF_gas solid, EulerianMPF_granular temperature, EulerianMPF_kinetic theory, EulerianMPF_solids pressure
Technology Type:	ANSYS Fluent, Eulerian Multiphase
Testcase Details:	Validation of NETL Circulating Fluidized Bed (CFB) benchmark test case using Eulerian Granular Multiphase models
Type of Testcase:	2_Validation



Usage Scenarios – Accessing Information (IV)

EKM Advanced Search:



CFD Solver V&V Database Status (May 2013)

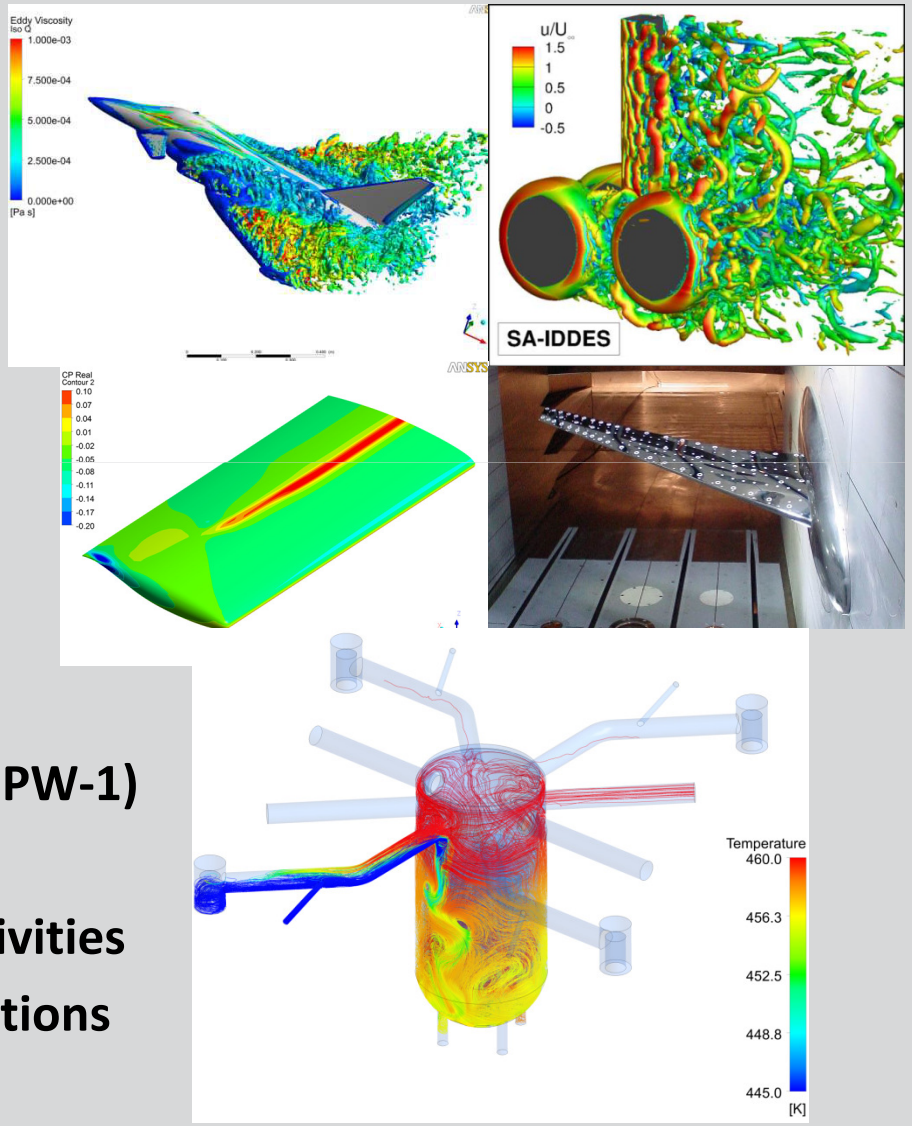
- **Approx. 220 test cases in 14 technology areas (~2.0 Tb):**

Technology area	Subareas	Test cases
01 – General Numerics	-	10
02 – Material Properties	-	3
03 – Turbulence Acoustics	10	93
04 – Eulerian Multiphase Flows	10	46
05 – Lagrangian Particle Tracking	7	14
06 – Reactive Flows / Combustion	9	17 (+ 1× ICE)
07 – Radiation & Heat Transfer / CHT	-	8
08 – HPC / Parallel Computing	-	-
09 – FSI & System Coupling	-	9
10 – Turbomachinery	2	10
11 – Internal Combustion Engine (ICE)	-	3
12 – EMHD	-	-
13 – Special Physics	-	-
14 – Solver Meshing	-	2

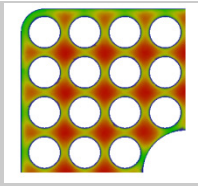
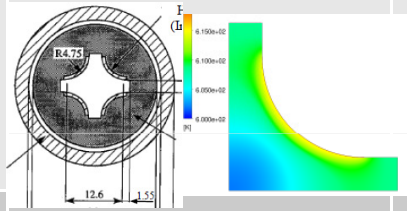
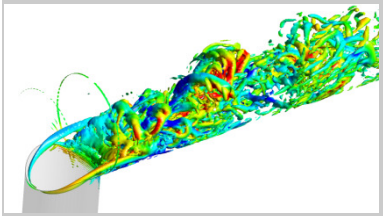
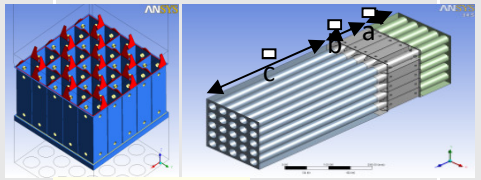
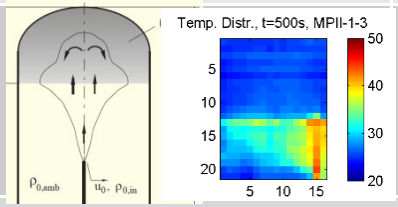
CFD Solver V&V Database – The Content

Sources of validation test cases:

- ANSYS CFD solver development V&V
- ANSYS internship students program
- Customer driven benchmarks
- ANSYS participation in R&D projects funded by EU & national organizations
- ANSYS participation in international CFD benchmark activities
  - AIAA 1st – 4th Drag Pred. WS
  - AIAA 1st & 2nd HiLift Pred. WS
  - AIAA 1st Aeroelasticity workshop (AePW-1)
  - OECD/NEA → see next slide
  - ERCOFTAC & ECCOMAS CFD V&V activities
- ANSYS conference & workshop publications based on CFD studies



OECD/NEA CFD V&V Benchmarks

Year	Title	Geometry	ANSYS Partici-pation
2004-2009	OECD/NRC Benchmark based on NUPEC BWR Full-size Bundle Test Sixth Workshop – BFBT		Fluent/ indirect
2009-2011	OECD/NEA & NUPEC PWR Sub-channel Bundle Tests Benchmark - PSBT		yes
2009-2011	OECD/NEA–Vattenfall T-Junction Benchmark on Turbulent Thermal Mixing and Thermal Fatigue Phenomenon		no/ indirect / post-test
2011-2013	OECD/NEA–KAERI MATiS-H Benchmark on Turbulent Flow Through 5x5 Rod Bundle with Spacers (Split and Swirl Type)		yes
2013-2014	Proposal : OECD/NEA – PSI CFD Benchmark on Erosion of a Stratified Layer by a Buoyant Jet in a Large-Scale Containment Facility		yes

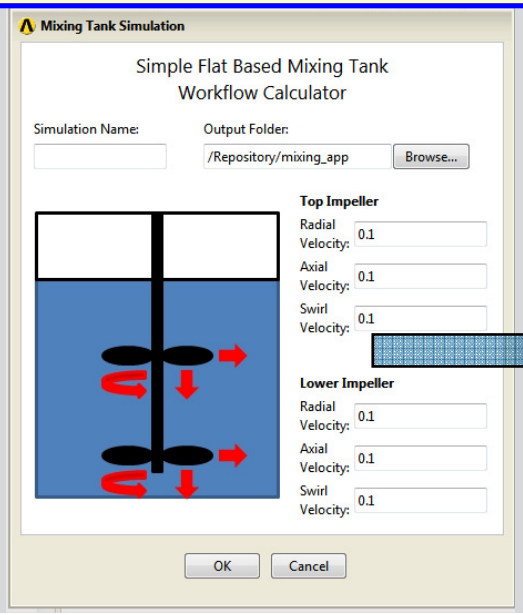
V&V Database – Future Outlook

Future development of the CFD Solver V&V database on EKM:

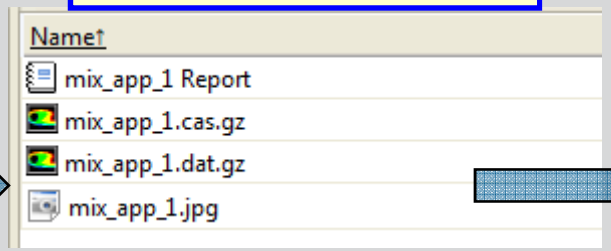
- Filling the gaps in our validation matrix for the ANSYS CFD solvers
- EKM R&D for automated & regular execution of V&V test cases
- Automated cross-comparison for V&V tests using different solver versions
- Linux cluster uplink for the EKM server and remote execution
- Automated postprocessing, acceptance criterion evaluation

  ⇒ Partially possible already today; more a usability / ease-of-use issue

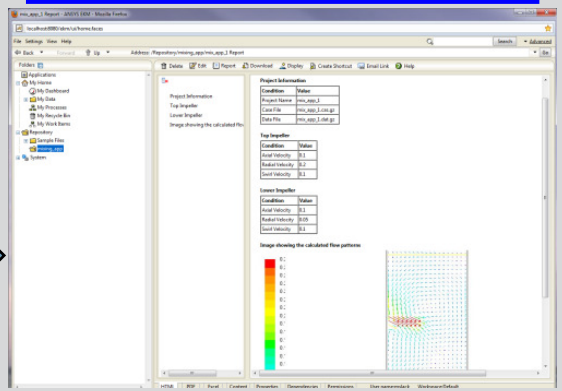
EKM controlled remote cluster execution



EKM re-import of results



EKM results visualization and automated cross-comparison



Summary & Outlook

- **With ANSYS EKM as the technical platform ANSYS is getting close to reach the set goal of:**

  Collect and store all available ANSYS CFD solver V&V test case material
  ⇒ in a single place
  ⇒ in a unified format
  ⇒ with a well-defined V&V process for the case studies
  ⇒ and with QA by an established test case reviewing process
  ⇒ Enable ANSYS world-wide access, knowledge sharing & team collaboration
  ⇒ Provide ANSYS customers with high quality CFD solver validation

- **ANSYS EKM has proven as a mature and flexible SDPM solution used today by ~1300 users in all world-wide ANSYS offices**
- **ANSYS is continuously investing in high verification and validation standards for the developed ANSYS software**

ANSYS

ANSYS®

Thank you!