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VERIFICATION AND QUALITY ASSURANCE IN THE SIMULATION ANALYSIS PROCESS

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Quality & Reliability of CFD Simulations
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- Project and analysis objectives
- Input control
- Process quality assurance
- Client communication and summary

Introduction

Simulation analysis process is used increasingly in the engineering world to complement experimental and testing programmes or even to substitute them !

Simulation process and its benefits

- greater flexibility in managing ‘testing’ environment
- faster turn-around time
- more comprehensive post-processing options
- lower costs

Introduction

Fundamental differences between the simulation analysis process and physical experimentation or testing

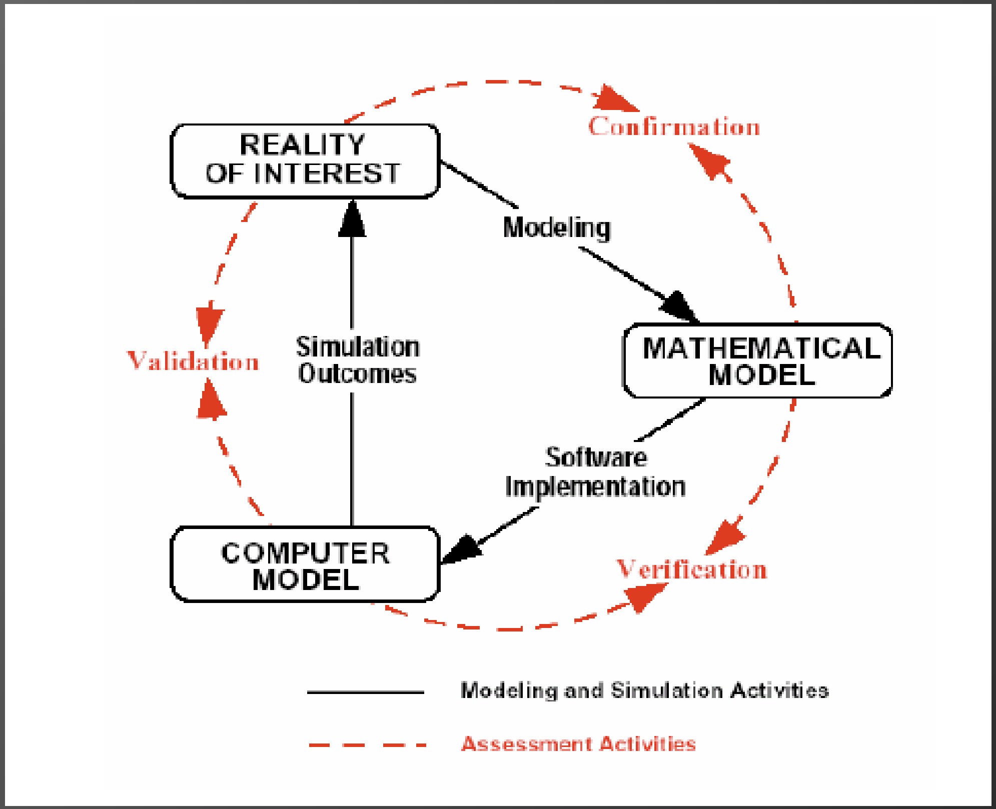


Figure 1: Concept relations in modelling analysis [1]

Introduction

Simulation analysis approach - greater flexibility, but larger errors incorporated much faster in the development process

Quality assurance (QA) processes - avoiding mistakes and mitigating their impact

- well established part of the engineering design and manufacturing procedures
- not always extend to the engineering analysis
- requirements have been defined (ISO-9001, 10CFR50 Appendix B, 10CFR21 and NQA-1).

Project and analysis objectives

Clearly defined analysis objectives, agreed between all stakeholders

- The analysis output; its content and form
- Separation of design process and analysis objectives
- Information propagation & understanding the analysis objectives

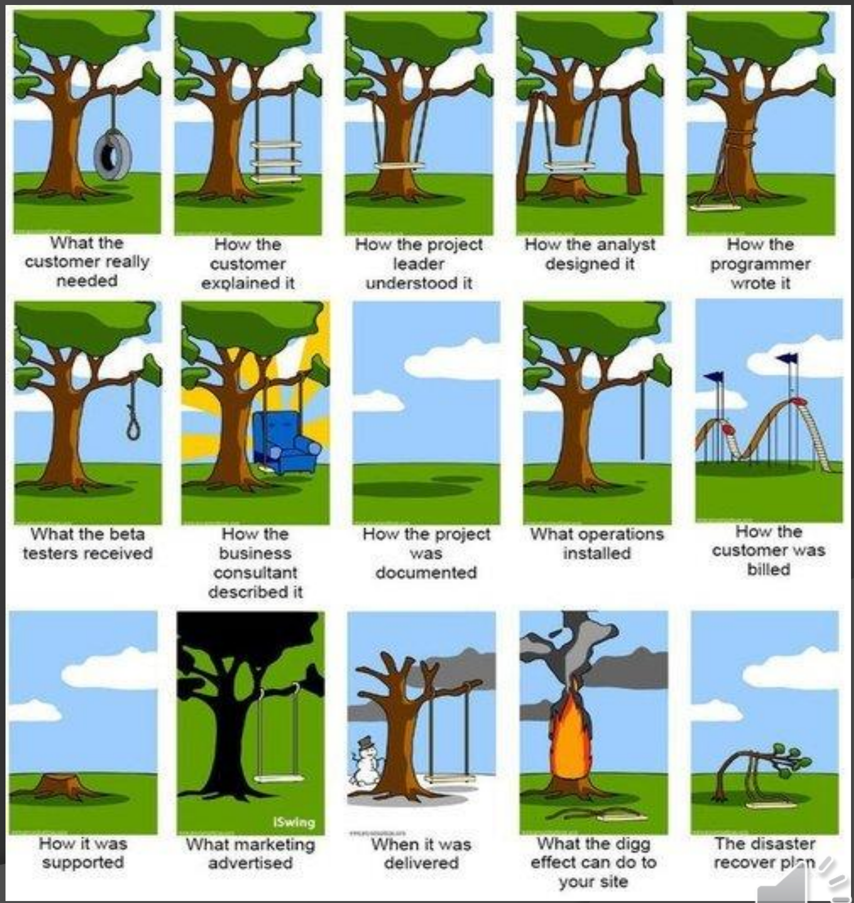


Figure 2:

Project and analysis objectives

- Quality parameters as an integral part of analysis objectives

Input control

Elements of input control process

- Toolset control (e.g. knowledge base, hardware, software)
- Personnel (e.g. suitable degree level, skills and experience)
- Analysis and quality control procedures (e.g. lumped parameter modelling, CFD)
- Project specifications and requirements

Generic activities and their applicability to different projects

Validation and verification - an integral part of the input QA control

Input control

Benchmarks – well documented cases that are used to independently validate and verify the declared software capabilities

- Validation – accurate representation of the real world

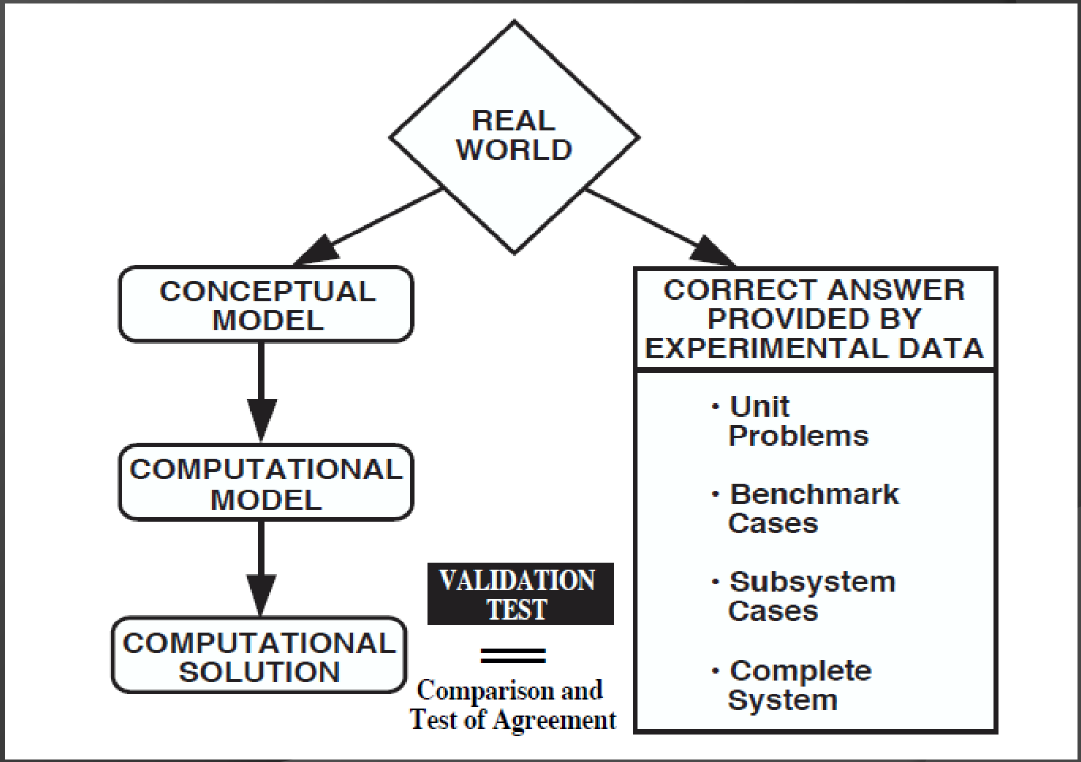


Figure 3: Validation process [2]

Input control

- Verification – accuracy of model implementation

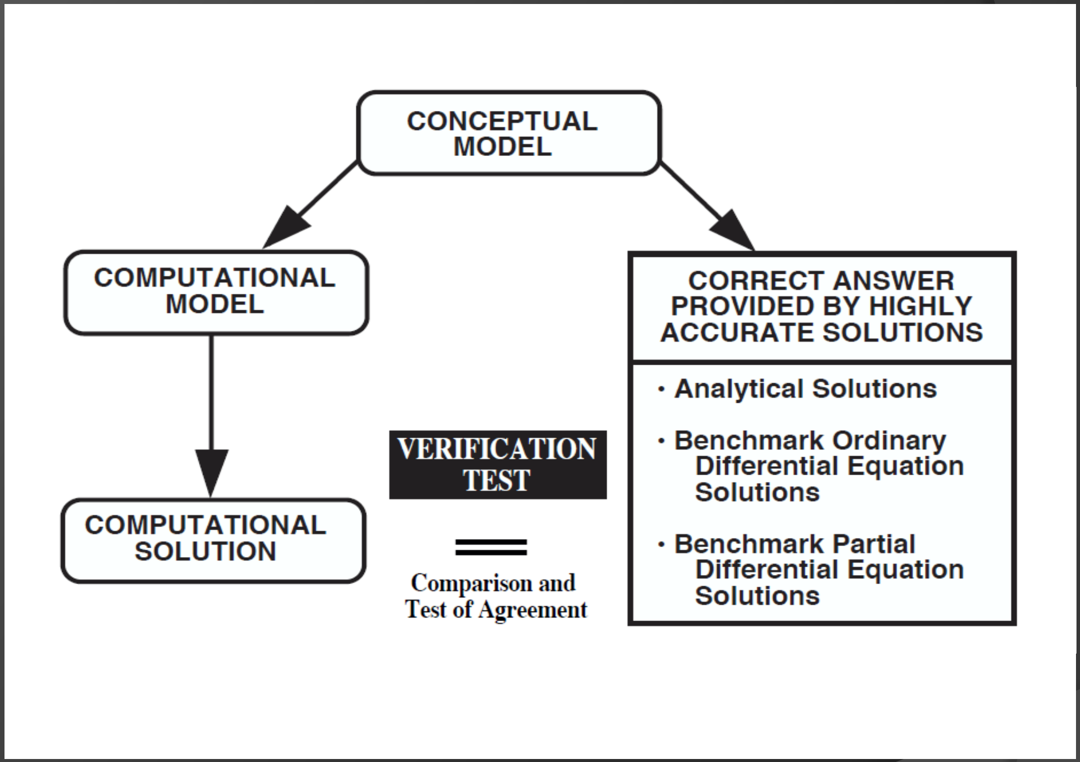


Figure 4: Verification process [3]

Input control

- Start of validation and verification efforts in CFD in 1970s
- Well accepted methodology and the associated terminology
- A number of online resources (e.g. ERCOFTAC, NASA, Uni. Manchester) with experimental databases, conferences and periodic exercises
- Strong focus on turbulence modelling
- Complexity and coupled nature of modelling problem (e.g. turbulence, multiphase, combustion, structural mechanics, electro-magnetics etc)
- Lack of supporting experimental data and theoretical investigations

Input control

- Commercial software vendors and validation / verification process
- Independence of the software validation and verification
- Individual projects and related modelling analysis “prototyping”

Input control

Recent EFDA sponsored 3PT project to examine readiness of available modelling software tools for coupled analyses in fusion technologies

- Pre-processing capabilities
- Simulation methods
- Fluid mechanics
- Heat transfer
- Multiphase modelling
- Structural mechanics
- Multibody mechanics
- Electromagnetics
- Neutronics
- Parallel processing
- Post-processing and visualisation

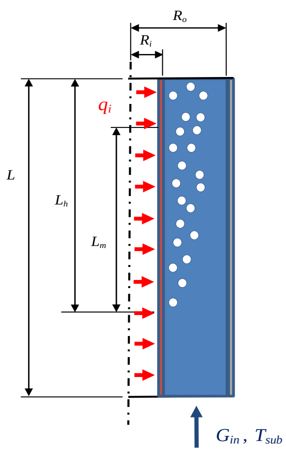
A number of benchmark cases covering relevant analysis areas

Input control

CCFE – Culham Centre for Fusion Energy	WALL BOILING	TEST NO 7	DATE / ISSUE 2013/07/26

ORIGIN	PPPT project
ANALYSIS TYPE	Multiphase, boiling analysis
OBJECTIVES	Testing of vapour volume fraction distribution

GEOMETRY



Annular domain height (L) is 2.376 m
Heating section height (L_h) is 1.670 m
Distance to the measuring plane (L_m) is 1.610 m
Outer radius of the inner tube (R_i) is 0.0095 m
Inner radius of the outer tube (R_o) is 0.01875 m

MATERIAL PROPERTIES	Material properties of water - vapour mixture covering the pressure range between 1 and 2 bar, and the temperature range between 30°C of subcooling and the saturation conditions.
LOADING	A limited set of experimental cases [2] is selected with • inlet mass flux G_{in} = 715.2, 714.4, 716.4 kg m^{-2} s^{-1} • inner wall heat flux q_i = 139.1, 197.2, 232.4 kW m^{-2}
INITIAL CONDITIONS	Due to the steady-state nature of the boiling heat transfer case, initial conditions are not important. They should be used to enhance stability of the solution procedure.
BOUNDARY CONDITIONS	At the inlet, the following mass flux values and subcooling temperatures used in the experiments [2] are prescribed: • G_{in} = 715.2, 714.4, 716.4 kg m^{-2} s^{-1} • T_{sub} = 12.0, 13.8, 14.9 °C At the outlet, a fix pressure should be set. It has to be adjusted to meet the requested inlet subcooling conditions. Due to pressure dependence of the boiling location, it may be more suitable to imposed fix total pressure conditions at the inlet and mass flux at the outlet. At the inner wall, fix heat flux values are prescribed: q_i = 139.1, 197.2, 232.4 kW/m^2 The external wall can be kept adiabatic.

MESH ELEMENTS

Such multiphase simulations in simple geometries are most often performed using a hexahedral mesh although other mesh types are not discouraged.

Maximum grid spacing should be below 0.01 m in the vertical direction, and below 0.0004 m in the radial direction. In the tangential direction, a finite volume should not cover an angle that is larger than 3°.

It is expected that mesh independency of the simulation results is demonstrated.

OUTPUT	The experimental results cover the radial distribution of water vapour volume fraction, liquid and vapour velocity at the plane elevation L_m. They are shown below. The modelling results should be compared with the experimental data for the above listed sets of parameters (i.e. inflow max flux G_i, subcooling temperature T_{sub} and the wall flux q_i).

Figure 5: Benchmark case for wall boiling flow (just a couple of pages) [8]

Input control

Periodic review of available personnel / analysts, their skill sets and capabilities

- Frequent and significant software changes
- Frequent career changes (internal and external)

Process quality assurance

Identification of suitable analysis process prior to start of the project

Cooperation of commercial, design and analysis teams in preparing the analysis specifications

Definition of key performance indicators:

- **commercial** (hourly rate, profit level)
- **technical** (method implementation, results accuracy)
- **scientific** (novel approach)
- **client satisfaction**

Process quality assurance

Simplicity of the process plan and importance of feedback

STAGE 1: Specification Review, CAD prep	5 days	Mon 02/01/12	Fri 06/01/12
Kick off meeting	1 day	Mon 02/01/12	Mon 02/01/12
Review of specification	2 days	Tue 03/01/12	Wed 04/01/12
CAD simplifications	2 days	Thu 05/01/12	Fri 06/01/12
Stage 2: CFD Analysis	46 days	Mon 09/01/12	Mon 12/03/12
Geometry discretisation	1 day	Mon 09/01/12	Mon 09/01/12
Engineering analysis of load cases	8 days	Tue 10/01/12	Thu 19/01/12
Meshing	3 days	Thu 19/01/12	Mon 23/01/12
CFD model setup	4 days	Tue 24/01/12	Tue 14/02/12
QA process and related meetings	2 days	Thu 26/01/12	Fri 02/03/12
Simulation of load cases	25 days	Fri 27/01/12	Thu 01/03/12
Post-processing and results analysis	2 days	Fri 10/02/12	Mon 05/03/12
Simulation time contingency	5 days	Tue 06/03/12	Mon 12/03/12
Stage 3: Report preparation	5 days	Tue 13/03/12	Mon 19/03/12
Report	3 days	Tue 13/03/12	Thu 15/03/12
Final Meeting	2 days	Fri 16/03/12	Mon 19/03/12

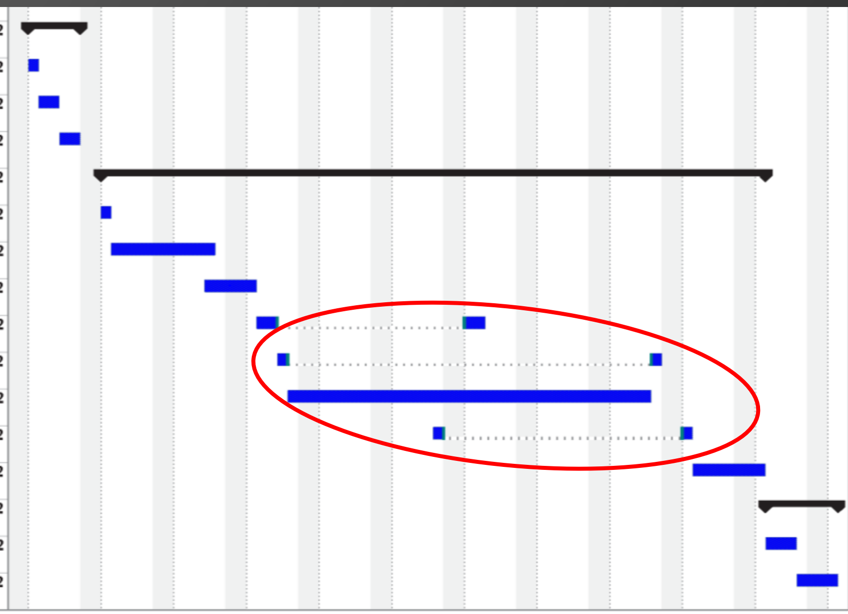


Figure 6: Typical Gantt diagram for CFD analysis

Process quality assurance

Task ownership & associated project interfaces

Preference for interactive task lists and feedback tracking

CFD Analysis of Particle Sampling
in MEMS

	Stage 1: Preparation stage	Completed
1	(AH – 2014/03/30) Discuss and define operating conditions.	
2	(AH – 2014/03/30) Define appropriate meshing strategy (AH – 2014/03/30) AH & PW discussed: (a) the extent of the simulation domain, (b) how to split the domain, (c) where to use tets or hexas	(AH – 2014/03/30)
3	(AH – 2014/03/30) Clean both CAD for both geometries	
4	(AH – 2014/03/30) Prepare the starting statement.	
5	(AH – 2014/03/30) Send to the client the starting statement and the clean CAD models.	
6	(AH – 2014/03/30) Mesh CAD models	
	Stage 2: CFD analysis of particle distribution for 2 inlet design variations	**Completed**
7	(AH – 2014/03/30) CFX setup – steady-state fluid only analysis. This has to be performed for 2 models.	
8	(AH – 2014/03/30) Perform CFX simulation for 2 geometries and a single	

Figure 7: Interactive task list

Process quality assurance

Quality control plan - if, how and to what extent the key performance indicators are met

Analysis check lists – definition of inspection categories and the related qualitative and quantitative analysis parameters

General

- Analysis information
- Review information
- Analysis report
- Analysis files

CFD analysis

- Analysis objectives
- Geometry
- Meshing
- Model selection & strategy
- Model preparation
- Analysis results
- Analysis validation
- Data archiving

Analysis report

- Front sheet
- General
- Introductory section
- Main section
- Final section

Review notes

- Review 1
- Review 2

Process quality assurance

required. The ordinary ‘Thermal Model’ would suffice.	
Is the analysis interested in steady-state or transient behaviour	Status: Steady-state
Symmetry flow conditions expected	Status: Yes
Vertical pressure variation considered Reviewer (2014/01/18): The analysis is interested in heat transfer. Even when pressure distribution is required, the vertical hydrostatic contribution will be small.	Status: Not required
MODEL PREPARATION	
Units (especially in the expressions and the additional model code) are consistent	Status: Yes
Material properties and related models are well defined and appropriate Reviewer (2014/01/18): The CFD analysis is isothermal (i.e. all wall boundaries are adiabatic). Therefore, the temperature level is unknown as well as its effect on the material properties.	Status: Cannot be determined
All important thermal effects are represented or their omission explained Reviewer (2014/01/18): There is no source of thermal energy in the simulation domain. Therefore, no thermal effects are actually simulated and, consequently,	Status: No

Figure 8: Section of an example CFD checklist

Process quality assurance

- Quality control plan and phases of the project execution
- Evolution of quality concerns and resolution of captured problems
- Quality control plan - a **living document**
- **Project performance** review - improving efficiency and quality of the overall analysis process
- Feedback to analysis processes and the corresponding quality plans

Client communication and summary

- Principles of quality assurance process - improving the quality of the output and reducing **commercial risks** associate with the project complexity
- Technical aspects of the quality control plan and client communication
- Accuracy of the analysis results and possible impact of the input parameter variations
- Results uncertainty and overstating the accuracy of the analysis results
- Simulation resolution, results accuracy and/or their variability

Thank you !

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