The Future of CFD in Engineering Design

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Abstract

This paper describes long-term trends in the field of fluid dynamics and how they will affect design engineering. Forecasts are made of what types of analyses designers will perform over the next decades. The analysis will be based on three key items: market demand in the form of the need for PLM systems; a technology driver, in the form of new rapid flow modeling software; and a technology enabler in the form of hardware speed advances.

While CFD has long been used to design high-end value added products that depend heavily on fluid flow, such as airplanes and automobiles, its use in many other markets is growing quickly. The role of CFD is in the process of being transformed from a forensic tool, primarily for studying the behavior of existing designs, to a method for predicting the performance of many alternatives in the early stages of product design. This development is driven by continuous advances in software technology and computer speed.

CFD was once the exclusive realm of highly specialized scientists, spending months on detailed analyses of single pieces of equipment. Recently, rapid flow modeling have become available that are much easier to use because they guide the user through the complete fluid flow analysis process using well understood terminology and procedures that are simple to execute and remember. Companies now also use this rapid flow modeling software to build automated tools that allow designers to rapidly execute their fluid dynamics calculations.

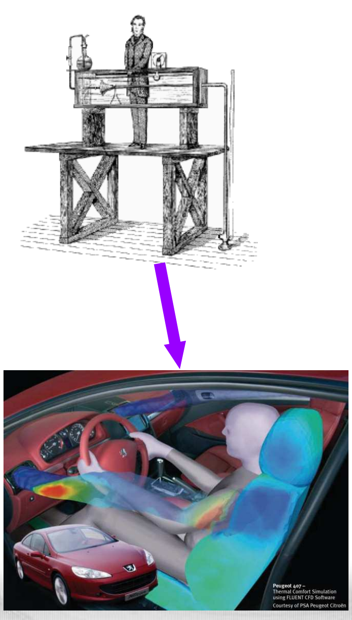
Future trends for the use of CFD in design engineering can be predicted from expected advances in computer speed. In design, timeframes are much shorter than in engineering analysis and scientific research. Researchers may accept CPU times on the order of thousands of hours, employing either large computing systems or patient students. By contrast, design projects often require a review of multiple design permutations in a single day, and are therefore restricted to computing times of an hour or less for each run.

Based on these different requirements, and on the historical progression in computer speed, a forecast can be created for the modeling methods that will be available to different user categories in the years to come. For example, while three-dimensional, steady-state models are usable for the typical design project today, it will take several years before time dependent simulations will be widely used. This will start with designers analyzing moving equipment looking at single flow snapshots, moving on to periodic motion in a few years, to detailed start-up and shutdown analysis between 2010 and 2015. Flow induced acoustic noise and vibration analyses methods are developed and tested by scientists today, but are not expected to be commonplace in design until around 2020. In general, there will be a time lag of about 15 years before methods developed in the laboratory will be available to the design community.

In this paper we will discuss in more detail the future of CFD in design engineering; expected use, applications, and benefits; and what will be available to the mass market at which time.

Introduction

- Future depends on:
  - Market demand.
  - Technology driver.
  - Technology enabler.
- A long term forecast is made of the types of analysis performed over the next decades.



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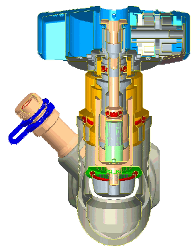
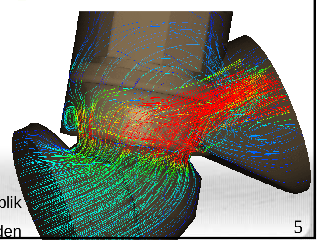
What is CFD?

- Computational fluid dynamics is an engineering field.
  - Compute solutions to fluid flow equations.
- It results in:
  - Detailed maps of fluid velocities, temperatures, pressures and related data.
- It is used for:
  - Analysis and improve understanding.
  - Design, optimization, troubleshooting.





Courtesy of Ivan Bublik
MMA, Sweden

Which industries use it?

- Nearly every manufactured good was once a fluid before it became a solid!
- Mostly used for high value product lines that rely heavily on fluid flow:
  - Process industry.
  - Power plants.
  - Planes.
  - Electronics.
  - Automobiles.
  - Medical technology.

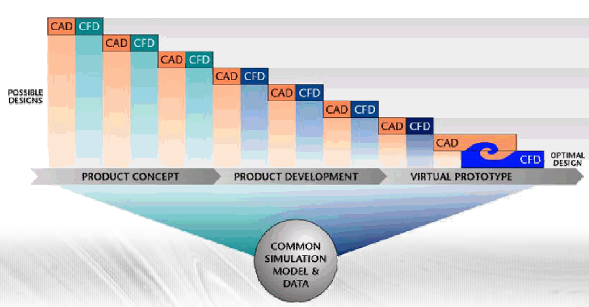
Courtesy of Maciej Ginalski, Silesian University of Technology, Poland

Who uses CFD?

- Traditionally used by:
  - Highly specialized analysts.
  - Months are sometimes spent on detailed analyses of single pieces of equipment.
  - Often used as forensic tool to study existing designs.

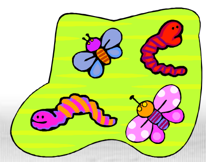
Transforming the role of CFD

- CFD is more and more used to:
  - Predict product performance early on in the design cycle.
  - Continued use for ongoing performance optimization throughout the product lifecycle.



What’s behind this transformation?

- Market demand:
  - Product lifecycle management (PLM).
- Technology driver:
  - Rapid flow modeling software.
- Technology enabler:
  - Computer hardware speed advances.



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Market demand:

Product Lifecycle Management (PLM)

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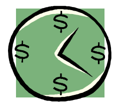
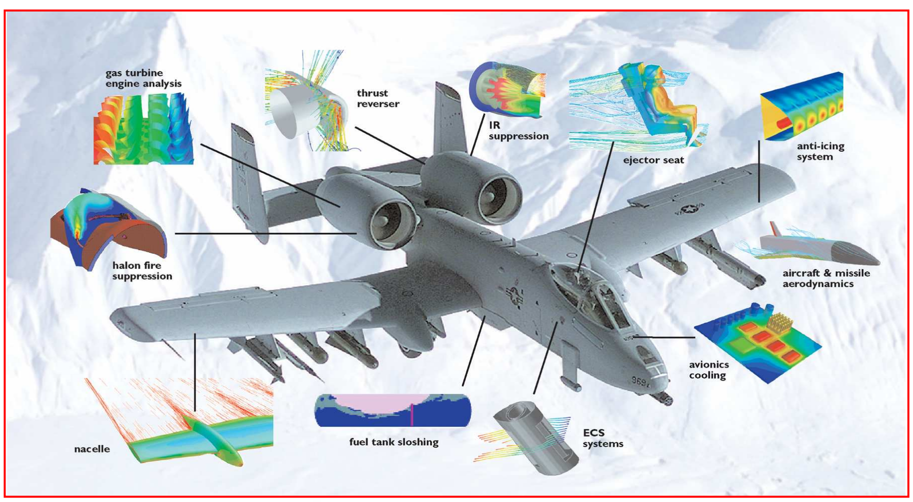
Market driver: PLM

- Manage entire product lifecycle: conception, through design and manufacture, to service, and disposal or recycling.
  - Necessary to meet increased customer, competitive, and regulatory demands.
  - Reduce overall cycle time.

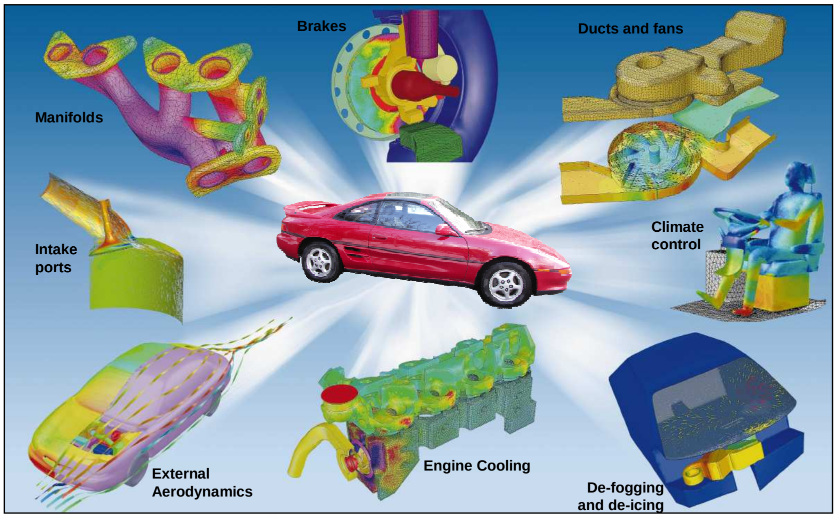


- Benefits:
  - Reduced time to market.
  - Improved product quality.
  - Reduced prototyping costs.
  - Savings through the re-use of original data.
  - A framework for product optimization.
  - Savings by integration of engineering workflows.

Aerospace: CFD and PLM



Automotive: CFD and PLM

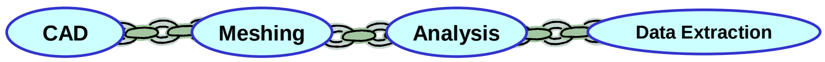


PLM requirements for CFD

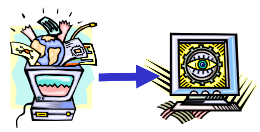
- Target engineering designers.
  - Rapid workflow through automation.
  - Work from CAD data.
  - Easy to use for infrequent users.
  - Reliable answers.
- Fit company workflow:
  - Collaboration, e.g. between designers and analysts.
  - Integrate with other software tools, e.g. FEA or other analysis packages.

Approaches to fit CFD in workflow

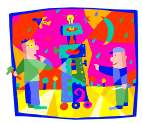
Chaining: use a chain of specialized tools.



Embedding: integrate all tools in one unified work environment.



Customizing: develop organization specific tools.



Connecting: use software that connects to others as needed.

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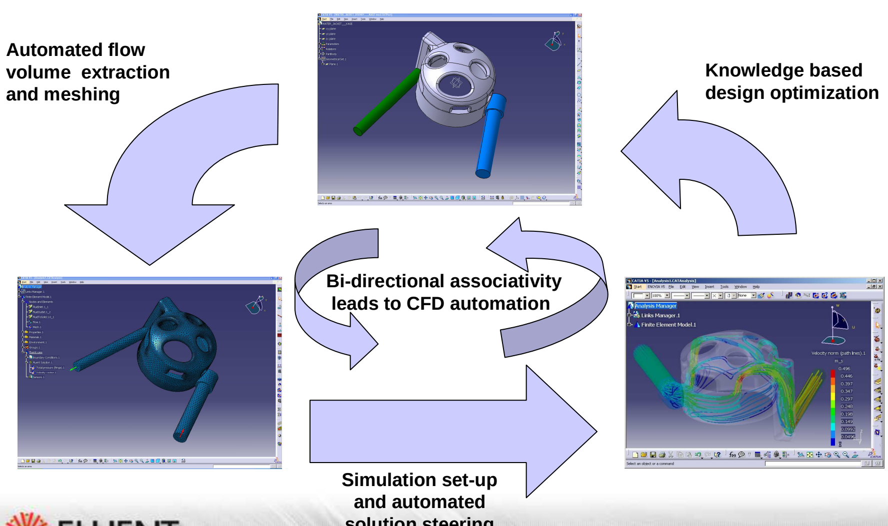
The PLM embedded CFD solution cycle



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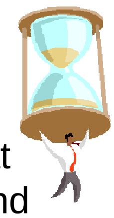
Time compression

- Common to:
  - all approaches to fit CFD in workflow, and
  - the various demands faced by companies.
- Time compression of:
  - Individual steps in a process,
  - Process as a whole (e.g. reduce steps).
- Rapid technologies: rapid prototyping, rapid analysis, rapid design, rapid manufacturing, rapid injection molding, etc.

Technology driver:

Rapid Flow Modeling Software

Rapid flow modeling software



- What is it:
  - An approach to CFD simulation aimed at compressing overall engineering time and increasing efficiency.
- How is it accomplished:
  - Encapsulate deep experience and well understood techniques into highly automated analysis tools.
  - Efficiently turn CAD models into CFD results.

Who is rapid flow modeling for?

- Rapid flow modeling is mainly for:
  - Companies that want to deploy CFD analysis tools within their global PLM environment.
  - Design engineers, equipment designers, CAD and PLM users.
  - Time limited CFD analysts.
  - CFD users with occasional needs, such as troubleshooters.

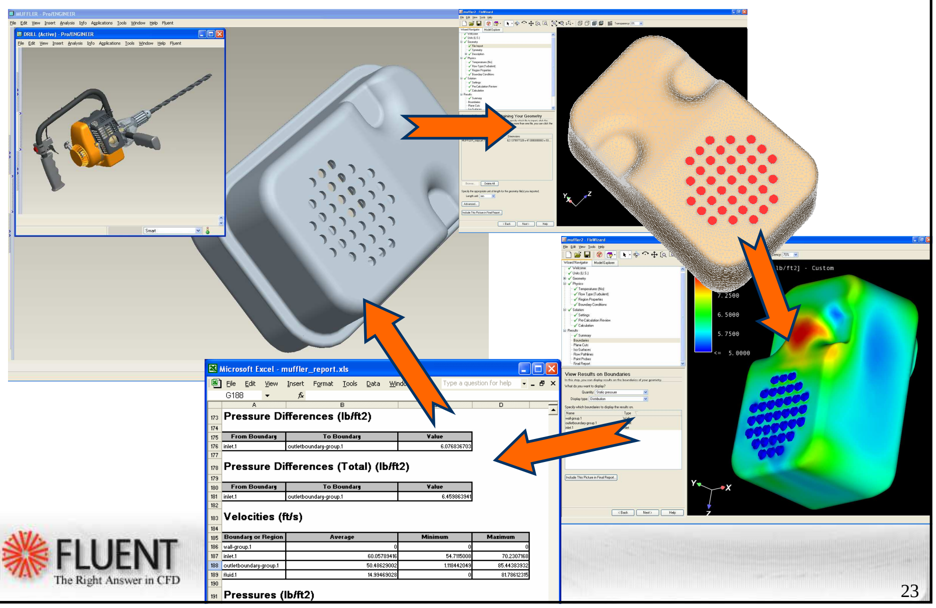
Rapid flow modeling

- What's the benefit?
  - Quick engineering design validation throughout the product lifecycle, resulting in better products designed faster.
  - Leads to a better and cheaper product design process.
  - Lowers risk to the company, resulting in better returns for a company's CAE/CFD/PLM investment.

RFM software characteristics

- Connectivity with CAD/PLM products.
- A high level of automation.
- Well understood physics.
- Solver technology: fast and accurate.
- Minimal learning curves.
- Collaboration.
- Fully compatible with CFD analyst tools.
- Relatively low barrier to entry.
- Extensible.

Connectivity with CAD



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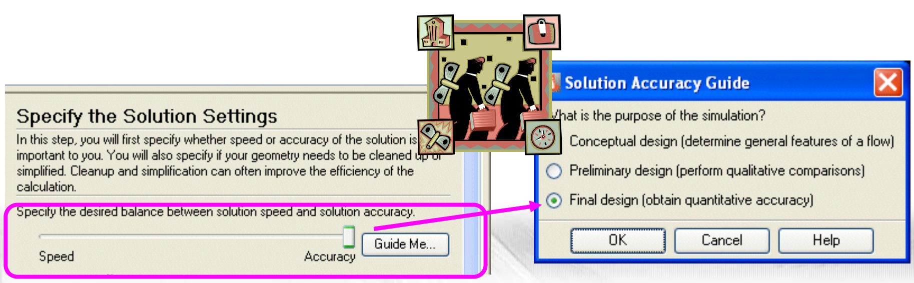
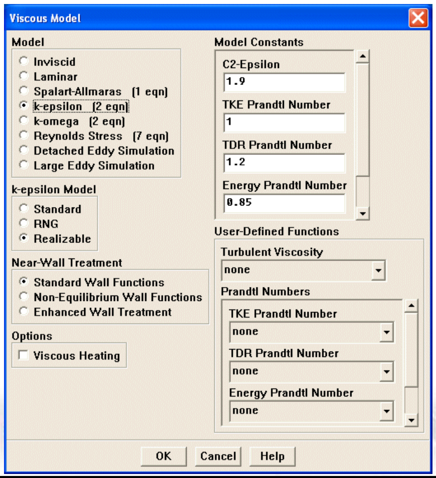
Experience based automation

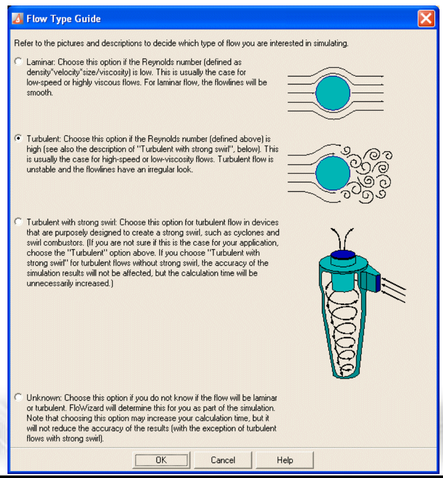
- Use deep experience to develop intelligent, automated algorithms.
- Shorten time consuming tasks such as geometry clean-up, flow volume extraction, meshing, solving, reporting.



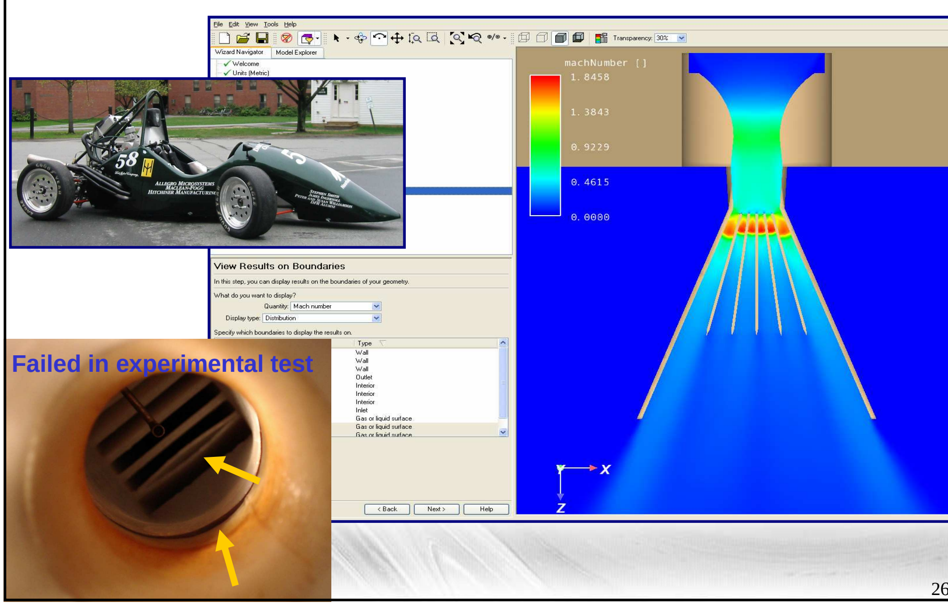
Well understood physics

- Comprehensive physics software: many user choices, including R&D style models.
- Rapid flow modeling: focus on design reliability.





Fast and accurate solvers 1/2

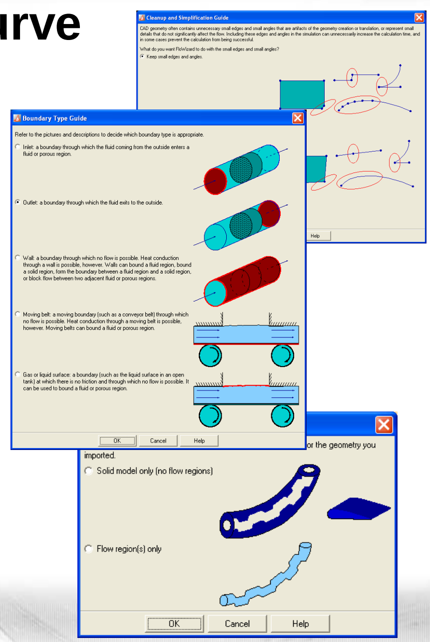


Fast and accurate solvers 1/2

- Explanation of the previous slide:
  - Fluent Inc.'s FloWizard RFM software uses the well tested FLUENT 6.2 solver.
  - This solver is well validated and gives good results for even the most difficult cases.
  - The example shown here shows compressible flow, modeled using the ideal gas law, in a diffuser.
  - This diffuser is placed in the air intake of the engine of a so-called "formula race car" as used in college racing competitions in the US.
  - The air intake has a prescribed maximum area, and the challenge is to design a diffuser that will allow maximum air flow through this small area.
  - Here the flow is from top to bottom. The Mach number is as high as 1.8, and FloWizard easily handles such flows.
  - Note that the plastic test model used in experimental tests broke at this high Mach number. In the actual final car engine the part will be made of metal and be much stronger. But for experimental testing that is too expensive. This clearly shows how FloWizard can be used to model systems for which testing is too difficult or expensive.

Minimal learning curve

- High usability software facilitates an infrequent user's ability to complete a given task.
- User centered software design process:
  - Common at large consumer and office software oriented companies.
  - Not commonly used in engineering software.
  - Engage target users throughout software design and development.



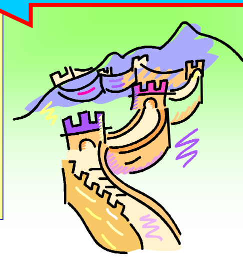
Compatibility

- PLM systems usually encompass many different software tools, used throughout an organization.
- Compatibility is needed with:
  - Analyst oriented CFD software.
  - FEA software: meshers and solvers.
  - Optimization software …although fully automated optimization is still very time consuming.

Collaboration - yesterday

CFD Analyst
- Mesher
- Solver

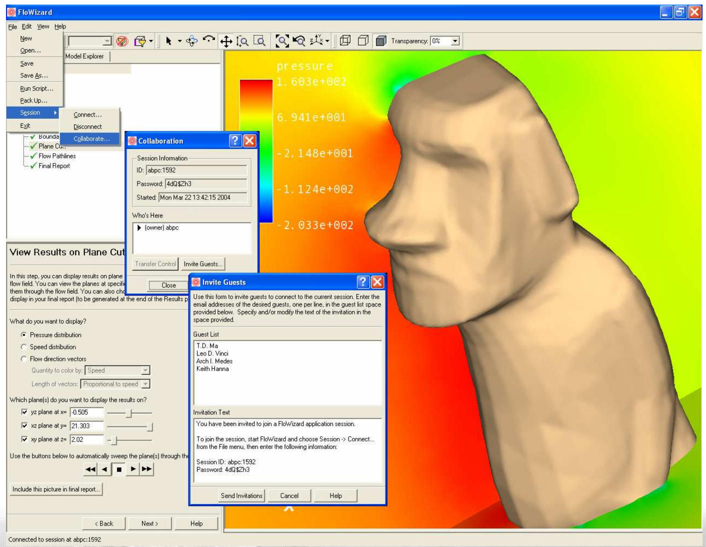
CAD FILES

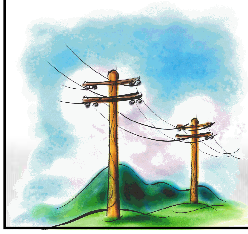


Design engineer
- CAD Software

Collaboration - today

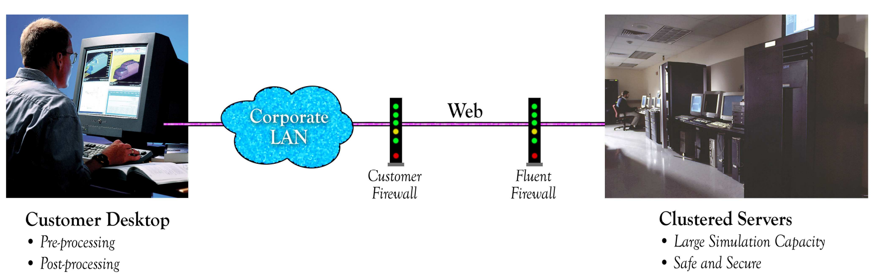
- Multiple users connect to shared sessions and collaborate in real time.
- Optimize the performance of the design team, regardless of geography.





Low barrier to entry

- Remote and scalable computing for high-end, supercomputer-like performance.
- Usage based pricing models.



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Extensibility

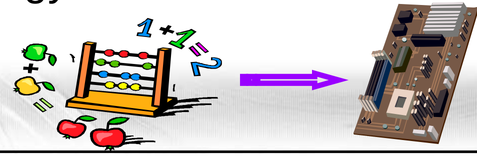
- For repetitive tasks, organization specific tools may be most efficient.
- Enables many users within an organization to perform specific analyses.
- Best developed on top of existing tools:
  - Maximize reuse of existing components.
  - Minimize development time.
- CFD software needs to be developed from the start taking this into account.

Technology enabler:

Computer hardware speed advances

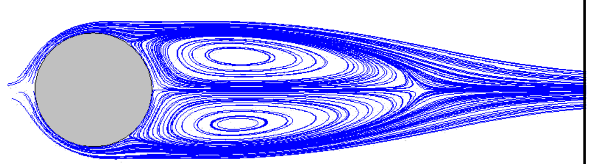
Hardware speed advances

- Premise:
  - *Slow* computers: take longer than the real life event to do a prediction.
  - *Fast* computers: compute faster than real life events.
- So: all of today's computers are slow!
- But they are getting better … and this acts as a technology enabler.

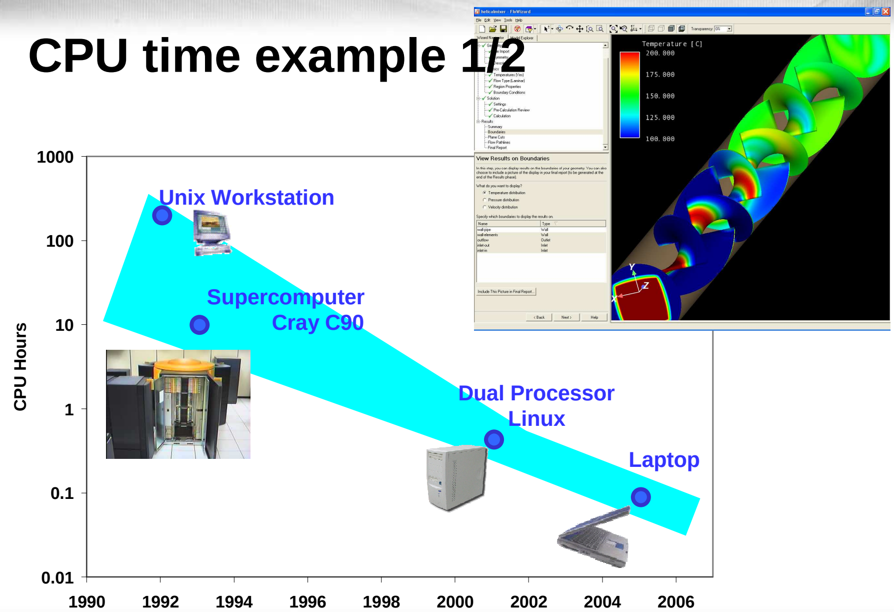


Consider that…

- In 1922, Richardson proposed a weather forecast factory:
  - A stadium with 64,000 people with mechanical calculators, and
  - A coordinator in the center, using colored signal lights and telegraph communication.
- 1953: Kawaguti took 18 months to calculate flow around a cylinder using a mechanical desk calculator, citing: "a *considerable amount of labour and endurance."*



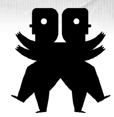
CPU time example 1/2



CPU time example 2/2

- Explanation of the previous slide:
  - An important determinant of the evolution of CFD technology and its use is computer speed.
  - Here we see an example of how increased computer speed has affected computational (CPU) time for a given problem.
  - The case shown here is a helical element static mixer. Laminar mixing is shown based on contours of temperature.
  - The graph shows the CPU time for this case and how it decreased over the years.
  - In the early 1990's, using Fluent 4 this case took hundreds of CPU hours on a Unix workstation (note about 200 CPU hours for a 100k cell mesh on a Sun Sparc II).
  - On a Cray C90 supercomputer this case took about 10 hours (350k cell mesh, Fluent 4).
  - Around 2001 this same case took less than an hour on a dual processor Linux computer (350k cell mesh, Fluent 5)
  - And today, this case can be run on a laptop with FloWizard in minutes (also 350k cell mesh).
  - This clearly shows how problems that once required supercomputers can now be analyzed quickly on commonly available computers.
  - It is this constant increase in computer speed that allows us to make CFD easier and easier and spread it to more and more people.

The CPU time paradox



- 15 years ago my most interesting calculations always took a full weekend.
- Today computers are so much faster, but my calculations still take just as long!
- Computers got faster, but … where did it go?

Where did it go: cynical view

- *Wirth’s law*

  Software gets slower faster than hardware gets faster.

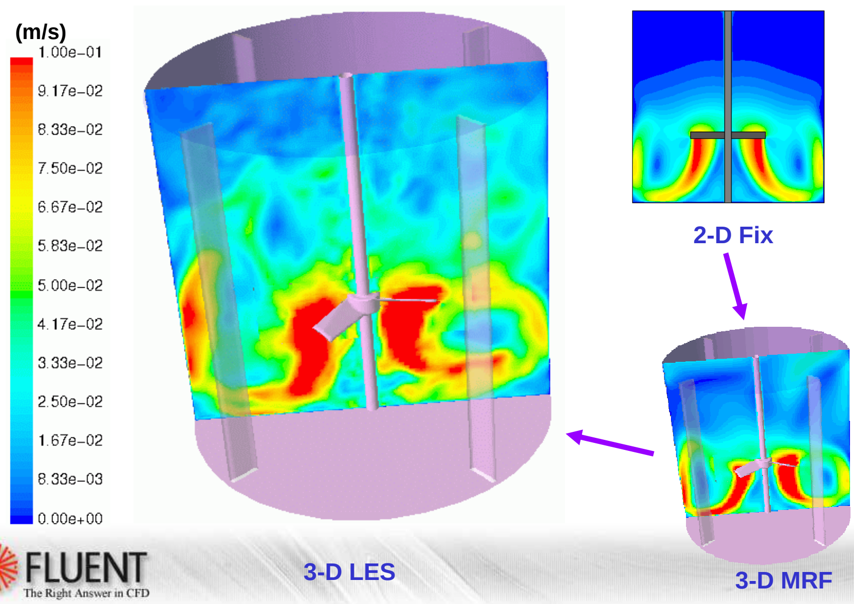
- According to Niklaus Wirth:

  – Work is not actually getting done faster.
  – Programs tend to get bigger and more complicated over time.
  – Programmers rely on Moore's law to justify writing slow code.

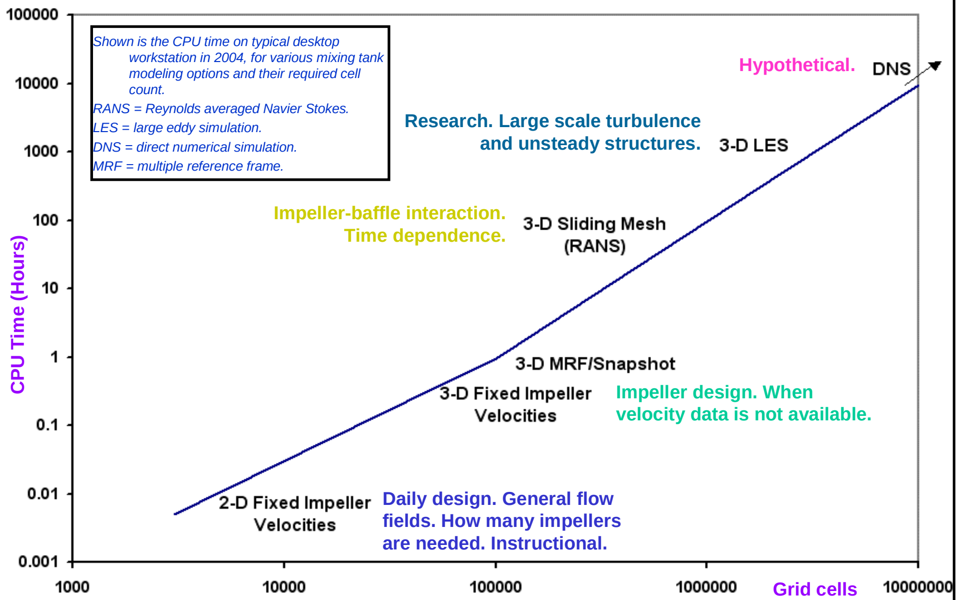
Where did it really go?

- Now, computers got faster, but where did this go?
- What engineers do has changed.
- Engineers tend to continue to use the same amount of CPU time for their work.
- The increased CPU speed is then used:
  - to make more complex models,
  - with finer meshes for increased accuracy,
  - and more physics.
- Note, however, that not everyone uses the same amount of CPU time. That is dependent on their line of work and profession.

More complex models …



CPU time for more complex models



Projection

- How long will these calculations take in the future?
- If a large LES acoustics calculation takes 10,000 CPU hours today, and speed doubles every 1.5 years, then it will take:

$$n = \frac{\log(CPUtime_{today} / CPUtime_{future})}{\log(1.5)}$$

$$22.7 = \frac{\log(10000/1)}{\log(1.5)}$$

- n=22.7 years before that CPU time is reduced to one hour.

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Acceptable CPU time depends on profession

- Researchers: long time horizon, months or years.
  - Complex physics, uncertainty acceptable, and for academic research even desirable.
  - Order of 1000 CPU hours typical.
- Analysts: medium time horizon, weeks to months.
  - Complex physics: some uncertainty acceptable.
  - 50 CPU hours typical.
- Designers: significant time pressure.
  - Short design cycles.
  - Physics: uncertainty is not acceptable.
  - 1 CPU hour or less is best.

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Forecast

- Now, what kind of problems can one analyze with these typical CPU times?
- We can look at what typical problems are that can be analyzed in 1, 50, and 1000 hours respectively.
- Since computer speed changes over time, the type of problem that can be analyzed in those times changes every year.
- The chart on the next slide shows three lines, for three professions, and the types of problems they can typically analyze within their respective timeframes.
- Shown is the year when these typical problems can be analyzed, as a function of the typical grid cell count.
- For example, in 2005, designers will usually perform 3-D steady state simulations.
- But most analysts worked on these about 7 years ago, and researchers about 15 years ago.
- Many analysts work on 3-D transient problems these days.
- And researchers right now often study problems requiring LES such as acoustic noise and vibration problems.
- Some day, probably about 15 years from now, such problems will be commonly analyzed by designers as part of their regular equipment design process.
- In the meantime, researchers and analysts will have moved on to other problems, quite possibly those involving DNS.

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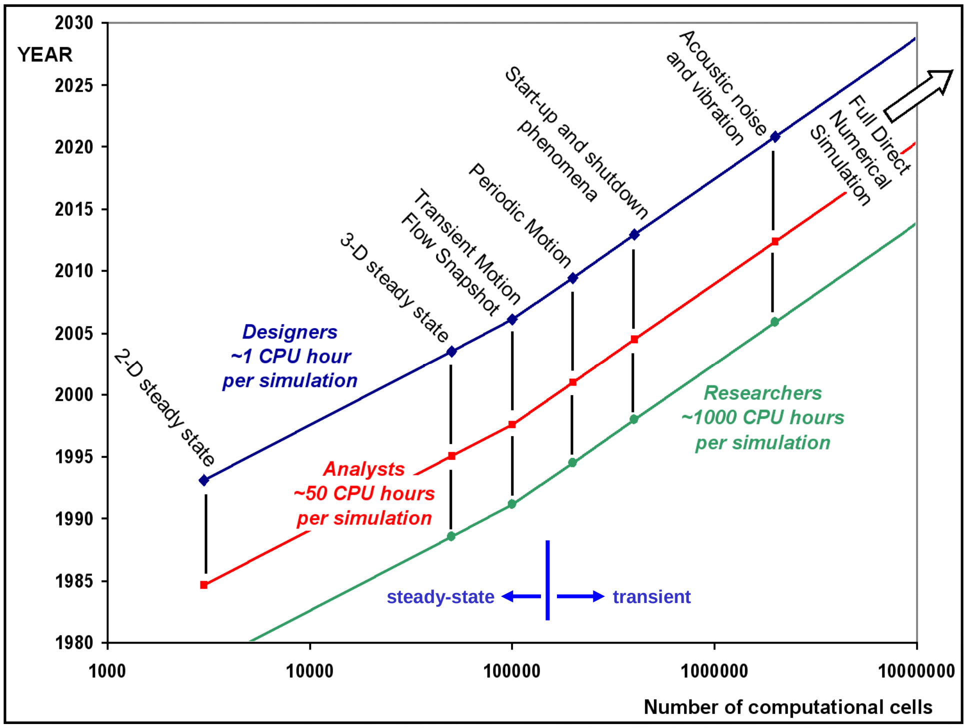

New technology development

- New technologies will continue to be developed.
- There is a time lag of about 15 years between new computational techniques being developed in R&D to when they become mainstream.

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Future CFD software market

- Expect three main long-term tracks:
  - Scientific: in-house codes, academic research software.
  - Comprehensive physics for analysts: currently the largest market segment.
  - Rapid flow modeling for designers and PLM adopters: high growth rates expected.

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THEN.	NOW.
Imagine.	Imagine.
Design.	Design.
Build.	Optimize.
Test.	Sell.

Rethink.
Redesign.
Rebuild.
Retest.

Rethink.
Redesign.
Rebuild.
Retest.

Rethink.
Redesign.
Rebuild.
Retest...

Retire.

Conclusion