Overview

Uncertainty Analysis
Regression - Simulation

Philipp Schlatter

Institute of Fluid Mechanics (LSTM)
Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg

December 2, 2024

Overview

Uncertainty Analysis

1) Recapitulation:
    1) Error propagation
    2) Monte Carlo method
2) Numerics:
    1) Floating point arithmetics
    2) Computations of derivatives
3) Regression
    1) Theory of linear (and nonlinear) regression
    2) Jupyter example
    3) Error analysis
4) Simulations
    1) Real data sets
    2) Time averaging (NOBM)

Before lunch

After lunch

Overview

Uncertainty Analysis

All the Jupyter scripts (and later also the lecture notes) are here:

https://github.com/pschlatt1/notebooks/tree/main/UA

For Jupyter, test this:

https://colab.research.google.com/github/pschlatt1/notebooks/blob/main/UA/ferr.ipynb

Some background

Quick bio

- From Zürich, Switzerland  
- Studied Mechanical Engineering at ETH Zürich
- Doctoral studies at the Institute of Fluid Dynamics (IFD) at ETH in Zürich
- Postdoc, Ass. Prof., full professor at Royal Institute of Technology (KTH) in Stockholm, Sweden
- Now Professor for Fluid Mechanics at FAU Erlangen since April 2023
  Institute of Fluid Mechanics (www.lstm.fau.eu)
- Main research interest: Turbulence, numerical simulation, high-performance computing, but any fluid mechanics in general

Pillars of Science & Uncertainties

Oberkampf and Trucano, 2002. Roache, 1997

S. Rezaeiravesh KTH, 2-3 Dec 2020 6

Pillars of Science & Uncertainties

Experiments

- Environmental uncertainties
- Device precision and bias
- Limited number of observations
- Human factor

Are we solving the model accurately?

Validation

Computing, HPC

Analysis, Calibration

Numerical Simulations

Numerics, Programming

Theory & Modeling

- Numerical errors
- Programming bugs
- Domain uncertainties
- Computational mesh
- Initial and boundary conditions
- High-performance computing

Verification

Are we solving the correct model?

- Incomplete knowledge
- Incomplete modeling
- Uncertain parameters

Oberkampf and Trucano, 2002. Roache, 1997

S. Rezaeiravesh KTH, 2-3 Dec 2020 6

Pillars of Science & Uncertainties

Experiments

- Environmental uncertainties
- Device precision and bias
- Limited number of observations
- Human factor

Are we solving the model accurately?

Validation

Computing, HPC

Analysis, Calibration

Numerical Simulations

Numerics, Programming

Theory & Modeling

- Numerical errors
- Programming bugs
- Domain uncertainties
- Computational mesh
- Initial and boundary conditions
- High-performance computing

Verification

Are we solving the correct model?

- Incomplete knowledge
- Incomplete modeling
- Uncertain parameters

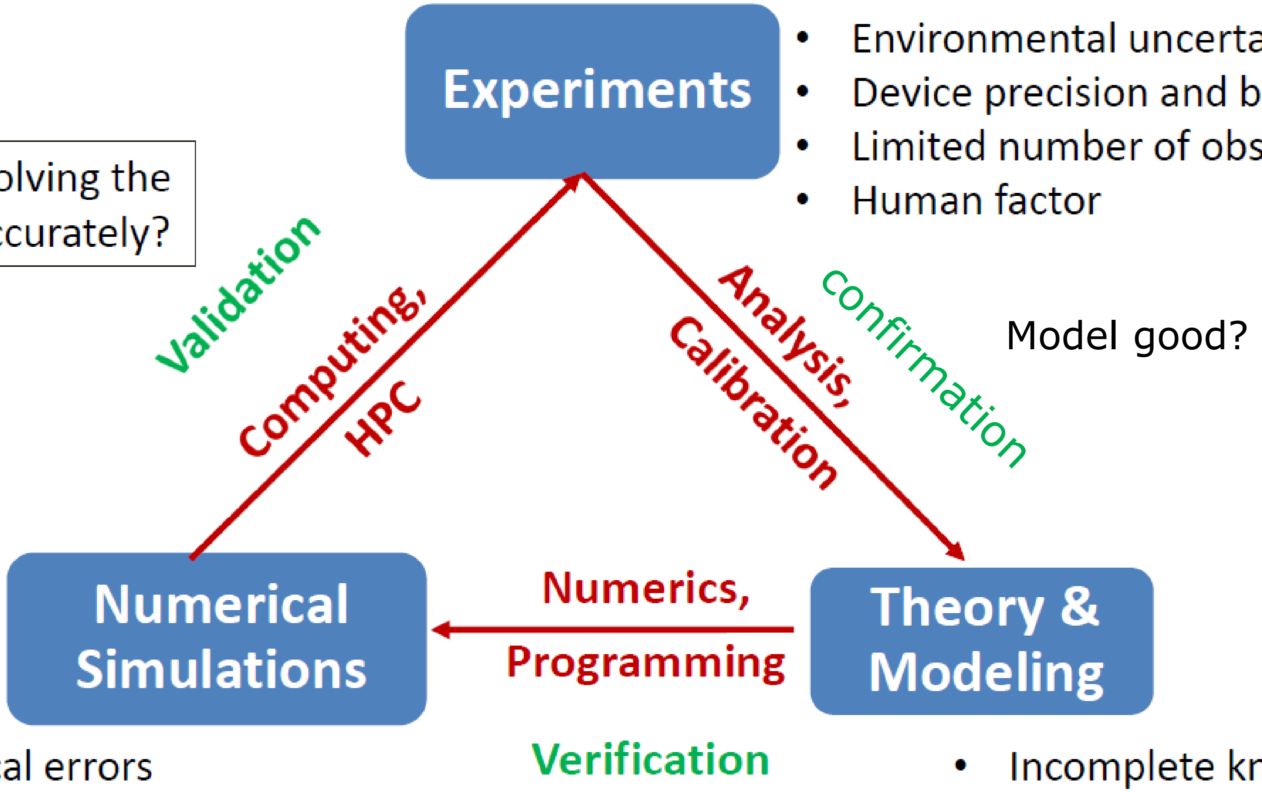
Oberkampf and Trucano, 2002. Roache, 1997

S. Rezaeiravesh KTH, 2-3 Dec 2020 6

Pillars of Science & Uncertainties

- Environmental uncertainties
- Device precision and bias
- Limited number of observations
- Human factor

Are we solving the model accurately?



- Numerical errors
- Programming bugs
- Domain uncertainties
- Computational mesh
- Initial and boundary conditions
- High-performance computing

Are we solving the correct model?

- Incomplete knowledge
- Incomplete modeling
- Uncertain parameters

Oberkampf and Trucano, 2002. Roache, 1997

S. Rezaeiravesh KTH, 2-3 Dec 2020 6

Pipe flow transition (2006)

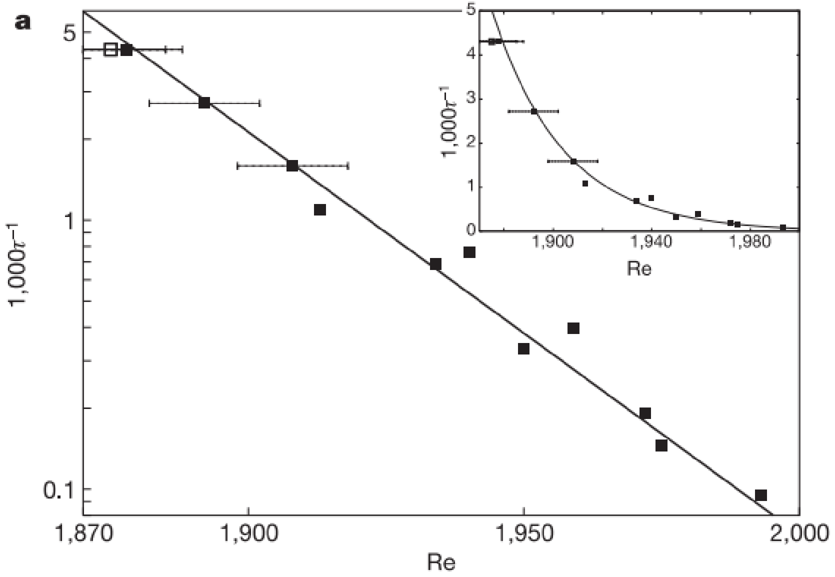
Vol 443|7 September 2006|doi:10.1038/nature05089 nature

LETTERS

Finite lifetime of turbulence in shear flows

Björn Hof[1,2], Jerry Westerweel[2], Tobias M. Schneider[3] & Bruno Eckhardt[3]

We have shown that in contrast to previous findings, the lifetimes of turbulence in pipe flow do not diverge at a finite critical Reynolds number. All the available data indicate that turbulence in pipe flows decays, and that eventually the flow will always relaminarize. Similarly, lifetimes for Couette[18,19] flow and for a shear flow model[25] do not appear to diverge, suggesting that a finite lifetime of turbulence may be a universal property of this class of flows. The rapid exponential increase of lifetimes explains why the transient nature of turbulence has not been observed previously: to detect the decay of turbulence in a garden hose at a flow rate as low as 1 l min^{-1} (Re = 2,400) would require a physical length of the tube of 40,000 km, about the Earth's circumference, and an observation time of almost 5 years. The dynamical connection between the turbulent and the laminar state implies that the flow can be relaminarized by infinitesimal perturbations in judiciously chosen directions. This implies in particular that turbulence control should be possible with minimal expenditures in energy.

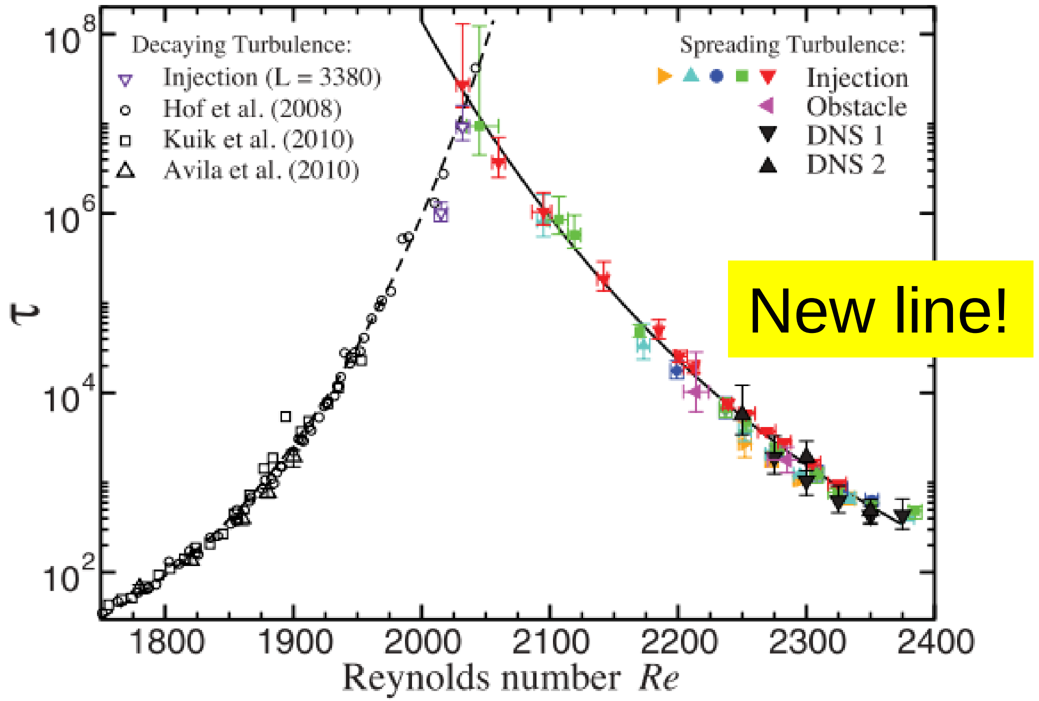


Pipe flow transition (2011)

8 JULY 2011 VOL 333 SCIENCE www.sciencemag.org

The Onset of Turbulence in Pipe Flow

Kerstin Avila,[1*] David Moxey,[2] Alberto de Lozar,[1] Marc Avila,[1] Dwight Barkley,[2,3] Björn Hof[1*]



Calibration errors (1628)

The Vasa

Multiple rulers found, one Swedish feet (12 inches) and one in Dutch feet (11 inches)

Mars Climate Orbiter: Metric vs imperial units (1999)

Some DNS/LES: mismatch of reference quantities (Reynolds number etc.)

Retraction of papers due to errors

PHYSICS OF FLUIDS **21**, 109901 (2009)

Retraction: "Direct numerical simulation of the Ekman layer: A step in Reynolds number, and cautious support for a log law with a shifted origin" [Phys. Fluids 20, 101507 (2008)]

Philippe R. Spalart,[1] Gary N. Coleman,[2] and Roderick Johnstone[2]
[1] *Boeing Commercial Airplanes, P.O. Box 3707, Seattle, Washington 98124, USA*
[2] *School of Engineering Sciences, University of Southampton, Southampton SO17 1BJ, United Kingdom*

(Received 13 August 2009; accepted 10 September 2009; published online 28 October 2009)

[doi:10.1063/1.3247176]

A retraction of our findings in Ref. 1 is necessary. The numerical accuracy was not up to the required standards, allowing an error of about 0.3 in U^+ in the buffer layer, and was insufficient to support the logarithmic law that was proposed. New results on two levels of finer grids are presented and found to be close, and to compare very well with the channel direct numerical simulation (DNS) results of Hoyas and Jiménez.[2] Conversely, the excellent agreement with an analytical fit to experiments proposed by Chauhan *et al.*,[3] well into the range of several hundred for z^+ is lost.

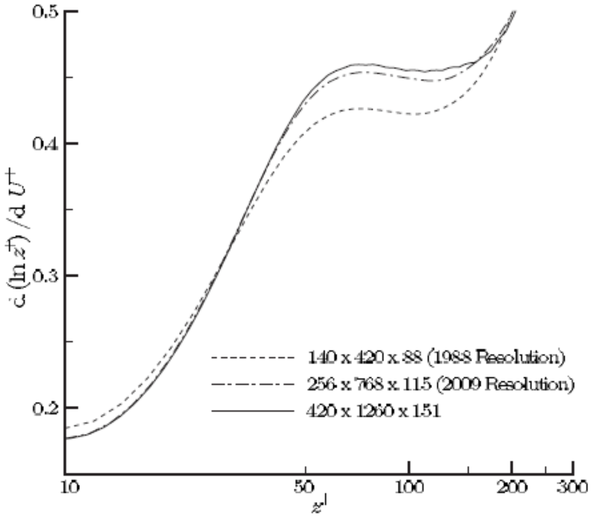


FIG. 2. Karman measure, Re = 1000.

Further reading…

PNAS

COLLOQUIUM PAPER

Issues with data and analyses: Errors, underlying themes, and potential solutions

Andrew W. Brown[a,1], Kathryn A. Kaiser[a,2], and David B. Allison[a,3,4]

[a]Office of Energetics and Nutrition Obesity Research Center, University of Alabama at Birmingham, Birmingham, AL 35294

Edited by Victoria Stodden, University of Illinois at Urbana–Champaign, Champaign, IL, and accepted by Editorial Board Member Susan T. Fiske November 27, 2017 (received for review July 5, 2017)

Some aspects of science, taken at the broadest level, are universal in empirical research. These include collecting, analyzing, and reporting data. In each of these aspects, errors can and do occur. In this work, we first discuss the importance of focusing on statistical and data errors to continually improve the practice of science. We then describe underlying themes of the types of errors and postulate contributing factors. To do so, we describe a case series of relatively severe data and statistical errors coupled with surveys of some types of errors to better characterize the magnitude, frequency, and trends. Having examined these errors, we then discuss the consequences of specific errors or classes of errors. Finally, given the extracted themes, we discuss methodological, cultural, and system-level approaches to reducing the frequency of commonly observed errors. These approaches will plausibly contribute to the self-critical, self-correcting, ever-evolving practice of science, and ultimately to furthering knowledge.

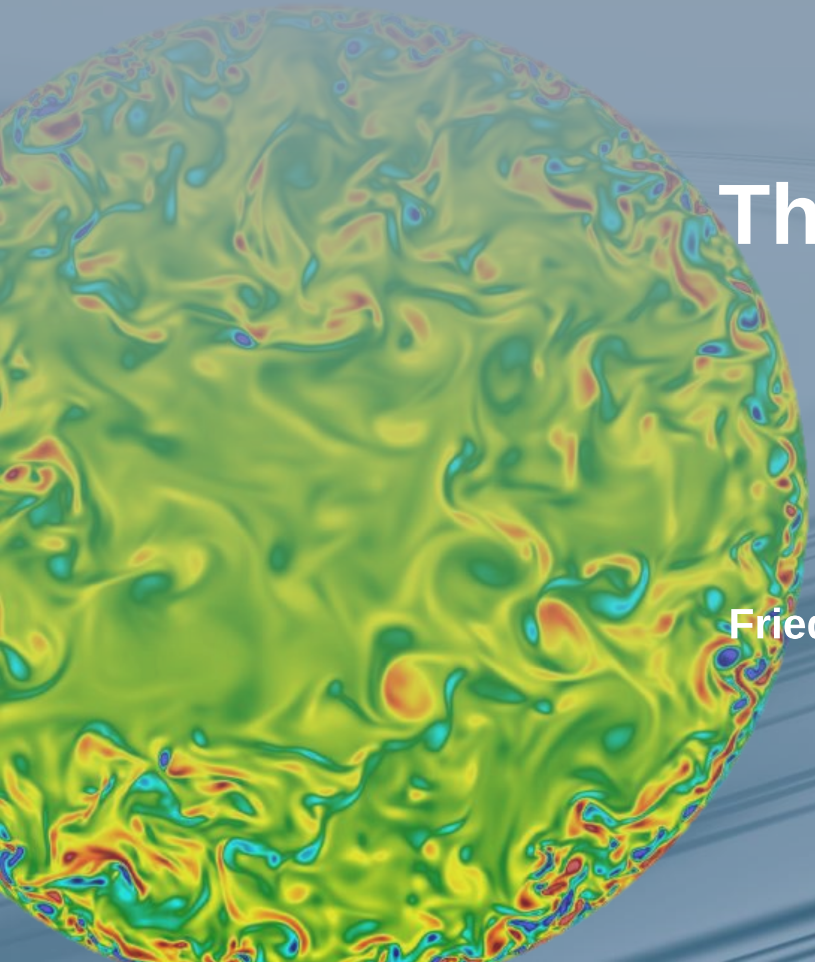
that a statistical expert of the day should have realized represented regression to the mean (9). Over 80 y ago, the great statistician "Student" published a critique of a failed experiment in which the time, effort, and expense of studying the effects of milk on growth in 20,000 children did not result in solid answers because of sloppy study design and execution (10). Such issues are hardly new to science. Similar errors continue today, are sometimes severe enough to call entire studies into question (11), and may occur with nontrivial frequency (12–14).

What Do We Mean by Errors? By errors, we mean actions or conclusions that are demonstrably and unequivocally incorrect from a logical or epistemological point of view (e.g., logical fallacies, mathematical mistakes, statements not supported by the data, incorrect statistical procedures, or analyzing the wrong dataset). We are not referring to matters of opinion (e.g., whether one measure of anxiety might have been preferable to another) or

STATISTICS

https://www.pnas.org/doi/epdf/10.1073/pnas.1708279115 (2018)

- Gamblers fallacy (watch out for bias though!)
- Regression to the mean
- Conditional probabilities / Bayes view



Thank you for your attention!

Institute of Fluid Mechanics (LSTM)
Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg