Challenges in the Design of Multi-Physics Validation Experiments

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Definition of Validation

The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model

i.e. quantify model credibility or accuracy

Wisdom vs Knowledge

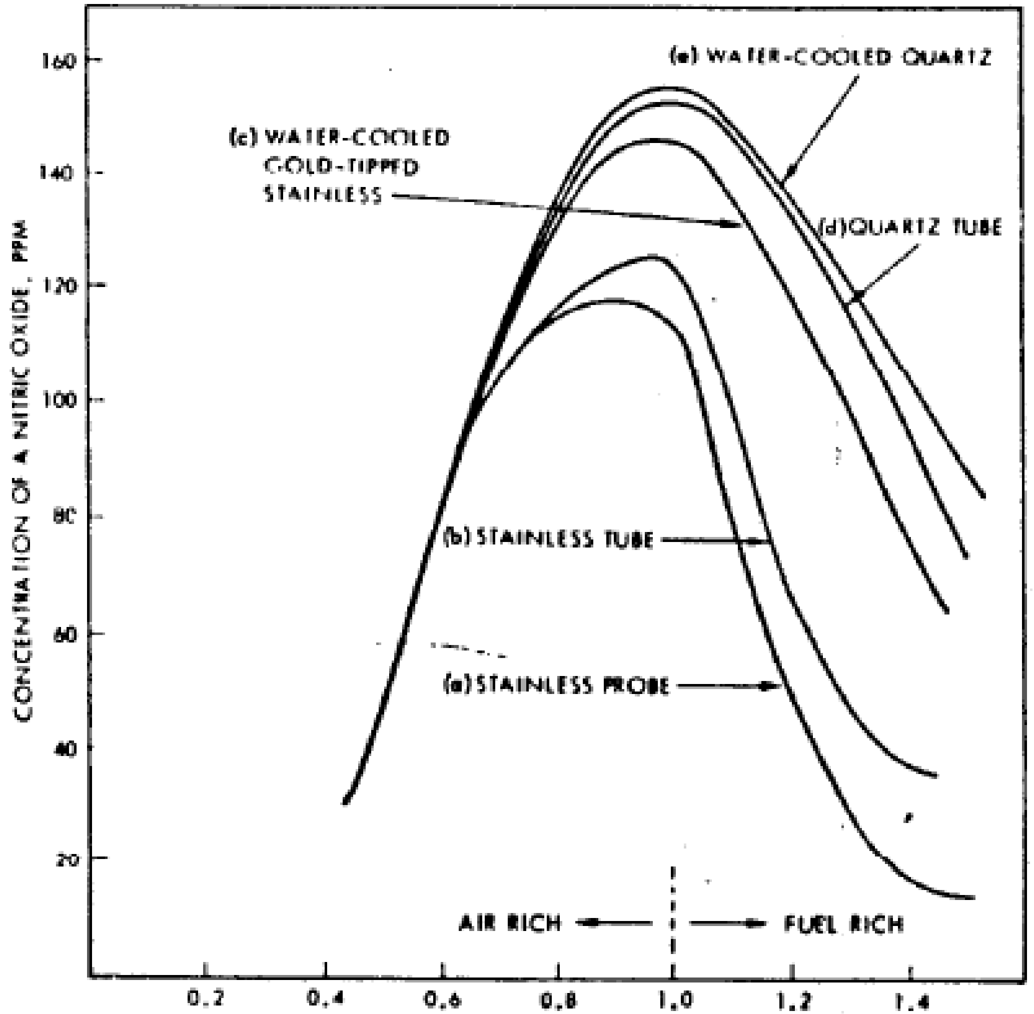
"Knowledge is knowing that a tomato is a fruit. Wisdom is not putting it in a fruit salad." Miles Kington

=> Model adequacy

Challenges of instrument deployment

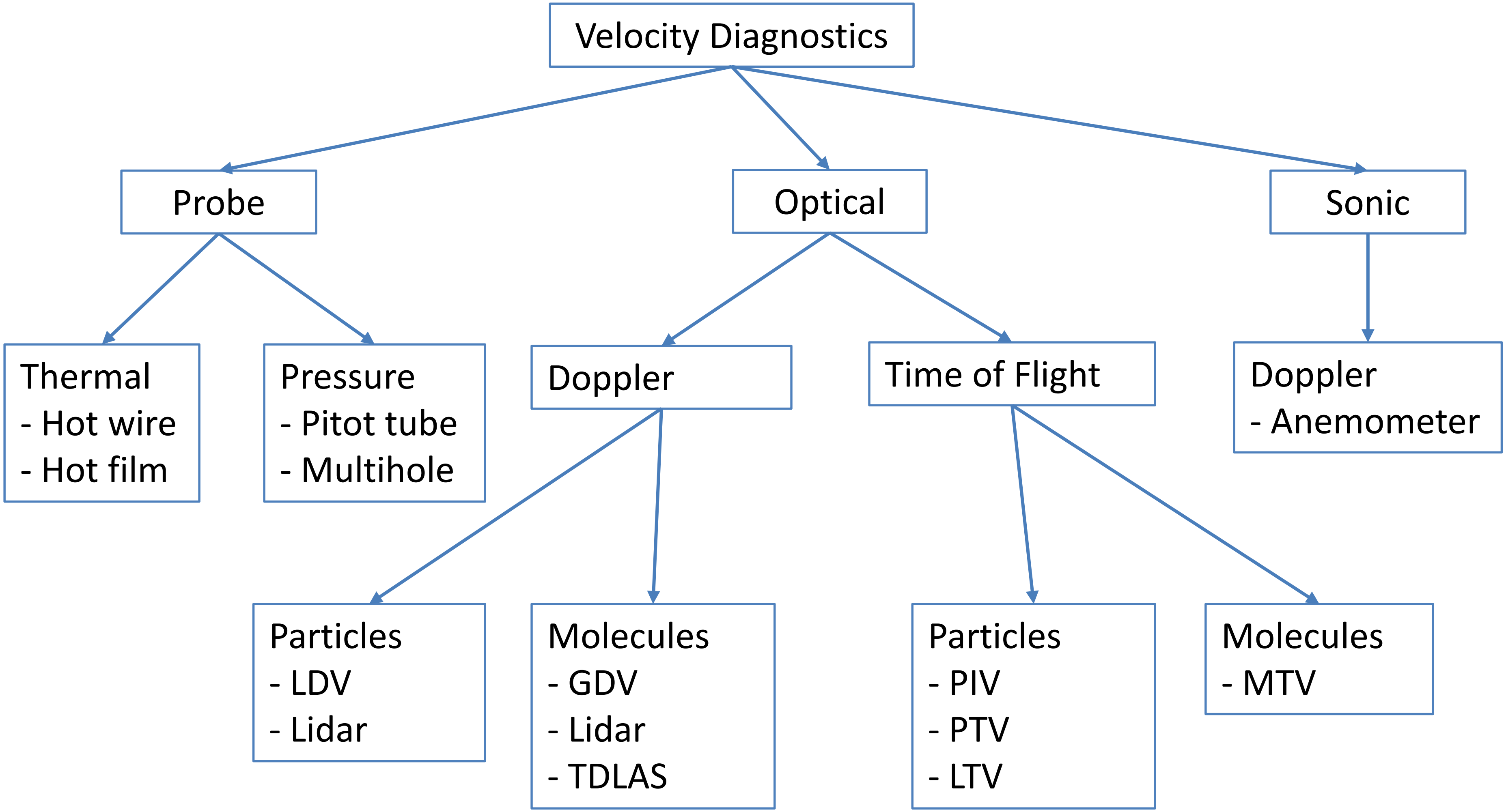
Undisturbed pre-mixed flame

Premixed flame disturbed by a thermocouple



England et al, 1973

Many Diagnostics are possible: Fluid Velocity



Design philosophy: start from fundamentals

- Experiment designs and operations require expert for each physics and/or diagnostics
  - Necessity to control all aspects of experiment & diagnostics
- Need collaboration between experts
  - Can be challenging: language barrier
- Or PI with broad expertise
  - Requires 3-5 years (1 PhD project) to become an expert

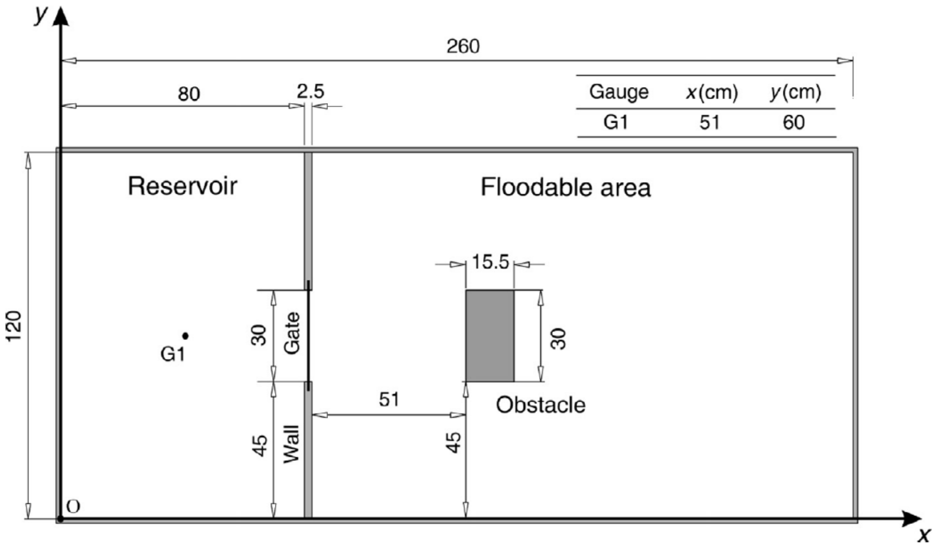
Sample case: FSI experiment assessment

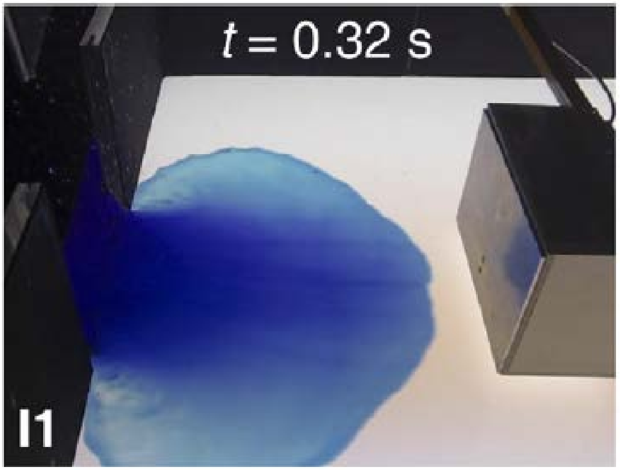
Fluid-Structure Interaction:

- Fluid motion
- Structural response

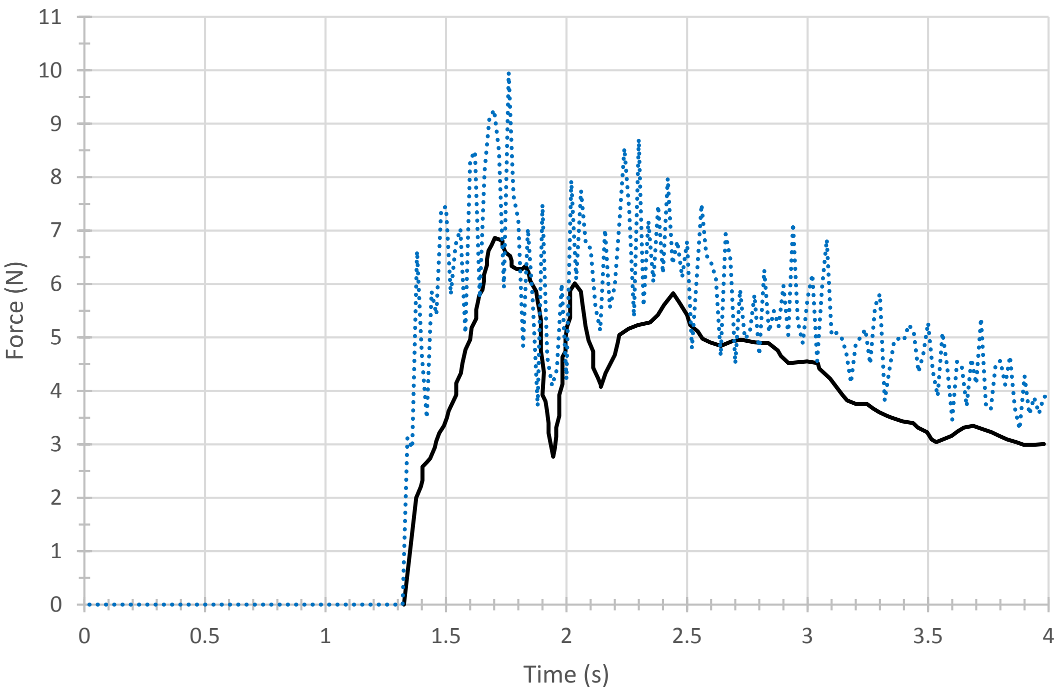
Response can be coupled, making high fidelity simulations one of the most challenging problem in modern computational physics

Case study: Dam Break Experiment





Experimental vs Numerical Results



- Experiment:
  - Peak: ~ 7 N
- High frequency fluctuations in CFD
- Bias:
  - CFD over predicts by ~1 N.
  - Bigly impact on impulse loading

Need to simulate sensor response

- Measurement is the convolution of sensor response with physical input

$$(f * g)(t) \stackrel{\mathrm{def}}{=} \int_{-\infty}^{\infty} f(\tau)\, g(t-\tau)\, d\tau$$
$$= \int_{-\infty}^{\infty} f(t-\tau)\, g(\tau)\, d\tau.$$

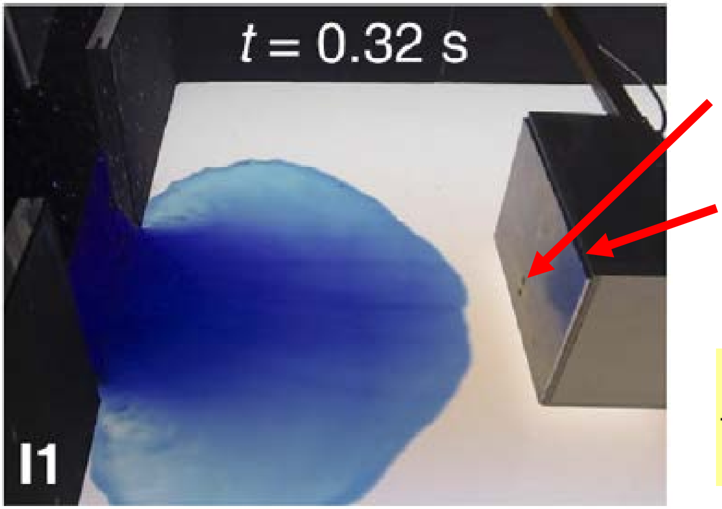
- Sometimes (all the times?) sensor response need to be modeled as well
- Might explain discrepancies between experiments and simulations here

Experiment design critic

- Sensor:
  - Load Cell: range of 50 N
- DAQ system
  - 24 bit
  - 1 000 kHz
- Similar rep rate on the simulations
  - High frequency fluctuations

- But:
  - Experimental data filtered at 50 Hz
    - Nyquiest: maximum frequency < 25 Hz
- Response time of load cell:
  - Overdamped, 0.1 s to 10 % of step input
  - Friction factor: 1.75 N
- Need to reassess design

Back to Fundamentals – 1: Dynamic Response of load cell



- Load cell:
  - Strain gage (ideal, 0th sensor) mounted on
  - Beam (2nd order)
  - Overall system is 2nd order.
  - ODE:

$$\frac{1}{\omega_n^2}\frac{d^2y}{dt^2}+\frac{2\varsigma}{\omega_n}\frac{dy}{dt}+y=Kx$$

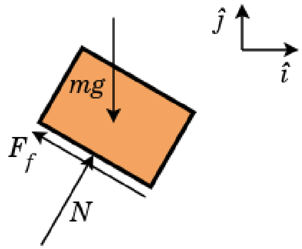
- Response to step-forcing (likely done in the tests) for overdamped 2nd order system:

$$\frac{y-y_i}{y_f-y_i}=1-e^{-\varsigma\omega_n t}\left[\cosh\left(\omega_n t\sqrt{\varsigma^2-1}\right)+\frac{\varsigma}{\sqrt{\varsigma^2-1}}\sinh\left(\omega_n t\sqrt{\varsigma^2-1}\right)\right]$$

- Need two datapoints to get
  - Undamped natural frequency: ω_n
  - Damping ratio: ζ
  - Wall will affect response of load cell, it adds
    - mass &
    - friction

Back to Fundamentals – 2: Friction factor

- Coulomb law of friction



- $F_f \leq \mu F_N$
- Valid for static and kinetic
- Ie friction force is independent of velocity once the object is moving
- $\mu_k \sim 60\%\ \mu_s$
- About 1N here?

Conclusions

- Multi-physics validation experiments require
  - Extra considerations
  - Larger team
  - Experience
- True for all validation cases:
  - Need to understand all aspects of facility and diagnostics
  - Should model sensor response
  - We only talked of challenges for experimentalists to talk together, no word on the numericists.