Optical Disturbance in Naturally Convecting Flow

2.29 FINAL PROJECT

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Motivation

High performance optical systems operated in the field are size, weight, and power constrained

- Detectors and optics are often temperature sensitive
- Limited availability of temperature control, subject to potentially harsh environments, sealed enclosure limits airflow
- Heat generating components stored in same enclosure as sensor and optics

Light often passes through air on its way to the sensor

- Index of Refraction (IoR) of air varies with temperature and pressure
- Effects on pointing and phase

Degradation of optical performance from free-space air IoR gradients is of interest

Source: FLIR

Optical “Disturbance” Metric

Optical Path Length (OPL) can be used to evaluate disturbance

- Integrate Index of Refraction along path length of light “ray”
- Evaluate RSS of OPL across optic pupil

$$OPL = \int_C n\, ds$$

Index of Refraction, n, formula for dry air

- $(n-1) * 10^8 = \left(2371.34 + \frac{683939.7}{130 - s^2} + \frac{4547.3}{38.99 - s^2}\right) d_1$ [1]
- $d_1 = \frac{P}{T}\left(1 + P\left(5.79 * 10^{-7} - \frac{9.325 * 10^{-4}}{T} + \frac{0.25844}{T^2}\right)\right)$ [1]
- Where n is index of refraction, P is pressure in mbar, T is temperature in Kelvin, and s is wavenumber of transmitted light of interest

[1] Applied Optics vol. 6 No. 1 1967 p51-59 JC Owens

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Application
    buoyantBoussinesqPimpleFoam

Description
    Transient solver for buoyant, turbulent flow of incompressible fluids

    Uses the Boussinesq approximation:
    \f[
        rho_{k} = 1 - beta(T - T_{ref})
    \f]

    where:
        \f$ rho_{k} \f$ = the effective (driving) kinematic density
        beta = thermal expansion coefficient [1/K]
        T = temperature [K]
        \f$ T_{ref} \f$ = reference temperature [K]

    Valid when:
    \f[
        \frac{beta(T - T_{ref})}{rho_{ref}} << 1
    \f]
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Solving Method

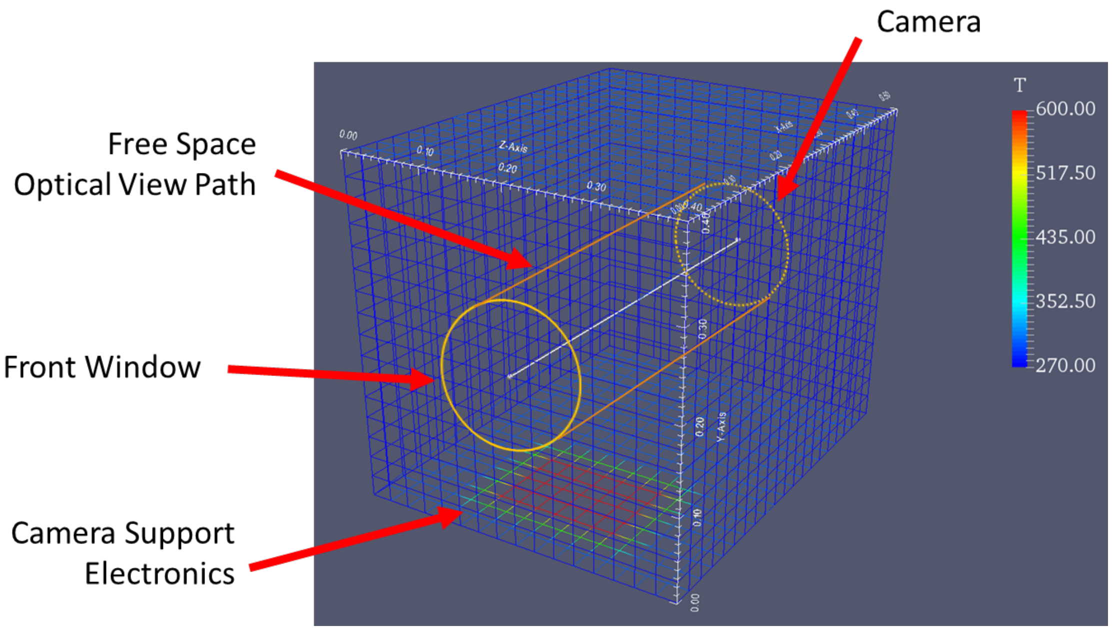
Notional optical sensor housed in small enclosure with support electronics

- Simplified for mesh representation
- 0.5 x 0.4 x 0.4 meters

Solved in OpenFOAM

- buoyantBoussinesqPimpleFoam
- Implicit, RANS
- Virtual machine on laptop
- Simulate 20s of time, with $\Delta t = 0.05s$

Case	Electronics	# of FVs	Run Time	Co Max
1	Hot	20 x 16 x 16	90s	0.50
2	Hot	30 x 24 x 24	300s	1.02
3	Warm	30 x 24 x 24	300s	0.75

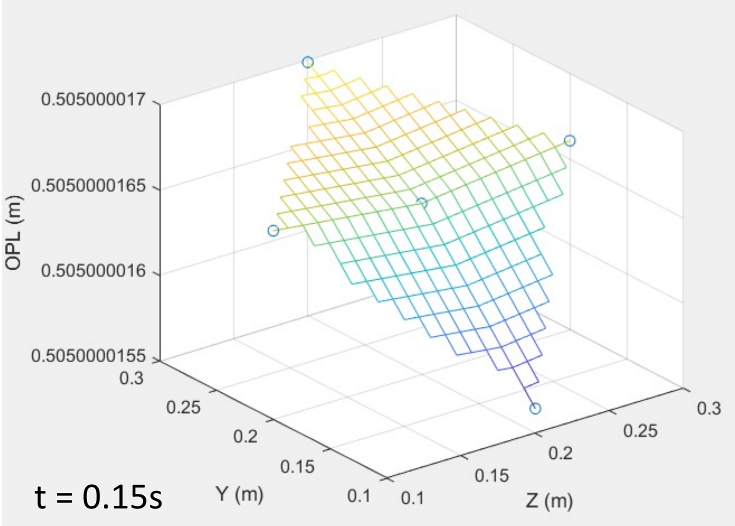


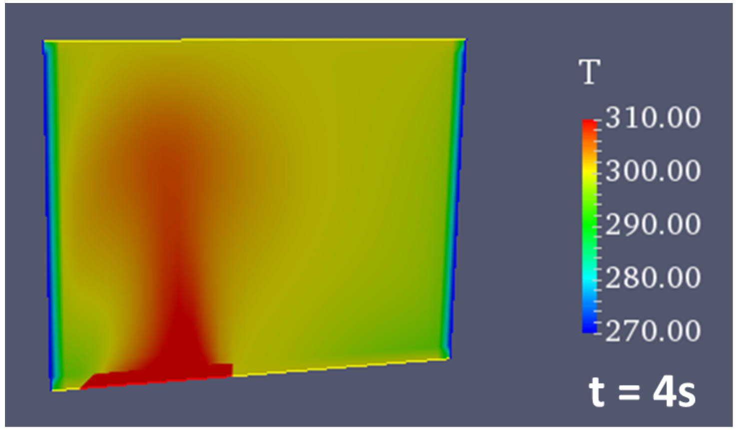
Fine Mesh Results

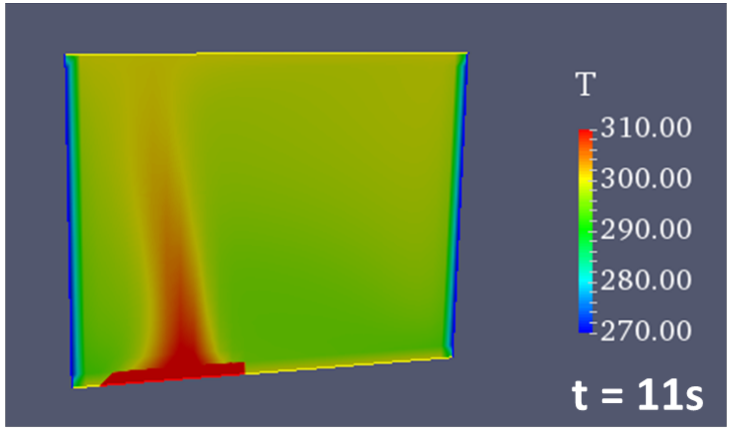
Case	Electronics	# of FVs	Run Time	Co Max
2	Hot	30 x 24 x 24	300s	1.02

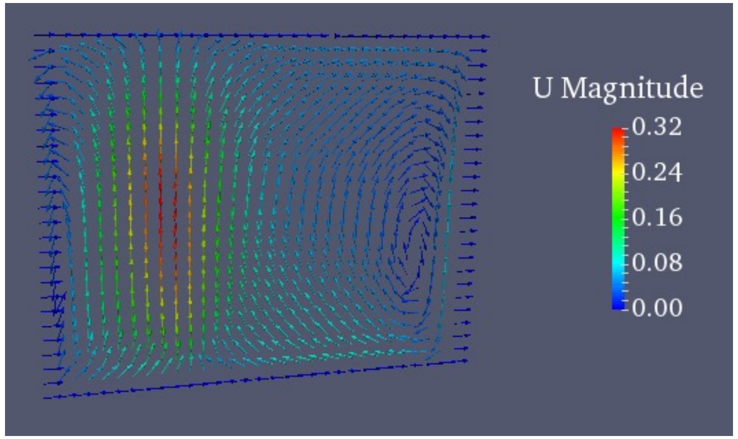
Rising heat stream waves back and forth somewhat

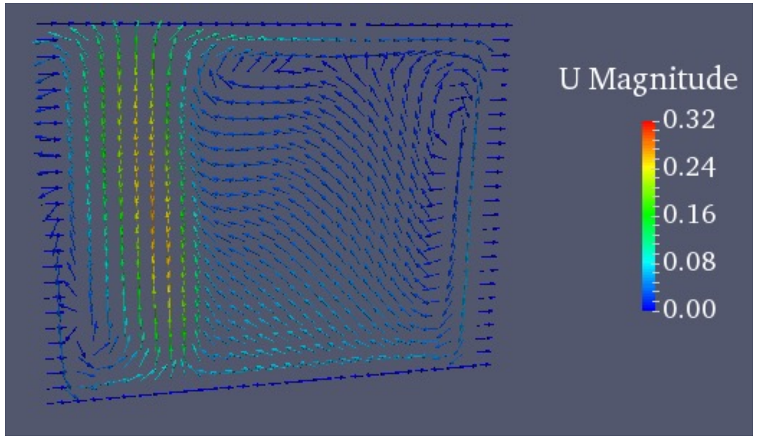
- Not completely steady











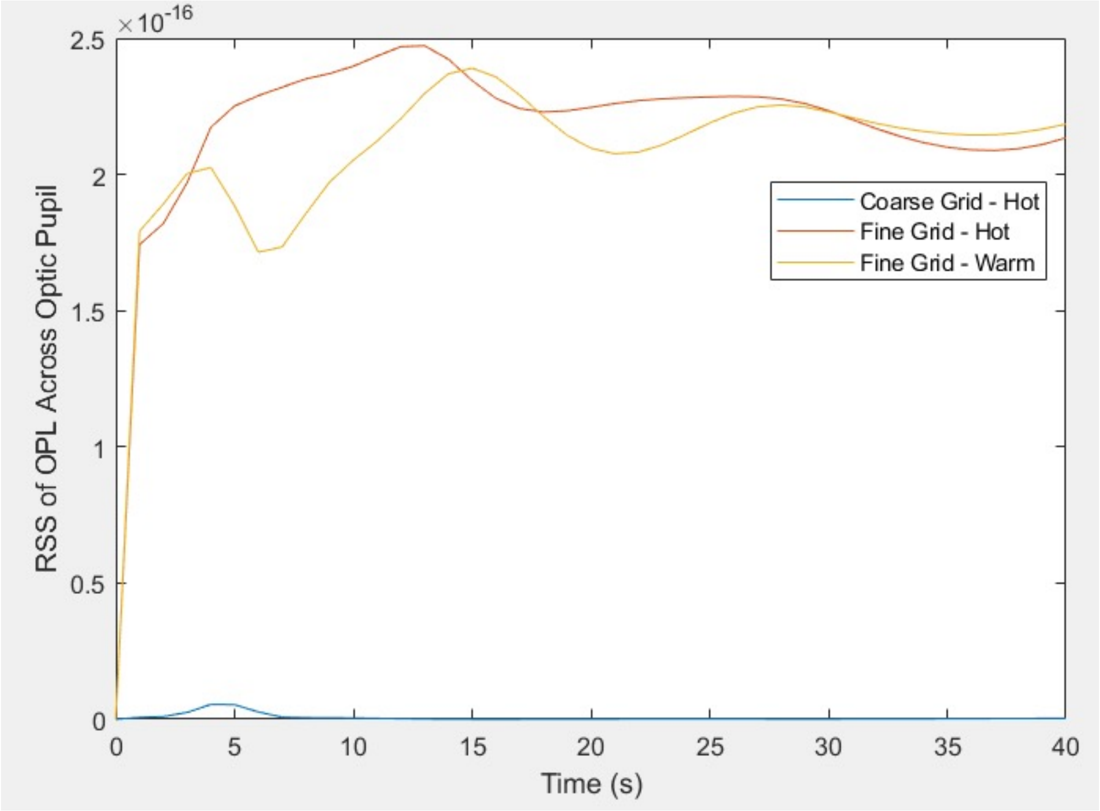
Optical Comparison of Solutions

Coarse grid is likely insufficient

- Increase of grid resolution is important and worth it

Design insight

- Lowering electronics power level
  - Appears to only benefit in the beginning, steady state is similar
  - May not be worth pursuing
- Could vary other parameters if were included



Future Work

Utilize GUI meshing tools to increase complexity of geometry

- Text editing blockMesh is very time consuming!
- Include internal optical components, heat exchangers, varying environmental loads

Implementing an LES scheme may capture important structures not captured with RANS

Automate ray optical path length data capture

- Quickly sample more than 5 rays

Apply to more complex flows, such as hypersonic boundary layer

Error analysis