Performance Evaluation of the 19th Century Clipper Ship Cutty Sark: A Comparative Study

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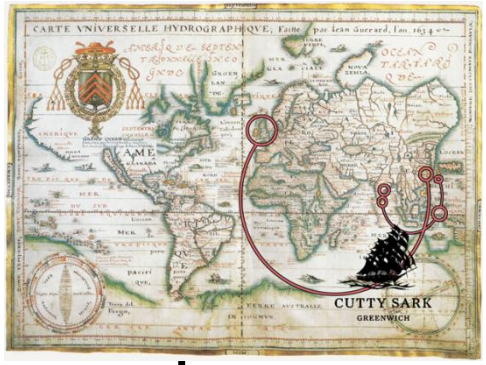
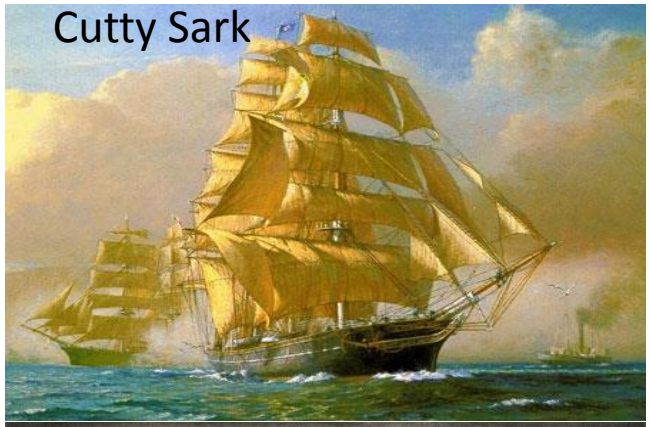
Introduction



- The *Cutty Sark* is the last surviving complete Extreme Clipper ship
- She was built for the tea trade in Dumbarton in 1869
- In 1872 she took part in the “Tea Races” with another extreme clipper the *Thermopylae* constructed in 1868

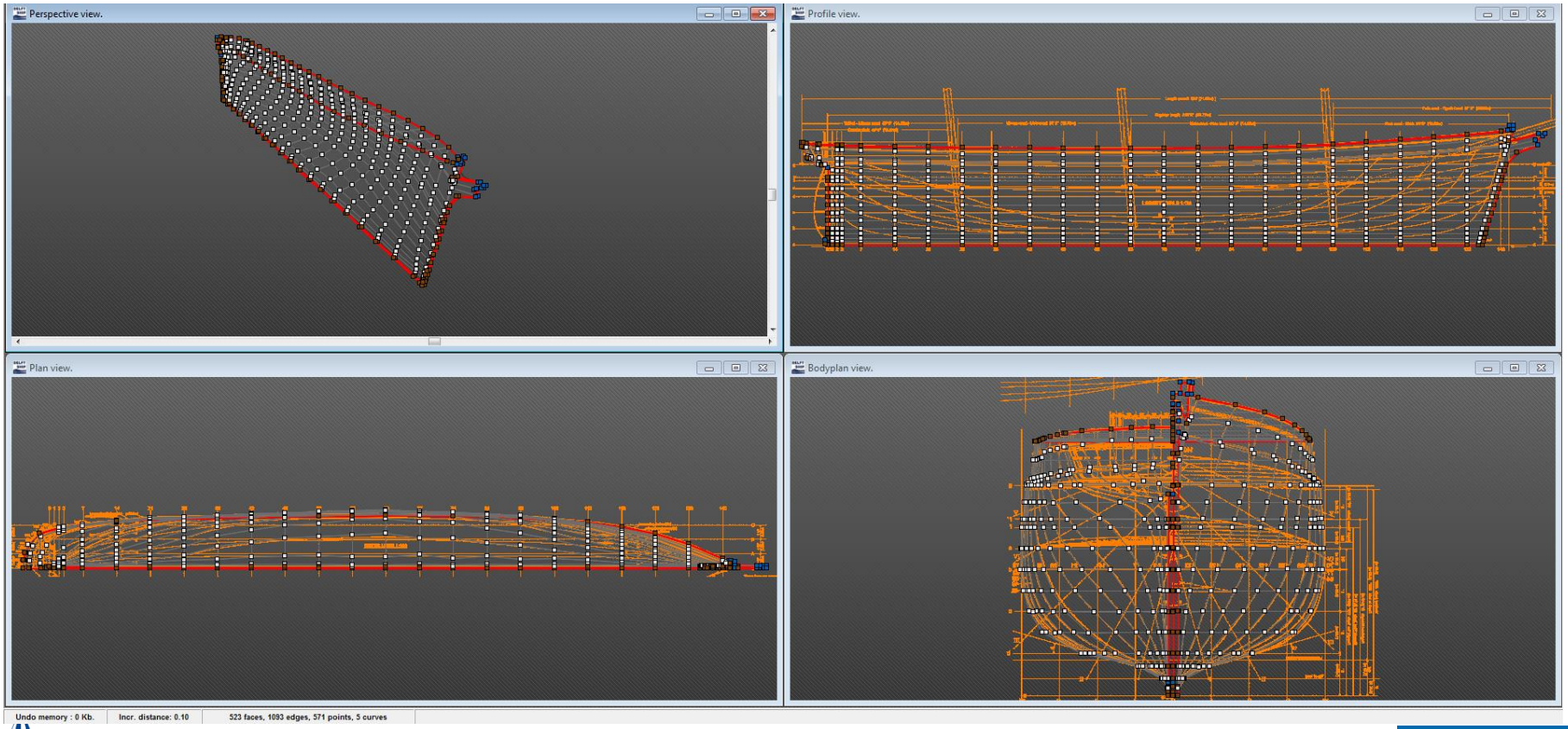
The Ships

In addition to the Cutty Sark and Thermopylae two other ships were chosen for comparison: The Farquharson an East Indiaman built in 1820 and the Erasmo a 4-Masted Steel Barque constructed in 1903



Building 3D Geometries

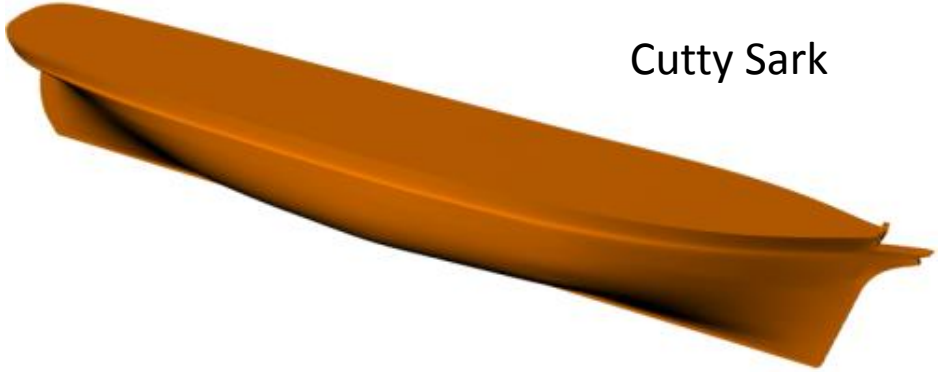
The 2D linesplans then needed to be translated into a 3D Geometry to do this a specialist software package called DELFTShip was used. This software a net of points is created which is then translated into a smooth surface in the shape of the ships



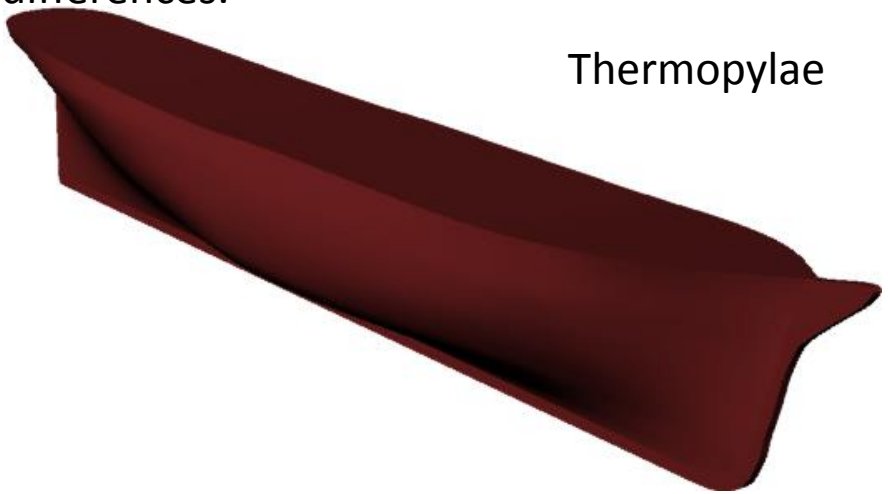
3D Geometries

These 3D geometries were produced using DELFTShip and show the main differences between the 4 Ships. The Cutty Sark and Thermopylae were both extreme clippers and so have a similar design, though there are notable differences.

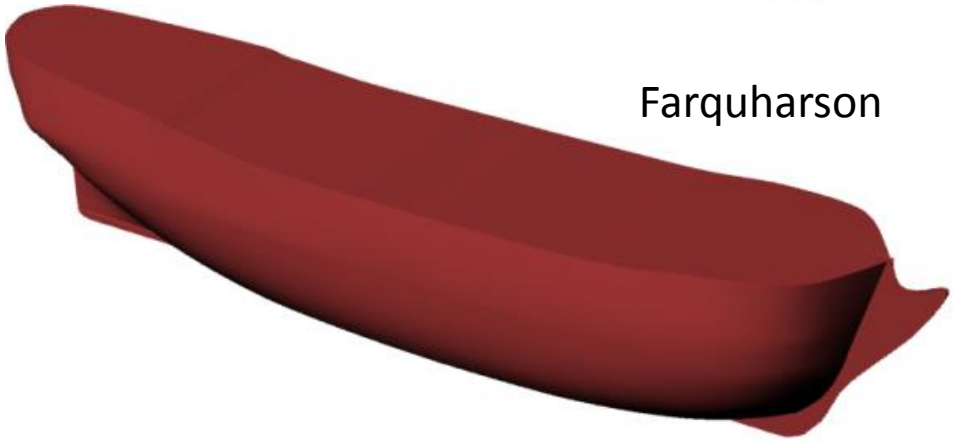
Cutty Sark



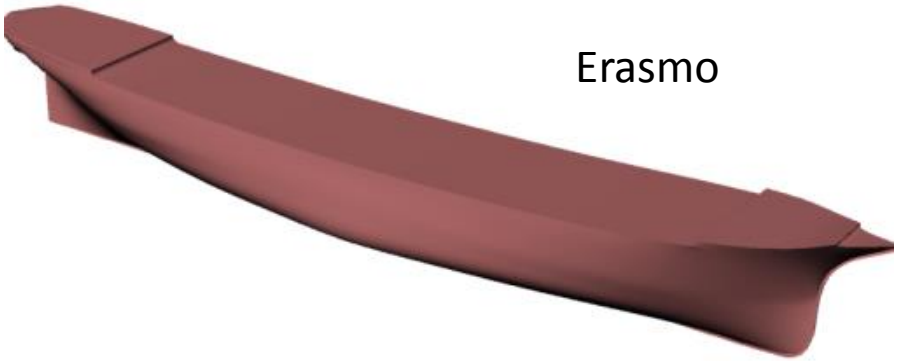
Thermopylae



Farquharson

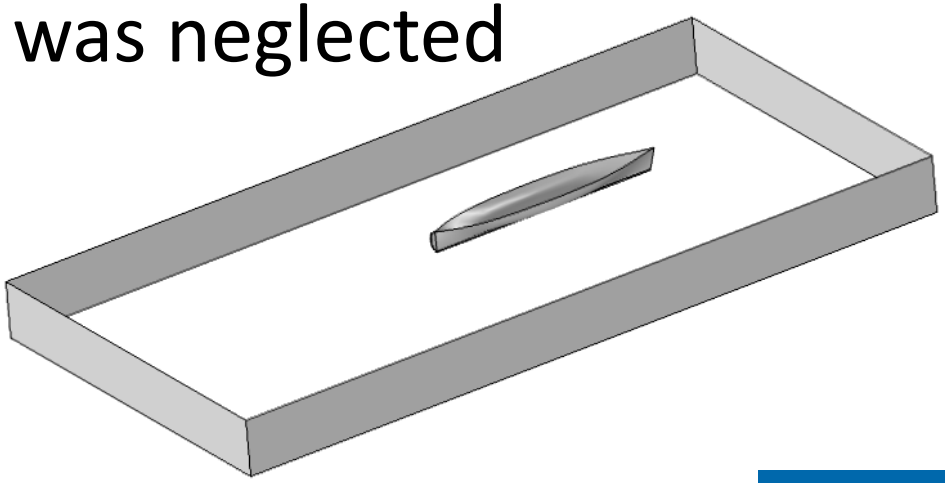


Erasmo



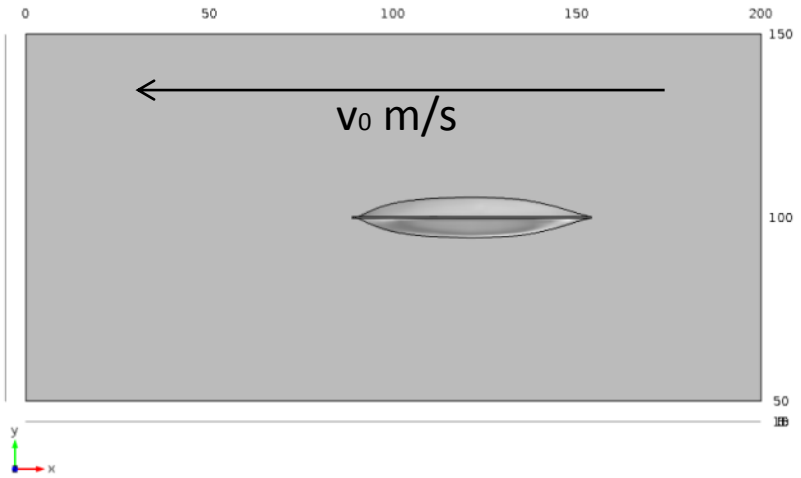
CFD in COMSOL 4.3b

- Modelling was undertaken using the single phase turbulent flow model
- Flow was assumed to be steady state.
- The top was taken to be a slip wall as modelling the waves was neglected



Model Setup

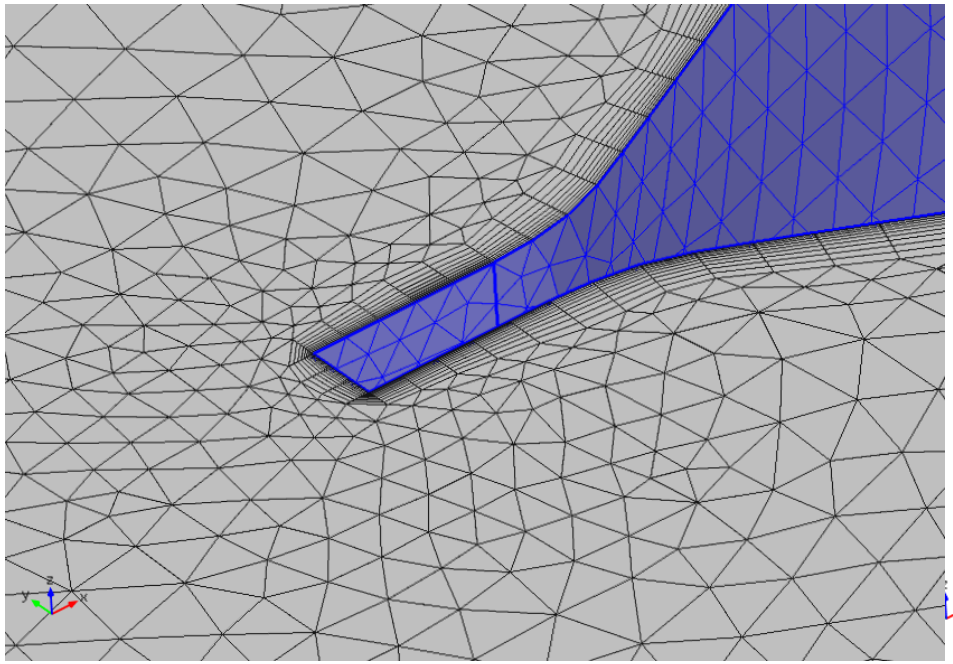
- Modelled in Ships frame of reference
- Domain is 200mx100mx15m
- Slip walls at sides and top of domain
- Inlet with a speed of v_0 m/s
- Zero Pressure outlet at opposite end and underneath
- k-ε turbulence model
- Ship is rotated to model, heel, leeway and trim

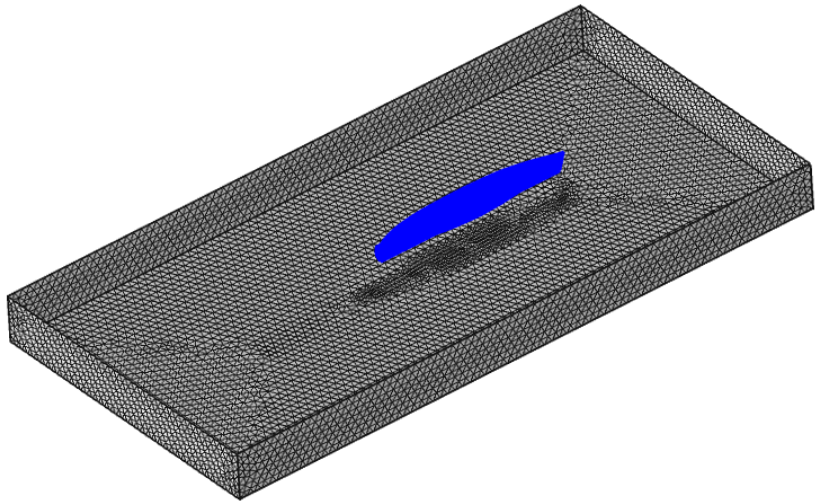


v0 = 10 Knots(5.1m/s), 12.5 Knots (6.4m/s) or 17 Knots (9 m/s) depending on the simulation

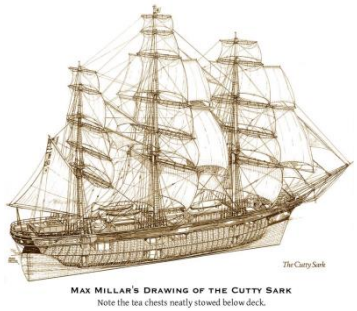
Mesh – Cutty Sark

- The meshes used were heavily refined around the ship, resulting in a mesh of around 2 Million cells.
- A boundary layer mesh was used around the ship





Convergence

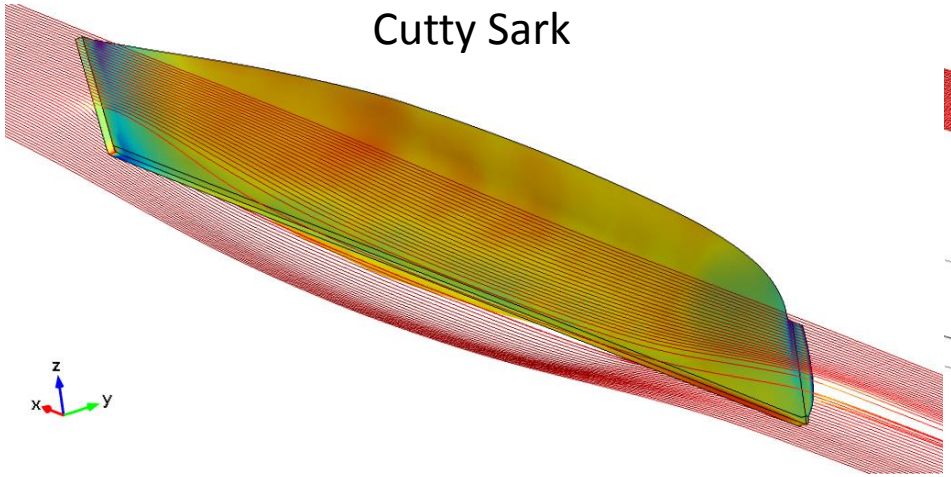


MAX MILLAR'S DRAWING OF THE CUTTY SARK
Note the tea chests neatly stowed below deck.

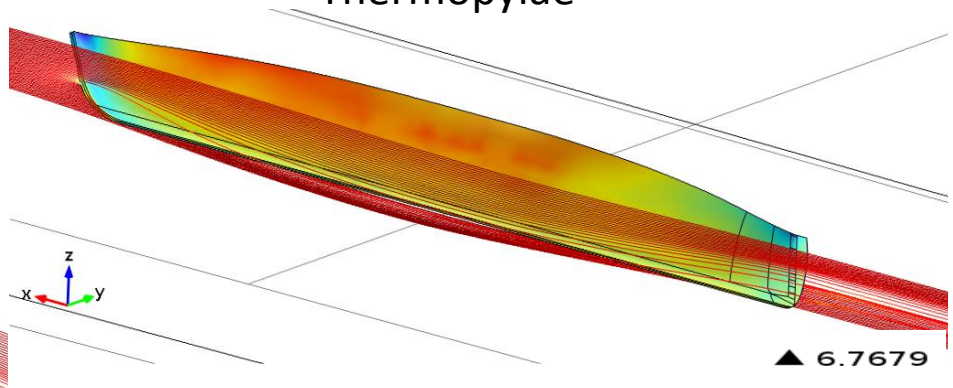
- A direct solver (PARDISO) was used on a Xeon box with 128GB of RAM to speed up solution
- Initially on the refined mesh there were convergence problems and a convergent solution was unable to be obtained.
- To obtain convergence the problem was first solved on a coarser mesh without the boundary layer and then the solution used as the initial conditions to solve on the finer boundary layer mesh

Velocities

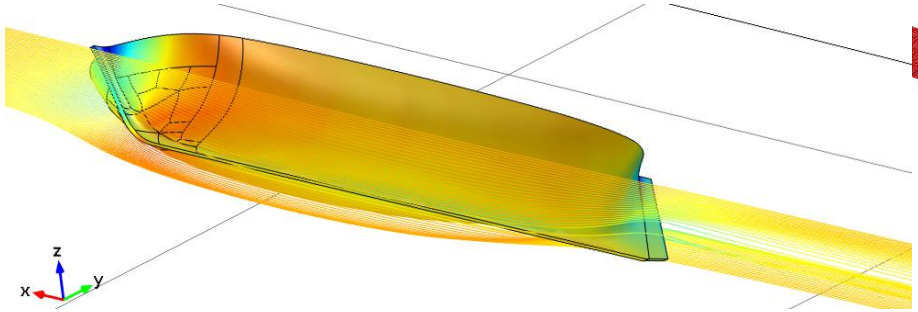
Cutty Sark



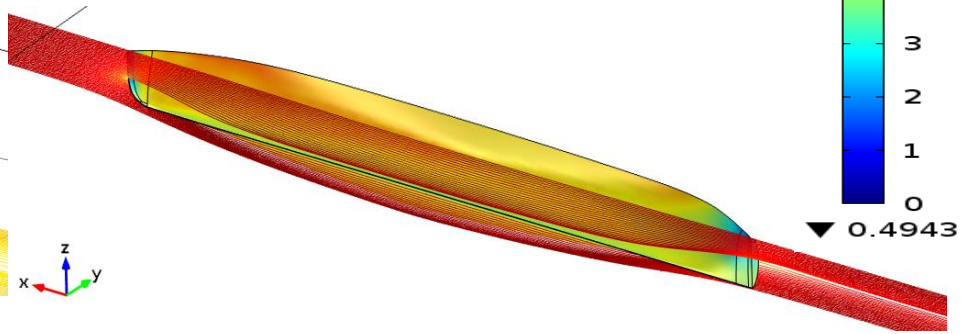
Thermopylae



Farquharson



Erasmo



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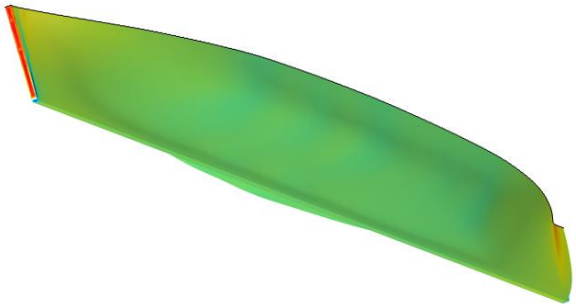
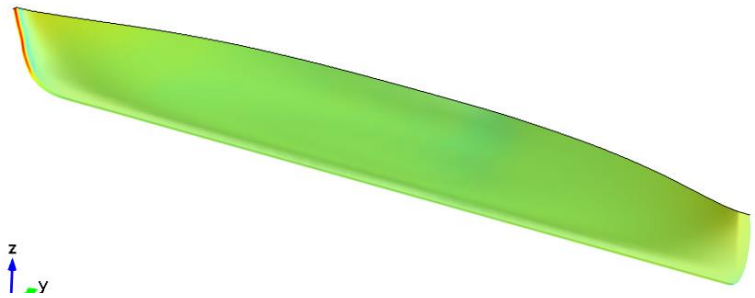
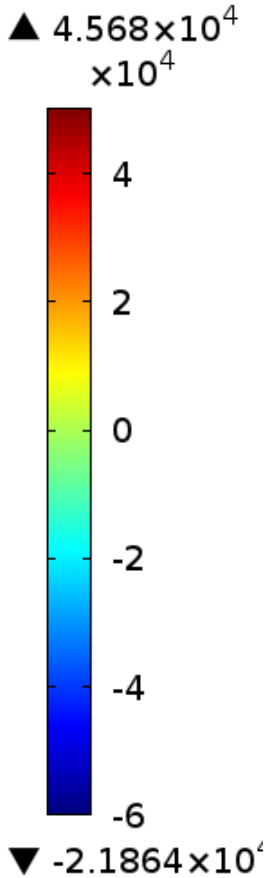
Pressure

Cutty Sark



Thermopylae





Farquharson

Erasmo

Results

Speed		Cutty Sark		Thermopylae		Farquharson		Erasmo	
m/s	knots	R_{PV}	R_F	R_{PV}	R_F	R_{PV}	R_F	R_{PV}	R_F
5.1	9.91					54134	25144		
6.4	12.44	47423	18584	42651	17877			15288	35868
9	17.5	61056	38541	68458	36750			23805	69711
With Representative Heel, Trim and Leeway									
9	17.5	86949	57842	79157	60698				

R_{PV} is the viscous pressure resistance and R_F the frictional resistance where:

$$R_{PV} = \sum_A p \cdot n_x \text{ and } R_F = \sum_A \tau_w$$

p is the pressure n_x the x component of the unit normal to the hull
τ_w the wall sheer stress and A the hull surface

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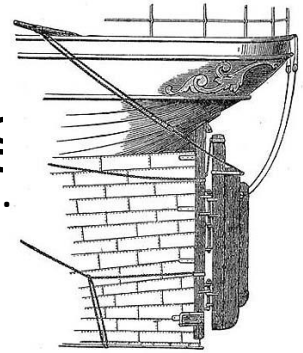
Future Work

- Incorporate a freesurface into the model to look at the wakes and calculate the wave making resistance.
- Look at the Bow of the Cutty Sark in more detail its shape is different to the majority of her contemporaries
- Look a[illegible] the Cutty Sark in [illegible] detail a[illegible] ost her the race!



A drawing of the Cutty Sark's rudder from Basil Lubbock's The Log of the Cutty Sark.

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