A Linear Maneuvering Model for Simulation of Slice Hulls

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Objectives

- *Create a Mathematical model of the SLICE hull in the horizontal plane*
- *Analyze Directional Stability*
- *Predict maneuvering performance based on rudder location and size*

Discussion

- *Equations of motion in the horizontal plane*
- *Prediction of hydrodynamic coefficients*
  - *Pods*
  - *Struts*
  - *Total slice vessel*
- *Vessel stability measures*
- *Vessel maneuverability*

Equations of Motion in the Horizontal Plane

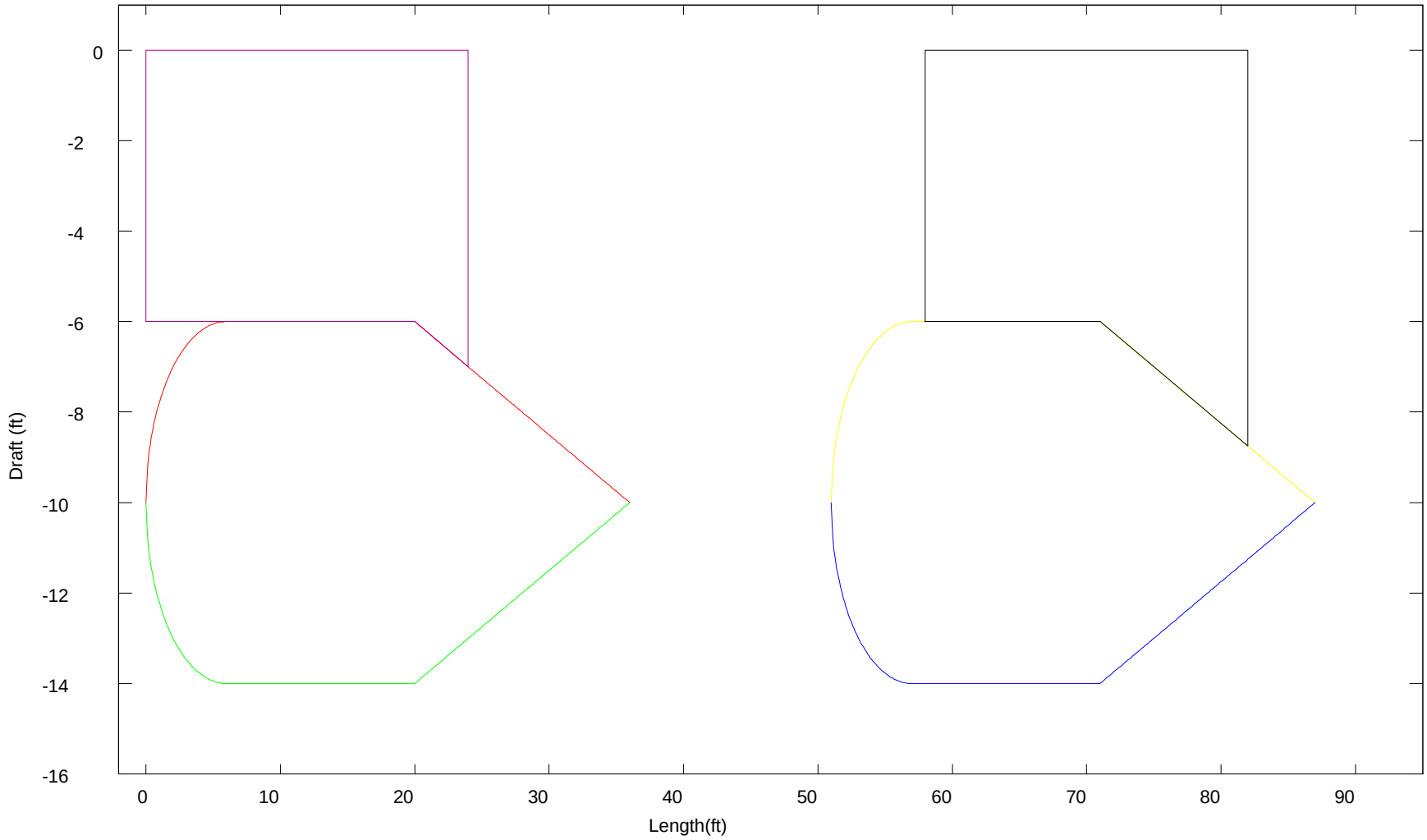
$$\begin{bmatrix} m' - Y'_{\dot{v}} & -Y'_{\dot{r}} \\ -N'_{\dot{v}} & I'_{zz} - N'_{\dot{r}} \end{bmatrix} \begin{bmatrix} \dot{v} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} Y'_{v} & Y'_{r} - m' \\ N'_{v} & N'_{r} \end{bmatrix} \begin{bmatrix} v \\ r \end{bmatrix}$$

- *Matrix components are hydrodynamic coefficients*
  - *Linearized by Taylor series expansion of force and moment components*

Prediction of Hydrodynamic Coefficients

- *Performed in steps*
  - *Pod coefficients*
  - *Pod with fin*
  - *Strut attached to pod*
  - *Translation of coefficients to amidships reference point*

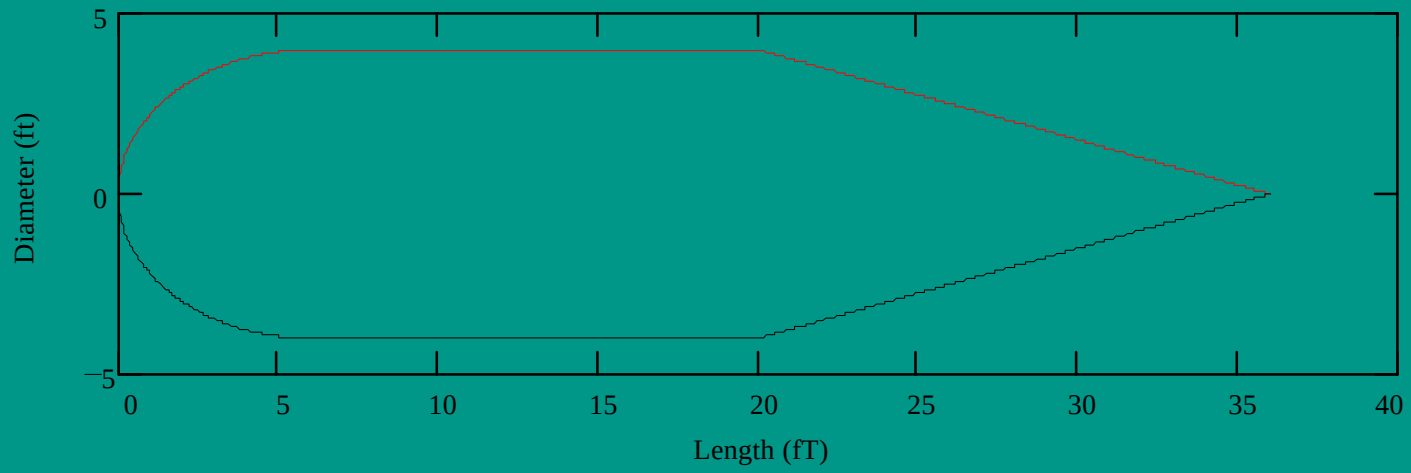
U/W Model of SLICE components



Pod Model

- *Elliptical nose section*
- *Parallel mid body*
- *Conical tail section*

Pod Model



Pod Coefficients

- *2 Semi-empirical methods applied*
  - *USAF Datcom for lateral and rotary coefficients*
  - *Humphrey's and Watkinson for added mass coefficients*
- *Verified against captive model tests for SUBOFF body*

Equations of Motion in the Horizontal Plane

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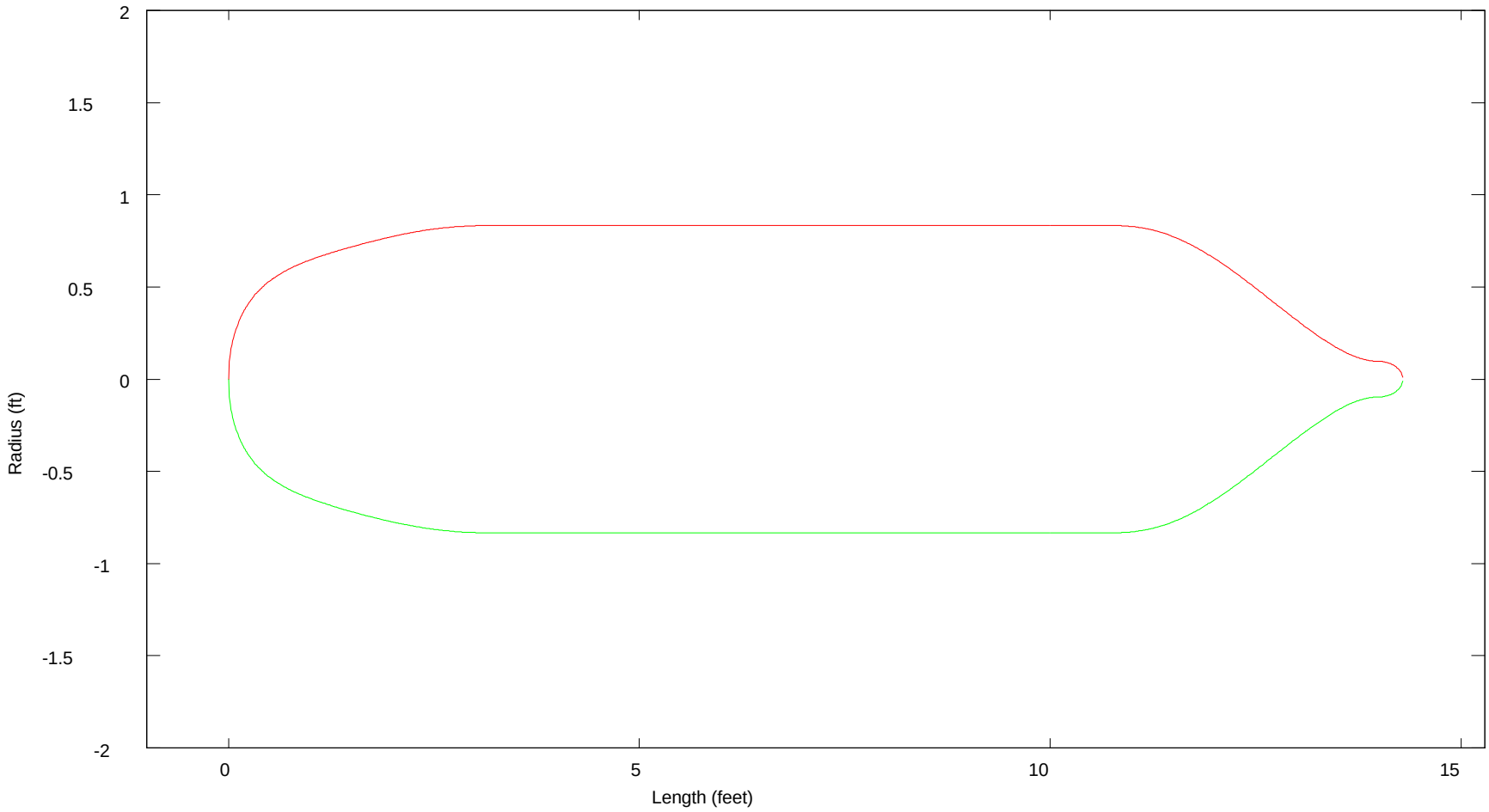
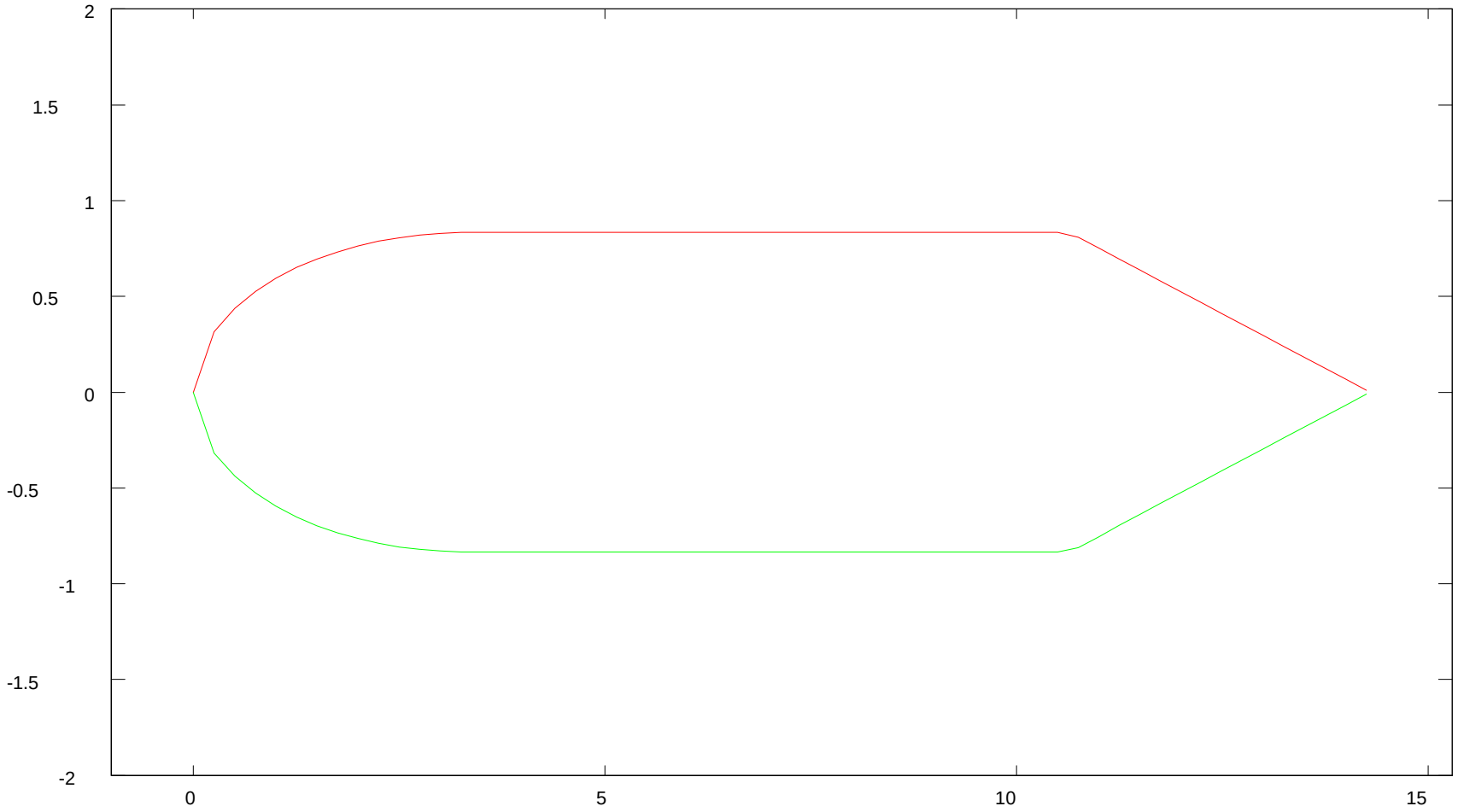
SUBOFF body



Approximate SUBOFF body and Pod Model



Struts and Fins

- *Struts modeled as flat plates*
- *Each acting as a fixed fin*
- *Calculated relative to pod*
- *Verified by previous work (PNA)*

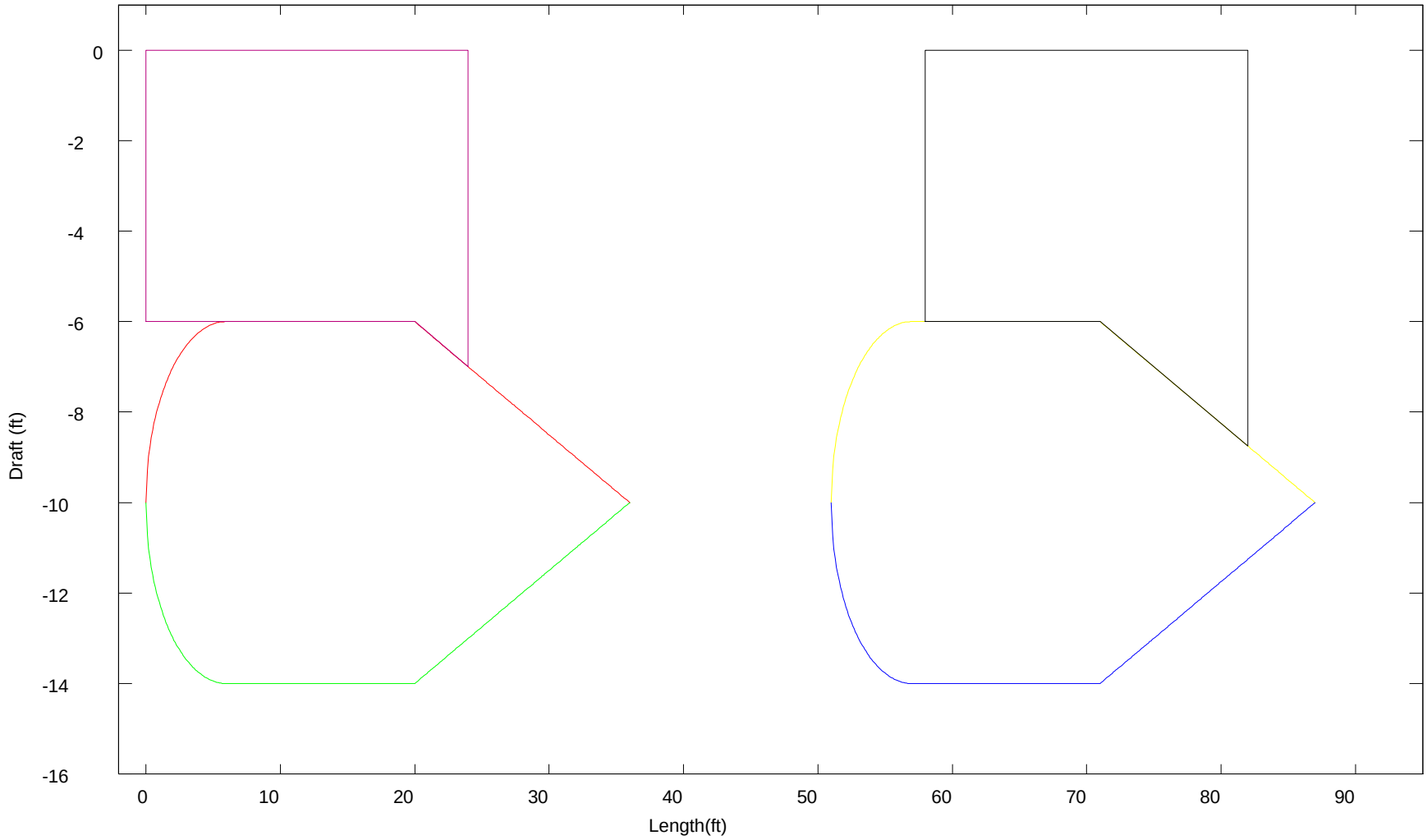
Translation of Hydrodynamic Coefficients

- *Performed by summing forces and moments about the vessels reference point*
- *Algebraically sum components to get coefficients for vessel*
- *insert Picture PNA4. here*

Assumptions

- *No interaction between struts and pods*
- *No pressure effects between port and starboard sides*
- *Propeller wash over aft pod has no significant effect*
- *Rudders have full effect on turning ability*

U/W Model of SLICE components



Rudders

- *Modeled as rectangular flat plates*
  - *6 foot span*
  - *Aspect ratios between 1 and 5*
  - *Areas between 5 and 35 ft^2*
- *Three configurations*
  - *Strut mounted*
  - *Pod mounted*
  - *Pod mounted with deadwood*

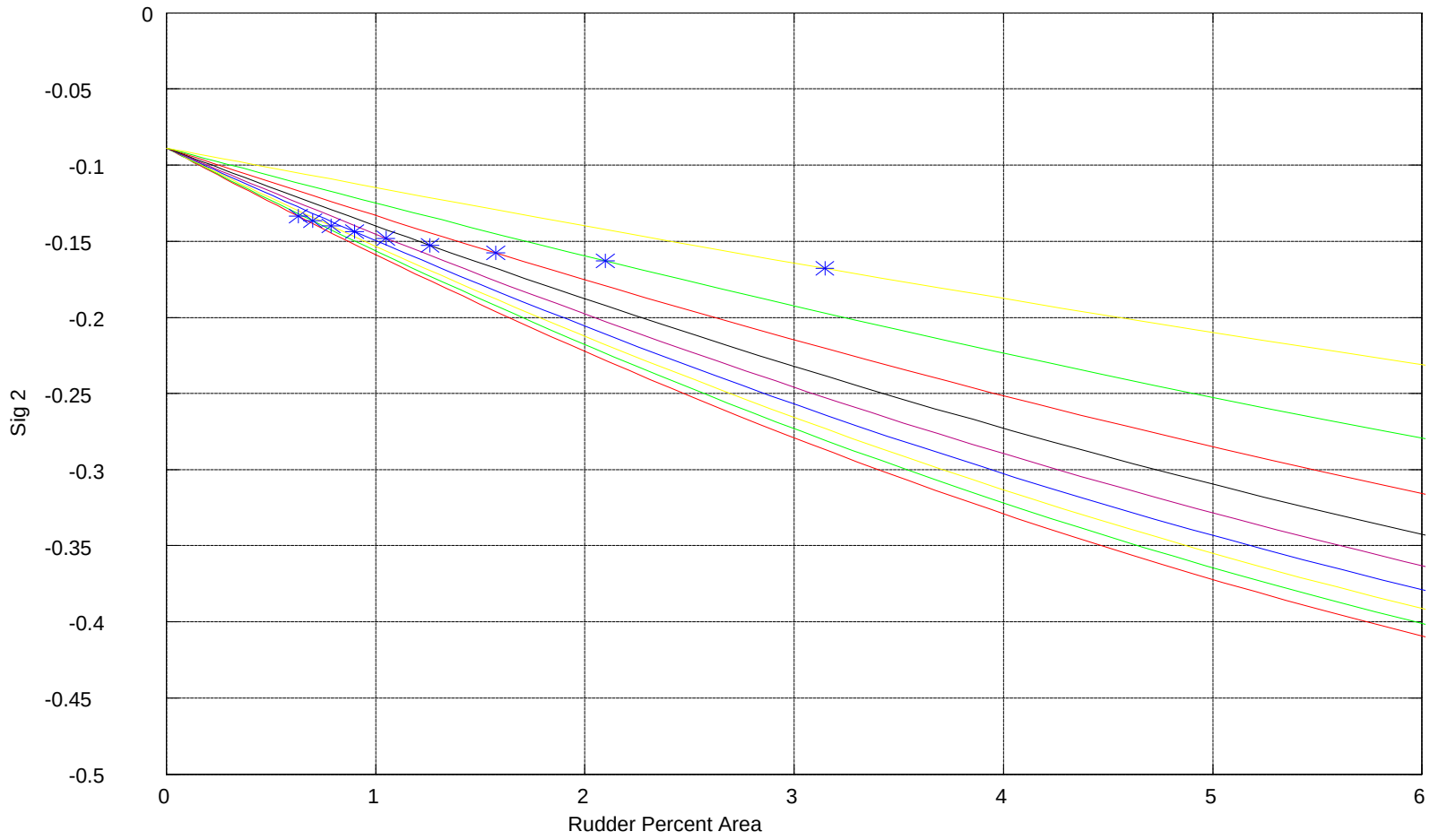
SLICE Stability

- *Eigenvalues of EOM are a measure of stability and turning ability*
- *Qualitatively*
  - *More negative means more stable*
  - *More stable means more effort necessary to turn*

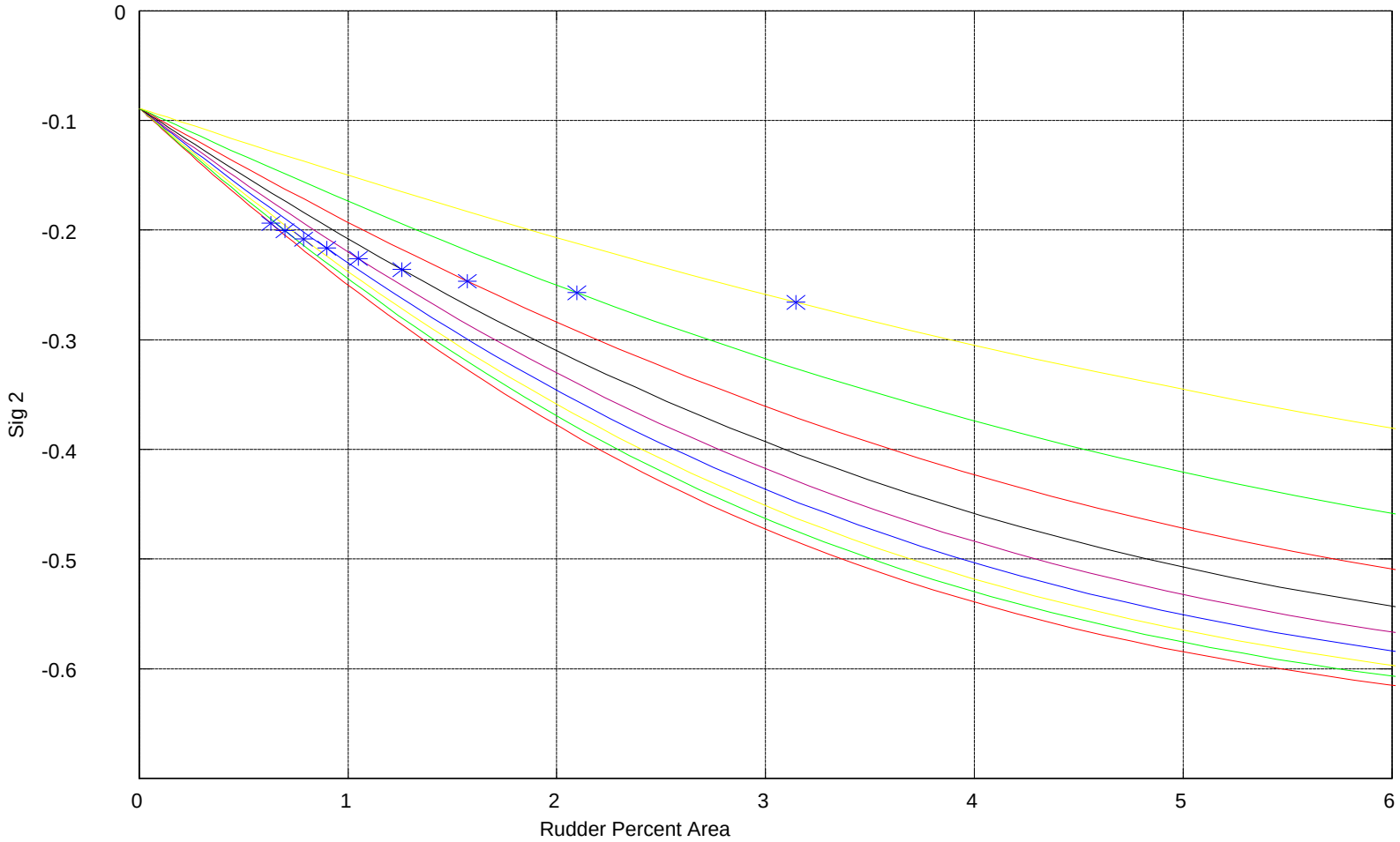
Numerical values of Dominant Eigenvalue

- *Based on data base of 173 vessels*
  - *$< -.331$*
    - *Stable, poor turning characteristics*
  - *$_2 > 0$*
    - *Unstable*
- *$-.331 << 0$*
  - *Good directional stability*
  - *Good turning ability*
  - *$_2$ closest to 0 gives best turning ability*

$_2$ for Strut Mounted Rudder



$_2$ for Pod Mounted Rudder



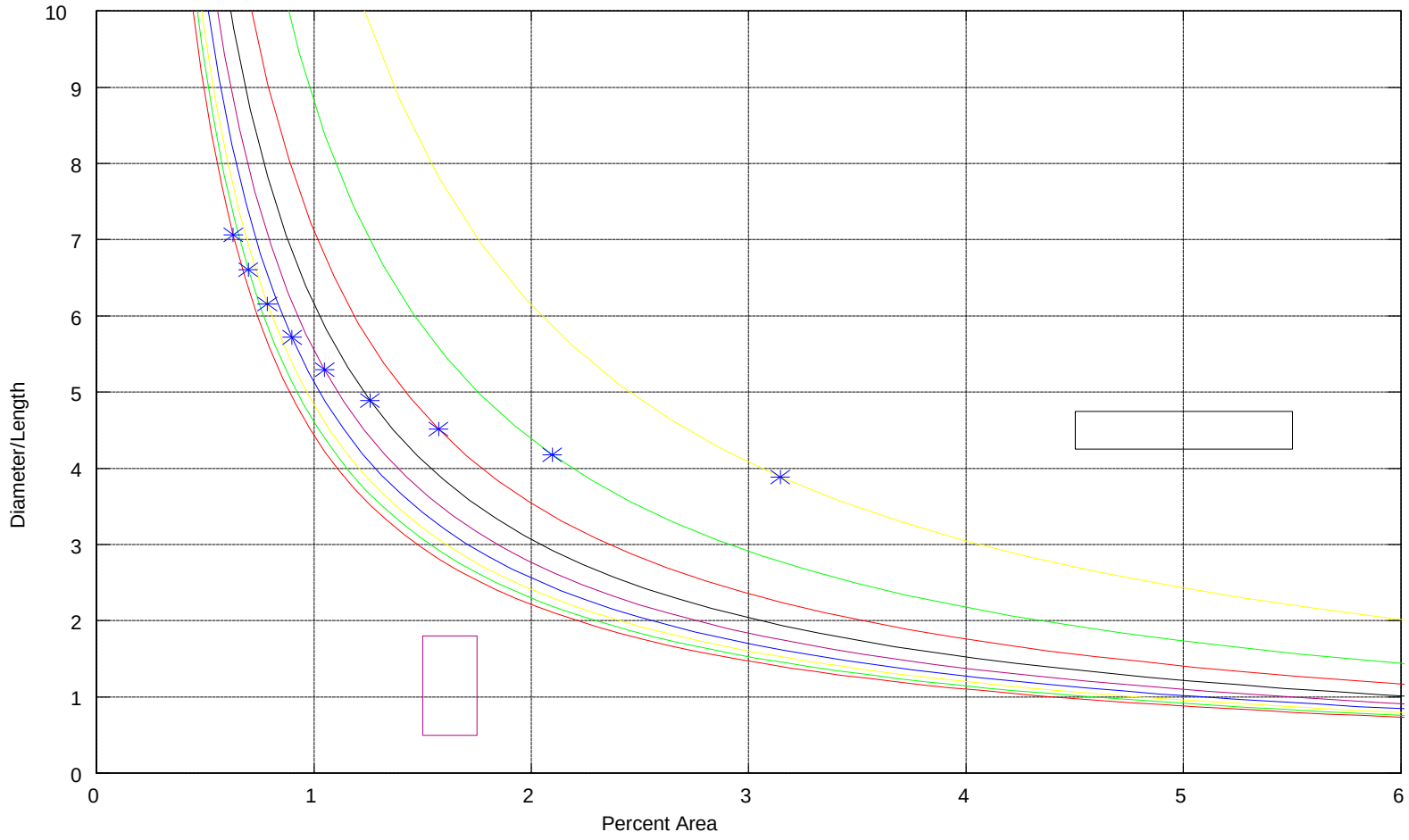
C_{D_2} for Pod Mounted With Deadwood

- Constant value of -.321
- Poorest turning ability of the configurations considered

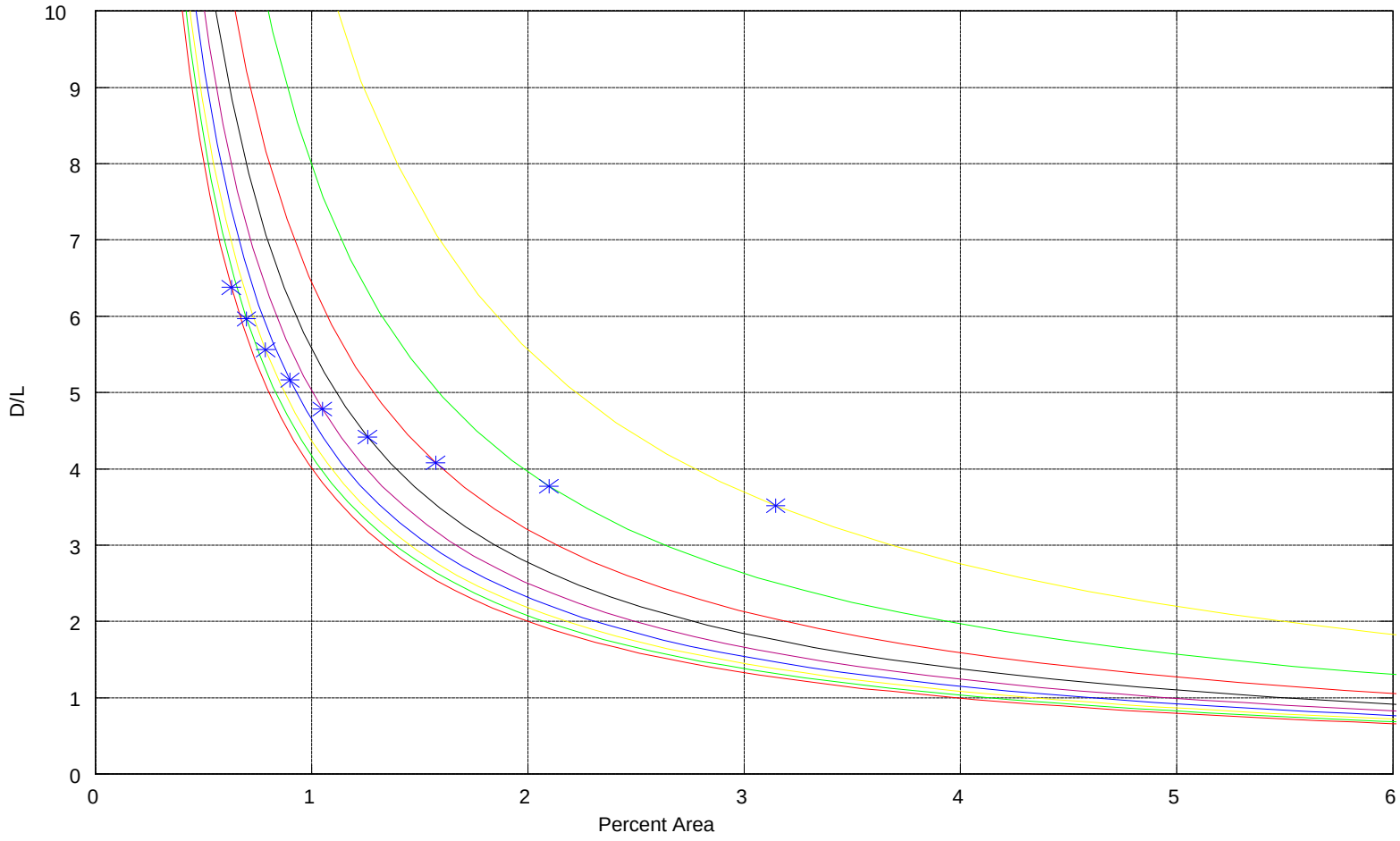
Steady State Turning Ability

- *Acceleration are zero*
- *Transients are settled out*
- *results in a constant radius turn*
- *Standard Rudder used for all*

D/L for Strut Mounted Rudder



D/L for Pod Mounted



Steady State Turning Ability Results

- *Pod mounted*
  - *Larger moment gives smaller turning diameter for a given aspect ratio*
  - *Dominant eigenvalue more negative*
- *Strut Mounted*
  - *Smaller induced rudder moment*
  - *Larger turning diameter*
  - *Larger (less negative) dominant eigenvalue*

Nomoto's First Order Approximation

- *Modeled turning ability as a first order system by manipulating EOM*
- *K: gain/course keeping index*
- *T: Time constant/Turning ability index*

$$\frac{r'}{} = K'\left(1 - e^{\frac{-t}{T'}}\right)$$

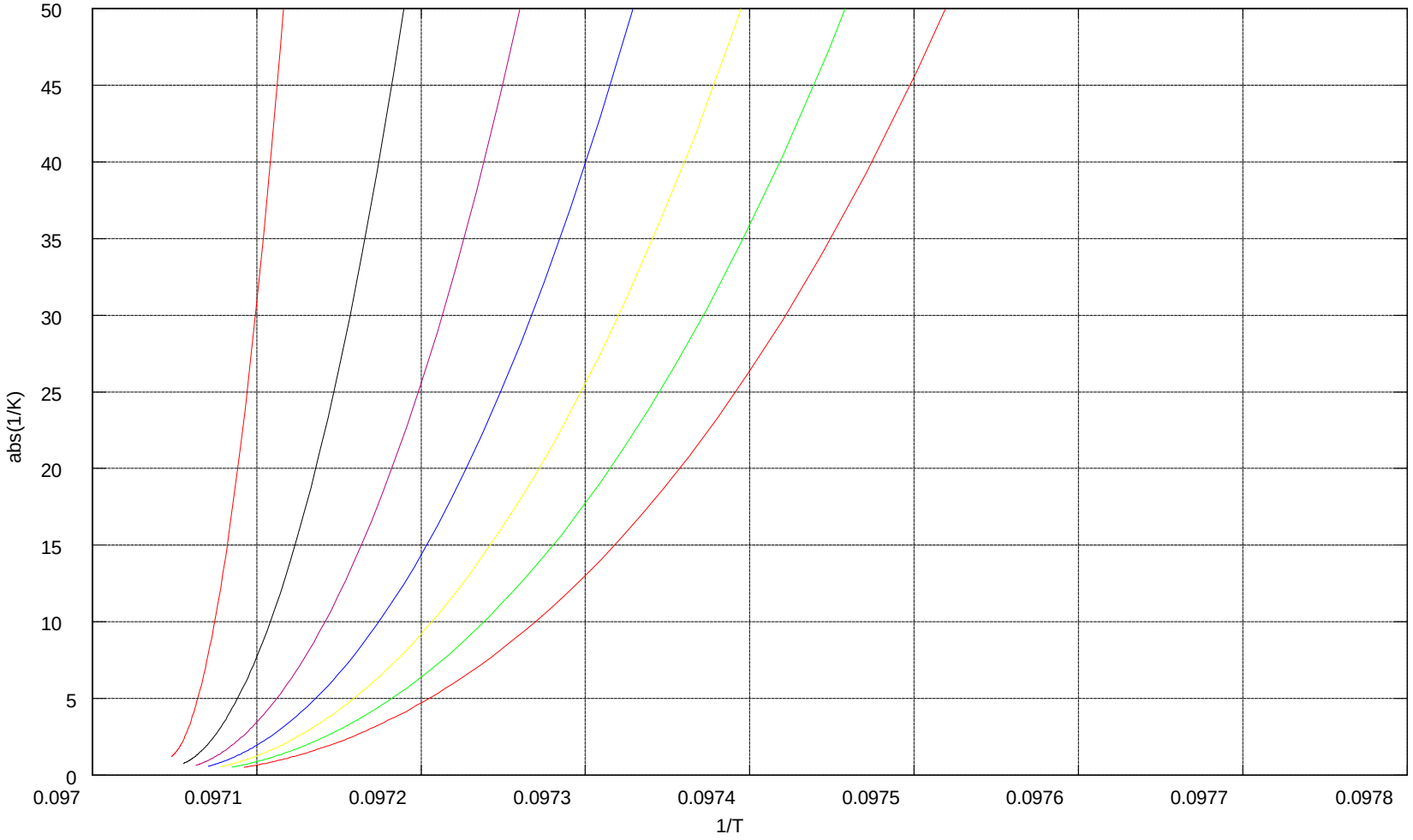
Course Keeping Index

- *Ratio of turning moment and yaw moment coefficients*
- *Larger value of K*
  - *Greater yaw rate*
  - *Greater steady state turning ability*

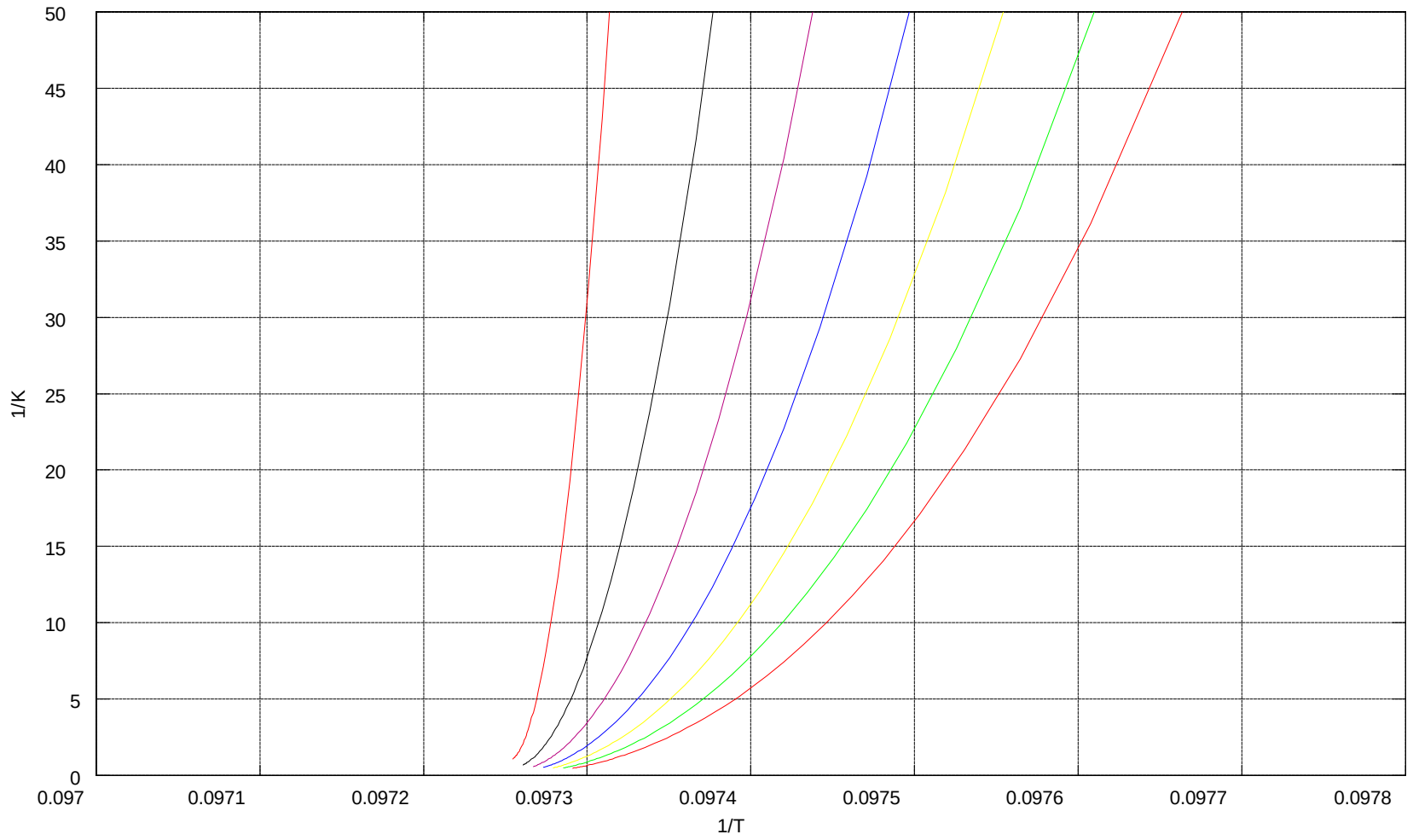
Turning Index

- *Ratio of Yaw inertia to yaw damping*
- *Smaller T*
  - *Quicker helm response*
  - *Good course keeping implied because of quicker response to rudder commands*

1/K Vs 1/T plot for Strut Mounted Rudder



1/K Vs 1/T plot for pod Mounted Rudder



Trends in K and T

- *Gain K is Sensitive to rudder placement and aspect ratio*
  - *K larger for larger aspect ratio*
- *T virtually constant for all rudders*
- *Pod mounted rudder better*
  - *Smaller T*
- *Both are relatively insensitive to changes in rudder area or aspect ratio*

Practical Considerations

- ***Pod mounted rudder***
  - *U/W protrusions aft*
  - *Machinery space*
  - *Connecting hardware/structures*
- ***Strut Mounted***
  - *Good turning ability based on model*
  - *No U/W protrusions aft*
  - *Machinery space available nearby*
  - *No large structures necessary to connect*

SWATH Comparisons

- *Current SWATH configurations have rudder area between 1 and 3 percent*
- *Turning Diameters between 4 and 16 dependent on displacement and U/W configuration*

CONCLUSIONS

- *Base line SLICE hull form directionally stable*
- *Exhibits good turning ability and course stability*
- *Model data supports use of rudder sizes similar to conventional hulls and current SWATH ships in use.*

Further Research

- *Use model test or full scale test data to validate or invalidate the model*
- *Assuming good model correlation*
  - *Predict rudder performance using various NACA rudder forms*
- *Experiment with flapped and un flapped rudders to increase turning ability*

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